ARCOM

ASSOCIATION OF RESEARCHERS IN **CONSTRUCTION MANAGEMENT**

# THIRTY-Seventh ANNUAL CONFERENCE 2021

September 6-7

# PROCEEDINGS

Association of Researchers in Construction Management (ARCOM)

# PROCEEDINGS OF THE 37TH ANNUAL CONFERENCE

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**ARCOM Declaration:**

The papers in these proceedings were double-blind refereed by members of the scientific committee in a process that involved, detailed reading of the papers, reporting of comments to authors, modifications of papers by authors and re-evaluation of re-submitted papers to ensure quality of content.

# Foreword

Welcome from the Chair of ARCOM 2021

Professor Lloyd Scott, Technological University Dublin

While the ARCOM conference committee had planned to return to Glasgow in both 2020 and 2021, the fall-out and the continued disruption from the COVID19 pandemic impacted heavily on our community resulting in the need to hold a virtual conference again this year. While we are delighted to hold the 37th Annual Conference in 2021 totally virtually it is our aspiration to return to the traditional face to face ARCOM conference in 2022 where it will take place in Glasgow, Scotland. A huge thank you to Glasgow Caledonian University for sticking with us and making that possible.

The ARCOM conference committee extends a warm welcome to the construction management research community and invites all to enjoy the great line up of sessions for this year's conference. Shifting the mindsets and practices of the built environment to change the future based on the challenges faced by society today ids the underlying scope of this year's conference. We will learn from those that shape the world and build knowledge in the 'here and now' as we focus on transformation and a new era that will require vigilance around our approach to COVID19. While the immediate global priority remains to tackle this public health emergency, society's long-term response must also address the underlying causes of such a pandemic and certainly the ARCOM community can make a strong contribution to this. I am humbled to welcome you to the second virtual ARCOM conference.

The Technological University Dublin extends a very special welcome to the delegates of the 2021 ARCOM conference. This year's conference attracted 267 submissions in January 2021. Following three rounds of double-blind peer-review, a total of 106 papers were eventually accepted for presentation at the conference. Once again, in a field that is now saturated with so many international conferences, this success rate demonstrates the rigour applied to the ARCOM peer-review process. Of course, this cannot be achieved without the support of the 90 reviewers drawn from across the world, including 21 ARCOM Committee members and 69 members of the extended Scientific Committee. A big thank you to all involved in the peer-review process.

This is the fifth year in which the ARCOM Conference has been themed. These thematic topics now form an important part of shaping the papers received and accepted and, we hope, of steering the discourse at the conference. Another significant area in this year's conference is the focus on sustainability in the built environment (25 papers), where authors address questions around low energy and low carbon construction along with governance and the changing of mindsets in construction. The construction management community of researchers can be seen to mature and expand their research activity within the fast-changing environment in which society finds itself and particularly the emerging aspects/ impacts of COVID-19.

My opening plenary session this year appropriately addresses a consideration of understanding where Construction Management research is as we advance into the 21st Century. My reasoning behind this choice of topic is that it is timely that some discourse take place to prepare us for the future and ensure that Construction Management research can build on the past. The first talk is by Dr Tara Brooks from

Queen's University, Belfast who offers her personal perspective as a young researcher in the field of Construction Management. The second from our own, Professor Chris Gorse will aim to provoke us to think about the role of the community in Construction Management research.

The second plenary session this year will chaired once again by Dr Craig Thomson with keynote addresses by Professor Tina Karrbom Gustavsson and Professor Andrew Karvonen, both of KTH Royal Institute of Technology, Stockholm. Our invited speakers will address the grand challenges facing our cities, but with the added flavour of how and where construction management research interacts with the urban field where a reflection on environmental, economic and societal issues seeks to facilitate a conversation and a sharing research between scholars is facilitated.

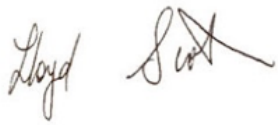
It gives me great pleasure to introduce this year's Langford Spotlight where the topic of "Collaborative Projects" is explored by Anna af Hällström, chaired by Dr Vivien Chow. It promises to offer some different perspective on collaboration in the sector and one that David Langford would have been interested to hear about. It is wonderful to showcase the depth of quality research taking place in our community.

ARCOM continues to attract an international audience, and we have delegates joining us this year from, inter alia, Europe (with colleagues from the Netherlands and across Scandinavia), the United States of America, South Africa, Sri Lanka, India, China, Malaysia, Australia and New Zealand. It is good to welcome colleagues from both developed and emerging economies alike. Following the successful 'Meet the Publishers' session at ARCOM 2020, we will run this session again at the virtual ARCOM 2021 Conference. The Publishers associated with the CM discipline have teamed up and have planned a very interactive session on day one. They will discuss what post COVID-19 in the field of construction management research may look like.

Lastly, but not least, I also wish to express my sincere appreciation to a number of key individuals for their support and help over this past year; the ARCOM Committee, Cath O'Connell, and of course, this conference would not have been possible without the relentless and unwavering efforts of our conference secretary, Chris Neilson. Chris Neilson is an exceptional person, and I can only say a big thank you to him for the major input he has made on this important annual event.

I would like to finally thank ARCOM past chairman, Professor Chris Gorse who been a rock of support to me in navigating my new experience and life circumstances.

Welcome to ARCOM 2021 and to the virtual experience. Enjoy!



Lloyd Scott

ARCOM Chair and Conference Chair, ARCOM 2021

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The success of the Annual ARCOM Conference depends on the voluntary efforts of the members of both the ARCOM Committee and our international Scientific Committee. We are indebted to the members of both commitees who together provided rigour and constructive feedback in the peer-review process.

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# Building Information Modelling

# A BIM-LCA INTEGRATED METHOD FOR ENHANCING EFFICIENCY OF EMBODIED CARBON ESTIMATION OF PREFABRICATED HIGH-RISE BUILDINGS

**Jiayi Xu[1], Yue Teng and Wei Pan**

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The integration of building information modelling (BIM) and life cycle assessment (LCA) has been increasingly underlined in recent years to simplify the data acquisition in LCA processes. Although BIM can facilitate establishing the bills of quantity (BoQ) for carbon estimation, a great deal of manual work is still needed in current BIM-LCA integrated methods for choosing appropriate LCA databases and assigning corresponding emission factors to construction materials. This research aims to develop an automatic BIM-LCA method to estimate embodied carbon emissions for prefabricated buildings based on a five-level analytical framework, i.e., material, component, assembly, flat, and building. SimaPro was adopted as the LCA platform and three successive modules were conducted, namely, establishment of BIM model, industry foundation classes (IFC)-enabled data transfer between BIM and LCA, and development of BIM-aided LCA model. A case study using a typical floor of a prefabricated high-rise public residential building in Hong Kong was adopted to validate the proposed method. The developed BIM-LCA integrated method achieved automated data extraction from BIM as well as automated data input and update in SimaPro, resulting in an 80% time saving in this case compared with the traditional labour-intensive process. The paper thereby contributes to smart embodied carbon estimation and facilitates quick feedback of embodied carbon emissions during the design phase to support building design efficiency.

Keywords: BIM; embodied carbon emission; LCA; prefabricated building

## INTRODUCTION

Climate change has been one of the most urgent environmental issues facing mankind. As the primary driver of climate change, carbon emissions have increased rapidly in recent years. Among all the carbon emitters, the architecture, engineering, and construction (AEC) sector plays an important role (Sadineni *et al.,* 2011). In high-rise high-density cities like Hong Kong, buildings account for over 60% of carbon emissions (ENVB 2017). Apart from the operational carbon, the embodied carbon emissions generated from the production, transportation, construction, replacement, and end-of-life of building components are also responsible for a large share of total carbon emissions with the emerging trend of using low/zero carbon design (Teng and Pan 2019). The manufacturing of building materials alone represents 5~10% of the global carbon emissions. It is thus important to address the embodied carbon estimation and reduction of buildings during the design stage. However, life cycle

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assessment (LCA) of buildings is a complex, time-consuming, and labour-intensive task since a large amount of information is required and selecting a representative dataset for a non-professional personage is difficult. As a result, the LCA of buildings is commonly conducted at the end of the design stage, when necessary, information is available, which is often too late to guide the design decision-making.

Building Information Modelling (BIM) can facilitate establishing the bills of quantity (BoQ) and support project teams by providing immediate insight into how design decisions affect the building performance. Hence, BIM is increasingly used to explore design solutions to improve the life cycle performance (Eleftheriadis *et al.,* 2017). BIM-LCA integration is a powerful approach to perform LCA for buildings during the design process and a growing number of applications is underlined in recent papers. For example, the most widely adopted method is to extract material quantities from BIM and carbon emission factors from LCA databases, and then to conduct the calculation in Excel (Peng *et al.,* 2016; Feng *et al.,* 2020). However, a great deal of manual work is still needed for choosing appropriate LCA databases and assigning corresponding emission factors to construction materials. Data interoperability between BIM models and LCA databases is another main challenge of current BIM-LCA integration. Different data formats of the material databases in BIM and LCA tools such as units, types, and names hinder the data mapping process (Yang *et al.,* 2018). Moreover, material databases in BIM software tools are usually not as detailed as LCA databases such as Ecoinvent so that materials obtained from BIM models may have several options of the impact factors (Rezaei *et al.,* 2019). All these limitations impair the efficiency and convenience of BIM-LCA methods.

The aim of this paper is to develop a BIM-LCA integrated method for enhancing the efficiency of embodied carbon estimation of prefabricated high-rise buildings. SimaPro was selected for conducting the LCA process as it is one of the leading software tools used for life cycle assessment and has been used in more than 80 countries. It has integrated with several LCA databases like Ecoinvent, ETH-ESU 96, U.S. LCI, EF, and so on, which can provide sufficient carbon emission factors of materials and energy. It can offer accurate and reliable carbon results, which was demonstrated by the comparison with other LCA tools such as GaBi and OpenLCA (Herrmann and Moltesen 2015). Interoperability between BIM and LCA was addressed by developing an Industry Foundation Classes (IFC)-enabled data transfer tool to transmit necessary data from BIM to SimaPro. This paper can achieve automated data extraction from BIM and automated data input in SimaPro, which gains a significant efficiency promotion in embodied carbon estimation compared with the traditional labour-intensive process. Moreover, the automatic updating of the LCA model in SimaPro can be conducted with any design alteration in the BIM model, so as to better facilitate quick feedback of embodied carbon emissions during the design phase to support building design efficiency.

**Previous Studies On BIM-LCA Integration**

To simplify and reduce the data acquisition during LCA application in building design, lots of researchers have developed innovative BIM-LCA integration methods in recent years. Antón and Díaz (2014) proposed two approaches for the integration of BIM and LCA. The first approach was to use automatic take-off tools to extract information directly from the BIM model, which were then combined with life cycle inventory data to perform an accurate LCA. The second approach was to incorporate environmental information into BIM objects to support decision-making. Wastiels

and Decuypere (2019) reviewed relevant papers and concluded five BIM-LCA integrated strategies, namely importing a BIM-based BoQ report into dedicated LCA software, importing BIM model into dedicated LCA software through IFC format, using a BIM viewer tool to associate LCA data to building components, using an LCA plug-in of BIM software, and establishing BIM objects with enriched LCA information or references. Taking different calculation platforms as the critical factor, previous BIM-LCA integration can be classified into four categories. A comprehensive description of representative cases for each category is listed in Table 1.

*Table 1: Representative cases for BIM-LCA integration*

| Year | Authors | Adopted tools/methods | Category |
|---|---|---|---|
| 2016 | Peng | Revit; Literature; Excel | Type I |
| 2016 | Shadram *et al.* | Revit; EPD; PowerPivot | Type II |
| 2017 | Abanda *et al.* | Revit; Navisworks; Bath ICE Database; Revit API | Type III |
| 2018 | Yang *et al.* | Revit; Glondon; Chinese Life Cycle Database; Ecoinvent; eBalance | Type IV |
| 2019 | Cavalliere *et al.* | Rhinoceros; Swiss Buildings Database; Bauteilkatalog; KBOB; Excel | Type I |
| 2019 | Rezaei *et al.* | Revit; Ecoinvent; openLCA | Type IV |
| 2020 | Ding *et al.* | Revit; literature/report/handbook; Access | Type II |
| 2020 | Feng *et al.* | Revit; Ecoinvent; Excel | Type I |
| 2020 | Kiamili *et al.* | Revit; KBOB; Ecoinvent; Dynamo | Type III |
| 2020 | Santos *et al.* | Revit; EPD; generic database; BIMEELCA | Type III |

The first type (Type I) is to use Excel as the calculation tool of carbon emissions, which is the most widely adopted method due to its simplicity and quick feedback irrespective of dedicated software tools. Material quantities are obtained and exported into Excel spreadsheets through element functions in various BIM tools such as Revit, ArchiCAD, and Rhinoceros. Emission factors are acquired from various LCA data sources. The second type (Type II) holds the same mechanism as Type I to acquire engineering quantities and emission factors while author-developed applications using Access, SQL language, C# net, and python instead of Excel are adopted to streamline the calculation process. The third type (Type III) performs a simplified LCA in the native BIM environment with LCA data inserted into objects or an embedded database. In this case, Revit is the most commonly used BIM software tool due to its accessibility to application programming interface (API) development. Such methods make full use of BIM technology in terms of flexible data modification, integrated data storage, quick feedback, and intuitive visualization. The fourth type (Type IV) is superior in the professionalism and reliability by importing the BIM data into dedicated LCA software tools for an accurate and comprehensive LCA. Material quantities generated from BIM can help to facilitate the establishment of LCA models.

Despite numerous advantages mentioned in BIM-LCA integrated methods, two challenges have been discovered and emphasized. The burdensome and cumbersome process of selecting proper LCA data from diverse data sources has been regarded as the first challenge. Generally, researchers obtain LCA data from LCA databases, environmental product declaration (EPD), or literature/report. It is usually time-consuming to collect all the carbon emission factors for materials and energy because one generic database cannot provide sufficient data especially in different regional contexts and accordingly a transversal search in several data sources is imperative. Data interoperability between BIM and LCA tools remains as the other challenge. An intermediate tool is required for data exchange to accommodate the data to a common structure. It is thus recommended that the development of data exchange tools based

on open data format such as IFC is superior to the development of specific plug-ins of certain BIM software.

Therefore, this paper adopts the fourth type of BIM-LCA integration by using SimaPro as the calculation platform, eliminating the manual work of selecting and collecting LCA data and better facilitating sensitivity analysis to perform an accurate and comprehensive LCA. To overcome the limitation of data interoperability between BIM and SimaPro, an automated data mapping and transferring approach based on IFC schema was developed for embodied carbon estimation of prefabricated buildings.

# METHODOLOGY

This section presents the methodology for the development of the proposed automatic BIM-LCA integrated method to estimate embodied carbon emissions for prefabricated buildings (Fig 1). The study was implemented through four steps: 1) establishment of BIM model, 2) data transfer between BIM and LCA, 3) development of BIM-aided LCA model, and 4) model efficiency validation. The whole process was based on a five-level analytical framework developed by Pan *et al. (*2018), i.e. material (e.g. concrete, steel), component (e.g. precast slab, precast staircase), assembly (e.g. non-volumetric precast facade and volumetric precast kitchen unit), flat (a residential unit), and building (the entire building), for estimating prefabricated buildings' life cycle carbon emissions.

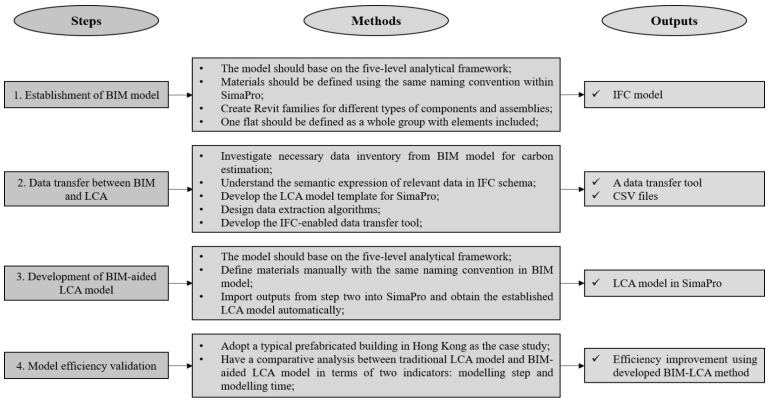



*Fig 1: Methodology framework for the development of the proposed BIM-LCA method*

## Establishment of BIM model

According to the five-level framework, embodied carbon emissions for prefabricated buildings were estimated at the levels of material, component, assembly, flat, and building. To automatically and accurately provide the containment relationship among five levels, the BIM model was established based on the five-level framework. At the material level, a naming convention was determined for both the BIM model and LCA model to tackle the data mapping issue. For components and assemblies of prefabricated buildings, the resources provided by the embedded component library of BIM software were inadequate so that new family types were created according to building information. Then all relevant components and assemblies were assigned into a whole group to identify various units at the flat level.

## Data transfer between BIM and LCA

An IFC-enabled data transfer method was adopted to extract necessary data from the BIM model and to convert data into an appropriate format of SimaPro. IFC is a common data standard supported by numerous BIM software tools. Instead of

developing specific plug-ins using APIs for specific BIM software tools, IFC-enabled data processing is more general without software limitation. Moreover, it is possible to define the containment relationship among five levels using sub-instances of IfcRelationship in IFC schema, which cannot be explicitly expressed in BIM software. Fig 2 demonstrates the data flow of the IFC-enabled data transfer method. The data transfer tool was developed using python after investigating the data inventory for carbon estimation and exploiting data extraction algorithms based on IFC schema. The proposed method achieves automated data conversion from BIM to SimaPro, reducing huge manual work and enhancing data interoperability between BIM and LCA.

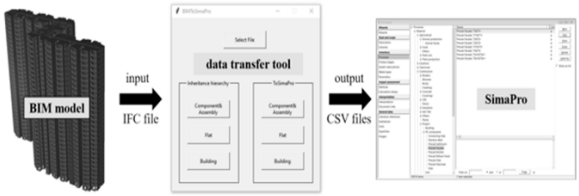



*Fig 2: Data flow of the IFC-enabled data transfer method*

**Development of BIM-aided LCA model**

Building elements are defined as products in the LCA model in SimaPro, which consist of corresponding carbon emitters. For traditional buildings without consideration of prefabricated systems, only three-level products need to be created namely material, individual component, and entire building. However, five-level products were established to obtain embodied carbon emissions for prefabricated buildings at the levels of material, component, assembly, flat, and building. The compositions of products were assigned based on the containment relationship among five levels. Fig 3 illustrates the overall framework of the BIM-aided LCA modelling process.

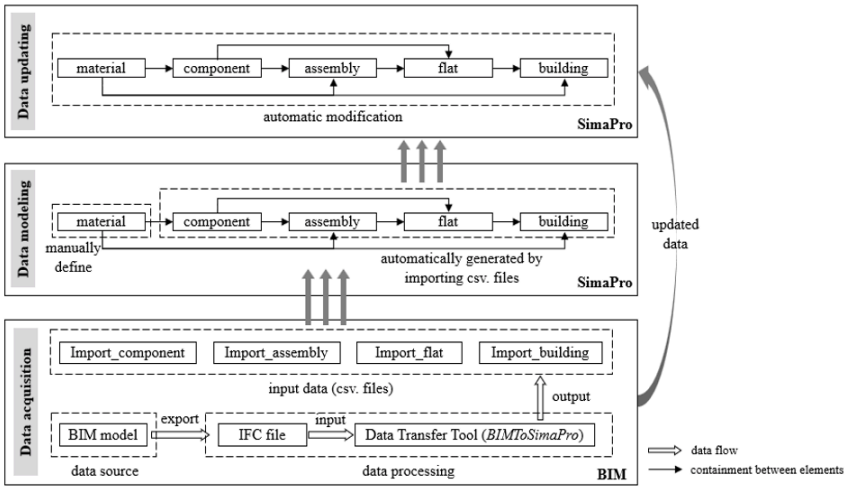



*Fig 3: Framework of the BIM-aided LCA modelling method in SimaPro*

For data acquisition, material quantities and containment relationships among elements could be directly obtained from the BIM model instead of asking project teams for site documents and building drawings or interviewing with stakeholders (Teng and Pan 2020) in the traditional case. Products at the material level included detailed material ingredients, consumed fuels, and transportation data during the material production process, which exceeded the usual level of detail (LOD) of the

BIM model. As a result, manual data input at the material level was inevitable and materials should conform to the naming convention in the design model to guarantee the automated mapping processes. Products at the other four levels of component, assembly, flat, and building were automatically set up by importing SimaPro-accessible files generated from the data transfer tool. Furthermore, automated updating of the LCA model in accordance with the design modification in BIM was realized by reimporting update files and overriding original data. The development of the BIM-aided LCA model eliminates large amounts of human efforts through an intelligent, rapid, and simultaneous establishment of numerous products rather than a separate and successive modelling. It also facilitates quick feedback of embodied carbon emissions for different design options during the design phase.

**Model efficiency validation**

The empirical validation of the LCA model was then implemented through a real case study. A typical floor of a 30-storey prefabricated residential building in Hong Kong was selected as it conforms to the five-level prefabricated system and it is able to validate the efficiency promotion through comparison with previous study using the same case, which was conducted by Teng and Pan (2019) for assessing embodied carbon emissions using the traditional LCA method. After adopting the proposed BIM-LCA method, the model efficiency validation was carried out by comparing LCA modelling steps and modelling time between BIM-aided method and traditional method. Fig 4 shows the BIM model and layout of the typical floor, including diverse types of prefabricated components and assemblies.

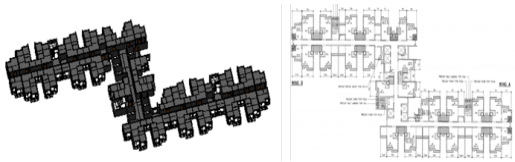


*Fig 4: BIM model and layout of the typical floor in case building*

Based on the five-level analytical framework, the containment relationships among elements of the typical floor are demonstrated in Table 2. The number of types for each product is included in the parenthesis. The typical floor involves flats and individual components such as precast staircases, precast refuse chute, and connecting slabs. Each flat may contain several assemblies and components like precast kitchen, precast bathroom, precast façade, partition walls, and precast slabs. For prefabricated products, the parameters of concrete amount and steel weight were extracted individually, while only a total amount was calculated for cast-in-situ materials at the building level. A comparative analysis between the traditional modelling method and the BIM-aided modelling method in SimaPro was conducted for assessing the efficiency improvement of the proposed BIM-LCA integrated method.

## RESULTS AND ANALYSIS

Two types of indicators were selected for evaluating the model efficiency, namely modelling step, and modelling time. The material ingredients were not defined in the BIM model and the products at the material level still remained manual input. The model efficiency promotion is therefore evaluated at the component, assembly, flat and building levels.

Fig 5 shows the comparative result of modelling steps at five levels of material, component, assembly, flat, and building for the case floor. In the traditional method,

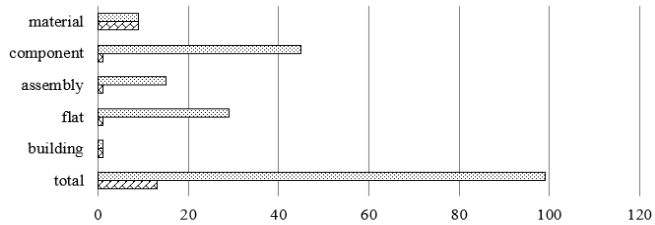
modelling steps depend on product types. For example, only one product at the building level was established in this study as only one typical floor was selected. If considering the whole building, thirty steps would be needed to establish thirty products at the building level. However, in the proposed BIM-aided method, modelling steps at four levels apart from material level are independent of case specification owing to the data import function provided by SimaPro.

*Table 2: Elements in the five-level LCA model of the case*

| Level | Product | Composition |
|---|---|---|
| Building | floor (1) | unit, connecting slab, precast refuse chute, precast staircase, on-site concrete, on-site steel |
| Flat | unit (29) | precast façade, precast bathroom, precast kitchen, partition wall, precast slab |
| Assembly | precast façade (8); precast kitchen (3); precast bathroom (3); precast refuse chute (1) | concrete; steel |
| Component | partition wall (2); precast staircase (4); connecting slab (25); precast slab (14) | concrete; steel |
| Material | concrete (8); steel (1) | material ingredients; consumed fuels; transportation |

*Note: The number in parenthesis represents the number of types for each product.*

The LCA model was automatically established through importing CSV files generated by the developed data transfer tool, which involves necessary information of products and corresponding compositions. Therefore, only the step of importing data was needed at these four levels. Fig 5 indicated that a total number of 86 modelling steps were omitted in this case, reducing repeated manual work and simplifying the establishing process of LCA model. At the levels of component, assembly, flat, and building, more types of products lead to more traditional modelling steps, resulting in higher step reduction. Thus, if applying the BIM-LCA method to the whole case building, more steps could be reduced during the LCA modelling process compared with the traditional method.




| | material | component | assembly | flat | building | total |
|---|---|---|---|---|---|---|
| Traditional method | 9 | 45 | 15 | 29 | 1 | 99 |
| BIM-aided method | 9 | 1 | 1 | 1 | 1 | 13 |
| step reduction | 0 | 44 | 14 | 28 | 0 | 86 |

*Fig 5: Comparative result of modelling steps for the case study*

Fig 6 illustrates the comparative results of modelling time and efficiency improvement of the case building at the five levels. In the traditional LCA method, time estimation was based on mean value since the processes of and time spent on creating products at each level were similar. Ten products at each level were randomly selected as samples for calculating the average modelling time. In this case, it took an average of 6, 2, 2, 3, and 20 minutes to establish one product at the levels of material, component, assembly, flat, and building, respectively. Thus, the total modelling time could be estimated by multiplying the mean value by the number of product types. When importing files in the BIM-aided method, it all took around thirty seconds for data

input at each level regardless of the file size and element quantities. It implies a high-performance potential of data processing in LCA model establishment. The right part of Fig 6 provides the time efficiency improvement at five levels. A significant enhancement of time efficiency above 97% was achieved in terms of component, assembly, flat, and building, while the total improvement decreased to 80% considering the whole process. It indicates that the process of creating materials plays a vital role in LCA model establishment so that it is important to promote smart data input at the material level in further research.

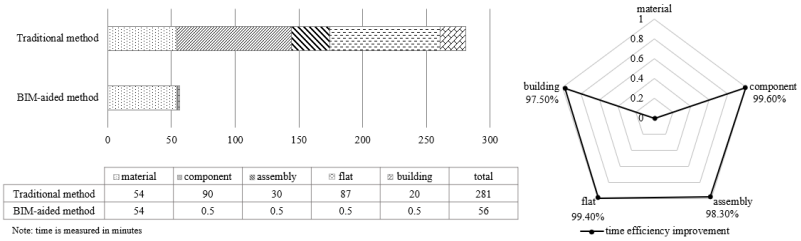



*Fig 6: Comparative result of modelling time for the case study*

# DISCUSSION

The proposed BIM-LCA integrated method aims to enhance the efficiency of embodied carbon estimation for prefabricated high-rise buildings based on a five-level analytical framework. Compared with previous BIM-LCA research, two kinds of research gaps were effectively addressed. First, by adopting SimaPro as the calculation platform, human efforts are reduced in seeking various LCA data sources such as databases, EPD, and literature (Ding *et al.,* 2020; Santos *et al.,* 2020) as well as extracting data into excel templates (Feng *et al.,* 2020). Additionally, dedicated LCA software can better facilitate scenario analysis and uncertainty analysis for embodied carbon emissions whereas only simple multiplication was conducted in most traditional BIM-LCA integration. Second, an IFC-enabled data transfer tool was developed to automatically adapt the BIM data to SimaPro-accessible LCA data structure. By investigating the data inventory for carbon estimation and semantic expression of relevant data in the IFC schema, data processing algorithms were developed for the tool. Besides, a naming convention was established for data mapping of materials. The developed tool can achieve automated data transfer from BIM to SimaPro, greatly enhancing the data interoperability between BIM and LCA. Third, the result of the case study using a typical floor of a prefabricated residential building validated the model efficiency of the proposed method. A total of 86 modelling steps were reduced and an 80 percent efficiency improvement in modelling time was realized. The reduction of modelling steps and modelling time makes the establishment of LCA model in SimaPro a more simplified and convenient process, decreasing the difficulty of using dedicated LCA tools and motivating more accurate and comprehensive LCA applications. However, the result is more of a qualitative analysis of efficiency promotion rather than a quantitative analysis because it depends on many parameters. At the case level, it is relevant to case specifications such as building height, floor areas, product types at five levels, compositions of products, etc. At the operation level, personal proficiency of BIM software and SimaPro, personal familiarity of the case building, and operation habits can also influence the testing result. Nevertheless, it can be concluded that the proposed BIM-LCA method can indeed enhance the efficiency of embodied carbon estimation of prefabricated high-rise buildings through automated data manipulation.

# CONCLUSIONS

To reduce human efforts in LCA data extraction and data mapping between BIM and LCA in previous research, this paper develops an automatic BIM-LCA integrated method to estimate embodied carbon emissions for prefabricated buildings based on a five-level analytical framework, i.e., material, component, assembly, flat, and building. The method includes three successive modules. First, a few criteria should be made for the establishment of the BIM model to define containment relationships of elements in the context of prefabricated buildings. Second, automatic data conversion can be achieved using the developed IFC-enabled data transfer tool. Finally, the LCA model in SimaPro can be automatically established by importing generated files from the second module. The method adopts the five-level analytical framework for embodied carbon estimation, promoting the standardization and benchmarking of prefabricated buildings' embodied carbon. Nevertheless, there are two limitations of this proposed method. First, it was developed based on the five-level analytical framework adapted from the prefabrication system in Hong Kong and it is thus only applicable to similar prefabricated systems comprising such five levels. However, the approach to defining the containment relationships among products at different levels in the LCA model can be applied in other prefabrication systems worldwide. Second, the method is limited to specific LCA software-SimaPro since the data transfer tool was developed according to the LCA data structure in SimaPro. However, it provides an innovative idea to enhance the data interoperability between BIM and LCA by adapting the data into a common data structure and new data processing algorithms should be exploited when considering other LCA tools. Overall, this innovative BIM-LCA method achieved a significant improvement to embodied carbon estimation efficiency compared with the traditional labour-intensive process through a real case empirical validation, contributing to a smart and convenient embodied carbon estimation and facilitating quick feedback of embodied carbon emissions to support building design efficiency. A comprehensive LCA study requires more kinds of data such as formwork, electricity, transportation, etc., which however are not considered in this method. Therefore, integrating more data into the LCA model using BIM or other smart technologies is recommended for future research.

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# Change Management

# THE ROLE OF KEY ACTORS IN THE EMERGENCE OF A STRATEGIC INNOVATION PROGRAMME: A TRANSLATION PROCESS PERSPECTIVE

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The ability to innovate and adapt to change is of central importance at all levels of society today. In this article, a strategic innovation programme (SIP) in the Swedish construction industry is addressed as a vehicle to facilitate system-wide innovation and change. Based on the need to further understand how to deliver industry-level innovation, and an identified scarcity of studies addressing the role key actors have in establishing a SIP, the aim is to analyse and describe how a strategic innovation programme is established and what role key actors play in this process. Theoretically, the study draws inspiration from actor-network theory (ANT) and especially the translation process, which previous studies have shown to be suitable to understand the challenges involved when mobilizing a network of heterogeneous actors. Empirically, the study is based on a qualitative approach and consists of 11 semi-structured interviews with individuals active in the early stages and the development of a SIP. In the article, a number of actor groups are identified and followed through what can be described as two cycles of translation, where one actor group is trying to make itself a 'legitimate spokesperson' for the emerging SIP. The analysis shows, for example, how the problematization of structural changes, digitalization, and industrialization enables the mentioned actor group to successfully translate the interests of other actors into an obligatory passage point (OPP). Apart from providing an understanding of the role that different actor groups play in the becoming of an innovation programme, the study also shows how it is not primarily the actors in the construction industry who are conservative; instead, there is an inertia in the system that complicates a collaborative development of innovations in the industry.

Keywords: strategic innovation; digital; sociology of translation; transformation

## INTRODUCTION

The ability to innovate and adapt to change is of central importance at all levels of society today. During the last decade, so-called strategic innovation programmes (SIPs) have emerged as a vehicle to facilitate system-wide innovation and change on industry level. The underlying idea of these programmes is that research, innovation, and development should manifest itself through mobilization of collaborative and actor-driven networks involving industry, public sector, and academia with an overarching goal of meeting industrial, societal, and global needs (Grillitsch et al., 2019; Schot and Steinmueller, 2018). However, these programmes do not come without challenges. Ensuring the functionality of SIPs is, at the outset, quite an

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intricate task due to their vastness and the inherent necessity to engage a wide variety of actors. These actors do not only represent different organisations but are most often also heterogeneous in the sense that they have different goals and represent different organizing logics. Like all organized efforts, the mobilization of a functionate interrelatedness among involved actors is key to the success of these programmes.

Despite the vast amount of research on innovation programmes, the majority of such studies have targeted 'internally' driven programmes within large corporations (see, e.g., Martinsuo, 2019; Midler, 2019). Studies on innovation programmes as actor-driven networks that targets system-wide innovation and change, such as SIPs, are less common. The studies that exist on these system-wide initiatives have however provided novel and useful insights into the back end of the programmes, for example by addressing how SIPs operate, how they struggle to deliver system-wide innovation, and how they are faced with challenges of measuring performance (see, e.g., Grillitsch et al., 2019; Håkansson et al., 2021). Studies focusing on the front-end of SIPs, and the role that key actors play in the establishment of the programmes are however scarce. In their suggestions for future research, Grillitsch et al., (2019) highlighted the need to further study the role and involvement of key actor groups. Given this background, the present study focuses on the front-end, or 'the becoming' of a SIP. More precisely, the study aims to analyse and describe how a strategic innovation programme is established and what role key actors play in this process.

Empirically, the study is situated in the Swedish construction industry, where governmental initiatives have laid the grounds for the development of a SIP. With the objective of facilitating structural changes in the way that the construction industry operates, a particular focus of the programme is on digitalization and the need for digital transformation. The study is based on a qualitative approach and consists of 11 semi-structured interviews with individuals active in the early stages and the development of the SIP. Theoretically, the study draws inspiration from actor-network theory (ANT) and the translation process, as described by Callon (1984), which has previously been shown to be suitable for understanding the challenges involved with mobilizing a network of heterogeneous actors in the industry in question (Harty, 2008; Lindblad, 2019).

## BACKGROUND

In 2012, the Swedish government initiated a call for 'Strategic Research and Innovation Agendas' as an attempt to find solutions to societal and global challenges, and to strengthen Sweden's international competitiveness (Vinnova, 2021). As a result of this call, over 100 agendas were formulated, three of which had a particular focus on the construction industry. With the construction industry's poor performance as a common denominator, their solutions in terms of technological scope, or focus, was different. The first agenda was developed with a particular focus on Building Information Modelling (BIM), the second on Geographical Information Systems (GIS), and the third focused on how to utilize and integrate industrial processes (IP) in the improvement of the industry. In 2013, the three agendas merged into one common agenda, creating the basis for the SIP in question (Håkansson *et al.,* 2021).

Unlike 'traditional' innovation programmes that focus on innovation within large corporations (see, e.g., Martinsuo, 2019; Midler, 2019), SIPs, like the one studied, are built around the idea that innovation is to be developed in collaboration among industry actors from different parts of the value chain (Grillitsch *et al.,* 2019). Thus,

innovation can be said to be a result of how successful networks of actors are mobilized. From a theoretical point of view, mobilizing these networks can be understood as a translation process (Callon and Latour, 1981; Callon, 1984) consisting of four moments of translation: *problematization*, *interessement*, *enrolment*, and *mobilization of allies* (Callon, 1984). These four moments will be used as a theoretical backbone for the present study to understand how the development happened.

**The Four Moments of Translation**

The first moment of translation is problematization, or how actors can become indispensable. According to Callon (1984), this moment comprises the way a focal actor identifies an idea as either a problem or an opportunity. Additionally, it involves the focal actors' identification of other actors who are seen as indispensable for solving the problem or reaping the benefits from the opportunity. As part of problematization, it is important for the focal actor to identify which roles and relationships other identified actors could have in the network to achieve the goals. If the network is heterogenous, the inherent goals and interests of the identified actors are not necessarily aligned with the interests of the focal actor. Therefore, Callon (1984) argued that the goal of problematization, from the focal actors' point of view, is to identify a question (or issue) whose answer is perceived as beneficial for all involved actors. This implies creating a so-called 'obligatory passage point' (OPP), which can be described as a funnel that forces actors to converge on a certain topic, issue, or question and become allies.

The second moment of translation is interessement, or how the allies are locked into place. Callon (1984:207f) described this second moment as "… the group of actions by which an entity (…) attempts to impose and stabilize the identity of the other actors it defines through its problematization". In other words, it implies that the focal actor tries to 'isolate' the identified actors from other influences that may affect their alliance with the intended network. Therefore, a key challenge, from the focal actors' perspective, is how to succeed in getting the identified actors to retain their interest in what is to be achieved within the network. Callon (1984: 208) wrote," … to interest other actors is to build devices which can be placed between them and all other entities who wants to define their identities otherwise."

In addition to problematization and interessement, the translation process consists of the moment enrolment, which relates to the way in which roles are defined and coordinated. With a network established there is, from the focal actors' point of view, a need to further stabilize the network by anchoring the actors in their positions. This is because interessement alone does not necessarily lead to the desired alliances (Callon, 1984). Motivation is key for enrolment. By infusing notions of more desirable states and how to reach them, the focal actors try to influence the other actors to accept their roles in the network (Holmström and Robey, 2002). The moment of enrolment neither entails nor excludes predefined roles. Rather, it can be described as a 'plan' in which a set of interconnected roles are defined and ascribed to the actors who accept them. However, these roles are not fixed. Callon (1984:211) stated that "… the group of multilateral negotiations, trials of strength and tricks that accompany the interessement and enable them to succeed". If the issue identified as an OPP during the problematization results in several satisfactory responses for the involved actors, the moment of enrolment is facilitated and the statements in the problematization are likely to be transformed into 'facts'.

The final moment of the translation process is the mobilization of allies, which relates to the question of whether the spokespersons are seen as representative. In previous moments, it is common for only a few individuals to be involved. These individuals are representatives for their respective actor groups and have spoken for their group during the translation process (Callon, 1984); that is, they act as spokespersons. Still, a key issue arises in terms of how representative these spokespersons really are for the actors they represent. Callon (1984) described this issue by asking, "… will the masses (…) follow their representatives?". In essence, for mobilization of allies to happen, the individuals involved must thus mobilize the group they have spoken for during the previous three moments. Table 1 provides a short summary of the key characteristics for each moment of the translation process.

*Table 1: The four moments of the translation process*

| Moment | Characteristics |
|---|---|
| Problematization | A new idea (problem and/or opportunity) is identified by a focal actor that requires mobilization of a new actor-network to solve the problem and/or reap the benefits of the opportunity. |
| Interessement | The actions taken by a focal actor to interest, impose, and isolate actors who are identified as indispensable for the network to achieve its goals. |
| Enrolment | Further stabilization of the network is needed by anchoring the actors' position in the network. The focal actor tries to motivate the participating actors to accept their role in the network. |
| Mobilization of allies | Often, only a few individuals are involved as representatives for their respective group. It is now up to the spokesperson to ensure that the group it represents acts according to its interests. |

# METHOD

This article sets out to understand the establishment of SIPs. As described in the beginning of the background, a Swedish SIP, with a focus on digital transformation in the construction industry was used as the case. With the explanatory nature of the inquiry, a retrospective qualitative interview-based approach - designed to identify what has happened and why - was considered appropriate for data collection (see, e.g., Stake, 1978; Yin, 2018). Due to the limited number of individuals formally involved in the establishment, interviewees were identified primarily using a snow-ball technique, where the first respondents were asked to inform about other individuals involved, and whether the themes addressed during the interview could be further enlightened by additional individuals. A total of 12 people were identified as involved in the establishment. All 12 were invited to participate in the study and 11 chose to do so. Consequently, a total of 11 semi-structured interviews were conducted: two with individuals from the programme management of the SIP, four with individuals representing the research councils backing the initiative, and five with individuals who were deeply involved in the establishment process and at the same time representatives from the three agendas that formed the bases for the SIP. In the remainder of the article, these five individuals will be referred to as *the initiators*.

Interviews were designed to address the establishment process following the timeline outlined in Table 2 below. With the initiation starting almost 10 years ago, this process called for a retrospective approach which relied on the interviewee's memory of, and presence in, the events that led to the establishment of the SIP. The interviews were conducted between November 2020 and January 2021. The average duration of the interviews was approximately 70 minutes; all interviews were recorded, transcribed, and sent back to the respondents for validation and approval. With transcripts approved, the material was thematically analysed using the four moments

of translation as the backbone. The terminology and concepts of the translation process, as described by Callon (1984), enabled the analysis and understanding of how the network of actors were formed.

# RESULTS

The results are presented in five consecutive parts. First, a short outline of the major events and history will be given. Second, the moment of problematization is described, where a focal actor is identified. Third, the moment of interessement is presented. It is shown how devices in terms of collaborative R&D projects are developed and used to interest and isolate actors. Fourth, the moment of enrolment is analysed, where actors' roles are to be defined and coordinated. Because not enough actors were enrolled in this moment, a second cycle of translation was needed. Fifth, and finally, the second cycle of translation is outlined, and it is shown how the initiators manage to enrol trustworthy spokespersons that represent important key actors in the construction industry, which leads to the development of a SIP.

## Setting the Scene

As mentioned in the background, the establishment of the SIP in question started in 2012 with a governmental call for 'Strategic Research and Innovation Agendas'. Based on the proposal of more than 100 agendas, 17 SIPs were established, where one focused on digitalization and digital transformation within the construction industry (that is, the case of use in this study). In the sections to come, the process of how a formulated agenda became an established SIP will be described as a translation process inspired by Callon (1984). Table 2 outlines the major events in this process.

*Table 2: Timeline of the creation of the SIP*

| Timeline | Event/happening |
|---|---|
| April 2012 | The call for strategic research and innovation agendas were announced |
| July 2012 | The three agendas (focus on BIM, GIS, and IP) were developed separately |
| July 2013 | A focal actor, the initiators, was formed due to a merger of the three agendas |
| July 2013-February 2014 | The idea of a SIP within the construction industry emerged through the first cycle of translation |
| February 2014 | First application submitted to develop a SIP in the construction industry |
| May 2014 | First application denied by the funding agencies |
| August 2014 | Second cycle of translation initiated |
| February 2015 | Second application submitted to develop a SIP in the construction industry |
| April 2015 | Application approved by the funding agencies |
| January 2016 | SIP officially launched |

## Problematization: Everyone Sees the Problem and a Solution is Offered

The performance problems of the construction industry - such as poor quality and low productivity - have been debated for more than 20 years. These problems are often attributed to the industry actors who, for a long time, have been accused of being conservative and unwilling to change. However, while the critique of the industry's poor performance might hold true, the initiators argue that it is an inertia in the construction production system rather than the industry actors' resistance to change that causes this problem. As described by Marge, one of the initiators:

> …this is what many calls conservatism, what I choose to call inertia in the system. Because it is not the actors that are conservative, it is built into the system that it becomes an extreme inertia when trying to change.

During the interviews, it was explained that the changes that need to be made to address the performance problem in the construction industry often lie in-between the traditional roles, processes, and responsibilities of individual organisations. Due to the fragmented construction process (no actor is responsible for the entire process), the short-term-oriented way of doing business (the project-way of organizing), and the downpipe thinking (improvement of internal and/or existing processes), it becomes extremely difficult for any individual organization to engage and/or change something outside their normal part/place in the construction process. With these problems as a foundation, and the awareness of what kind of challenges the Swedish government aimed to address with the SIPs, a solution focusing on facilitating collaboration between organisations from different part of the value chain emerged. However, for the initiators to reap the benefit of this opportunity, more actors needed to recognize the problem and engage in the suggested solution (Callon, 1984).

*Identification of actors*

Through the analysis, it was possible to identify three actor groups that were indispensable for the initiators to succeed: the actors of change, academia, and the funding agencies.

The actors of change are represented by a selection of industrial actors in terms of companies, organisations, and/or authorities in the construction industry. To ensure that the solutions that originate from the SIP is orchestrated in a bottom-up way, the initiators needed to identify those who either want to change (and know where the problems lie), are market leaders (based on size, competence, or innovativeness), or could influence large parts of the process (e.g., the municipalities and their monopoly of land-use).

Academia is represented by universities and research institutes. Collaborative development between industrial actors and academia is not as common in construction as it is in other manufacturing industries. Even if the emerging SIP is intended to be an actor-driven programme, the relationship between the actors of change and academia has been highlighted as a crucial building block to develop sustainable solutions that fits the industry.

The funding agencies are represented by three research councils that have been assigned responsibility over the agendas that were developed and, in the initial stage of the process, have the authority to approve/deny the SIP its funding. They are the outpost, the last actor to be enrolled. If the initiators can show that the problem the SIP has set out to solve is solid, and that the idea has a strong support by both the actors of change and the academia, it is more likely that the funding agencies supports the SIP as well.

*Defining the obligatory passage point*

The goal of the problematization is to identify a question, or an issue, called an obligatory passage point (OPP) in which the answer, or solution, is beneficial for the participating actors (Callon, 1984). So far, the idea of developing a SIP to address the performance problem of the construction industry has been the sole work of the initiators. By involving the identified actors, the initiators wish to show that the suggested SIP creates an opportunity to collaborate outside the roles, processes, and responsibilities of traditional construction activities. The SIP represents a new collaborative and actor-driven change initiative where the actors of change, academia and funding agencies are given the opportunity to address the long-lasting problems of the construction industry and structurally change how to collaborate and do business

within the industry. However, for this to happen, the identified actors need to understand their role, as well as the other actors' roles, and that their alliance around this SIP can be beneficial for them all.

**Interessement: What's in It for Us?**

While the performance problem in the construction industry was relevant and recognizable for many of the identified actors, a solution in the form of a SIP was somewhat hard to understand; specifically, the intended roles and relationships between the involved actors and how they were supposed to collaborate within the SIP. The idea of the SIP was also perceived by some as a way to outcompete existing initiatives. For example, existing 'interest organisations' (for example, BIM Alliance) with specific technological focus, smaller development programmes (for example, Bygginnovationen; in English: Programme for construction innovation) that already supported the actors of change with their innovative ideas, and some representatives from academia did not really understand the idea of mixing research with construction practise. As a result of all of this, a question was raised: Who will benefit from this SIP and how is this different from what already exists?

To strengthen the identified actors' interest, the initiators needed to impose the SIP in such a way that the actors understood that the fulfilment of their internal goals depends on their engagement in the SIP. Callon (1984) described this as building devices that can be put between the identified actors and other conflicting network that defines their identity/interests otherwise. While investments in R&D within the construction industry are low compared to other manufacturing industries, the R&D that exists focuses more on intra-organizational development - that is, working in downpipes and improvement of internal processes - as explained by Abraham from the programme management:

> In traditional construction activities, the focus is very much on the interfaces between the actors involved, and not on the parts that needs to be solved in collaboration (…) and what you do, when for example implementing change in terms of new digital tools, is that you develop a small part of the entire process. But it has no major effect on the construction process as a whole.

Even if this development is important for the individual organization's competitiveness, its impact on the industry's performance problems is negligible. By introducing the use of collaborative R&D projects, the initiators intended to position the SIP as the industry's collaborative platform for change and digital transformation. Many of the industry's problems are either too large for one actor to address alone or have been overlooked in traditional construction activities. By enabling, and funding, these collaborative R&D projects all actors who gets involved are now given a form where problems that lie in between the traditional roles, processes, and relationships in the construction industry could be addressed in new inter-organizational and collaborative forms outside the traditional construction activities. Abraham from programme management continues:

> … this kind of programme can be seen as an opportunity to apply for money that might be the difference between if you dare to change or not (...) this money could be seen as stimulation to actually go through with your idea.

**Enrolment: Time to Make a Stand**

To further stabilize the situation, the initiators needed to anchor the other actors' position in the SIP and motivate them to accept the roles and relationships that was given to them. This is what Callon (1984) described as the moment of enrolment in

which multilateral negotiations, trials, and tricks are needed. While this is one of the most crucial moments in the establishment of the SIP, it comes down to the engagement of both the actors of change and academia. The whole idea of the SIP builds on a bottom-up approach where these key actors are supposed to collaborate in new forms to be able to influence how to do business and collaborate over the traditional interfaces of construction activities. For this to happen, the SIP required a wide support from actors of change in terms of companies and organisations that are spread throughout the value chain. It ranges from governmental authorities and municipalities in the early stages, to facility and operations management at the other end of the construction process. However, due to the problem of downpipe-think and intra-organizational development of construction activities, the engagement of academia is crucial for the SIP to produce sustainable solutions that are beneficial for the construction industry, and not only the sole actors involved in the programme.

In 2014, the initiators submitted their first application to develop a SIP targeted at the Swedish construction industry but were denied funding from the funding agencies. The initiators did not manage to enrol enough key actors to support the SIP and could not show a united front for the funding agencies. Even if this was not the only reason for the application to be rejected, it became clear that the actors involved in the earlier moments of the process did not fully understand their roles in the SIP and how they were supposed to engage. As described by Bart, one of the initiators:

> …'but how are we supposed to engage?' That is what I felt was the resistance from the actors. The fear, or maybe not the fear, but they wanted to stand next to the side-line for a while and be like - 'well, let's see what happens with this.' You know, they sat with their arms crossed and 'well, run this for a while and we will see if we engage or not'.

**Mobilization of Allies: The Importance of Reliable Spokespersons**

While both the actors of change and academia struggled to understand their intended role in the SIP, the funding agencies though that the scope of structurally changing the construction industry was a little too broad. In what we have chosen to call the second cycle of translation, the programme scope needed to be modified. Among many things, this included a modification of the problematization where the importance for structural changes was placed in relation to both the global, national, and societal development goals. The focus on digitalization and digital transformation - that is, the integration of the three previous agendas relating to BIM, GIS, and IP - was put forward as the centre of the programme. Now, the short-term focus was to strengthen the industry's digital competence while the scope of structurally changing the construction industry, by facilitating inter-organizational collaboration outside traditional construction activities, was emphasised as a more long-term goal.

Finally, to increase the reliability of the SIP, more actors needed to be enrolled in the programme. So far, the actors involved in the previous moments of this translation process had only been represented by a few individuals. In this moment of the translation process, it became important that these individuals were representative and trustworthy spokespersons for the group they represented, for them to mobilize their allies (Callon, 1984). In the second cycle of translation, more actors were enrolled, were CEOs from some of the larger organisations in the construction industry showed their support and willingness to participate. Now, the SIP had strong enough support with representative spokespersons from both the actors of change and academia, which led to the enrolment of the funding agencies and approval of the SIP.

## DISCUSSION

In this article, we set out to analyse and describe how a strategic innovation programme (SIP) was established and what role key actors play in this process. By using the translation process as an analytical frame, it is shown how the immediate role of the key actors - that is, the actors of change and academia - is to represent a stable network for the funding agencies to be able to fulfil their role of funding the SIP, and thereby support the development of the industry. However, since the initiators did not fully manage to get the key actors to accept their roles, because they did not really see the benefits that the SIP was offering, the mobilization of allies (key actors) was untimely. When the initiators tried to mobilize the funding agencies, by sending the application the first time, the key actors had not yet accepted their roles in the network. Even if the actors of change saw the need for digitalization, they were still more aligned with existing industry initiatives for R&D projects, and therefore hesitant regarding the proposed SIP. However, this moment of 'wait and see', or reactive stance among actors is well known in the industry (see, e.g., Löwstedt and Räisänen, 2012). Thus, it can be argued that the first cycle of translation, and the initiators original idea of using the SIP as something that should facilitate structural changes of the industry, was too abstract and not appealing enough for the key actors.

When the initiators revisited the problematization, the focus changed from structurally changing the industry to digital transformation and how to make use of digitalization. Thus, the short-term focus was on strengthening the industry's digital competence, whereas the structural transformation became a more long-term goal. Therefore, it can be claimed that this translation was more recognized by the actors of change because they have a tendency to look more at short-term benefits than long-term goals (see also Jacobsson et al., 2017). Thus, the initiators managed to create a sense of urgency by comparing the level of digitalization with other industries, at the same time as the SIP became an OPP to solve the more immediate problem with lacking digital competencies. This reframing of the problematization facilitated the enrolment of CEOs for larger firms, which implies that the initiators became more representative as spokesperson for the industry's interests when the revised application was sent to the funding agencies. However, getting the SIP approved was just the first step towards the long-term goal of a structural change of the industry. The devices, in terms of collaborative R&D projects, are what holds the key actors in place due to the opportunities to get funding for collaborative activities outside traditional construction activities. If the more long-term goals would be reached, the next challenge in the proceeding translation process is that the collaborative R&D-projects would, in some sense, contribute to the long-term goals.

## CONCLUSION

In this article, an SIP in the Swedish construction industry is addressed as a vehicle to facilitate system-wide innovation and change. However, this paper has shown how the emergence of a SIP is not a linear process, and how it includes the involvement of both initiators, key actors, and funding agencies. By drawing on the translation process (Callon, 1984) as a perspective for analysing the emergence of the SIP, it can be concluded that the immediate role of key actors is to represent a stable network of heterogeneous actors for the funding agencies to support and fund the SIP. While this is the immediate role in the emergence of the SIP, this is still just the first step towards structurally changing the construction industry. Future challenges lie in how the key actors can become more proactive, learn how to collaborate outside traditional

construction activities, and engage in collaborative R&D projects to ultimately achieve the SIPs long-term goal of using digitalization to structurally change the way the construction industry collaborates and does business.

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# Construction Design and Technology

# BRICKLAYING ROBOTS IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY: THE CONTRACTORS PERSPECTIVE

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The construction industry has been slow in adopting new technological innovations, even though studies have shown that the adoption of automation and robotics would result in the construction works being executed in safer environments, with better alternative building methods, that could ensure that the works are executed with greater accuracy therefore improving the quality of construction works. This paper investigated the contractor's perception of adopting the semi-automated mason (SAM) a bricklaying robot in the South African construction industry as an alternative building method that would contribute to the introduction of automation and robotics in the industry. A qualitative research design was used. The non-probability purposive sampling method was used to select 20 construction companies based in Durban, KwaZulu-Natal for the purposes of conducting this study. Data were collected through telephonic semi-structured interviews with respondents from construction companies and were thematically analysed using NVivo 12. The study revealed that the construction industry professionals are willing to adopt the semi-automated mason into their working structures, but believe that, currently, the South African construction is not ready to implement such technological innovations. The challenges identified by the respondents where the high unemployment rate in South Africa, the risk of mass job losses among manual labourers and the cost of the robot would be great barriers to companies willing to adopt SAM.

Keywords: bricklaying robots; automation; semi-automated mason; robotics

## INTRODUCTION

The demand for efficient construction processes and innovative construction techniques has increased within the construction industry, and this has been largely due to the rising competition in the globalised market, and the advancement of technology in the 21st century (Hasegawa, 2006). Automation and robotics have been identified as the main and most important means of swiftly moving the world of construction towards the simplification and computerisation of almost all construction tasks and processes (Oke, Akinradewo and Aigbavboa, 2019). For centuries, the construction industry has relied on the use of manual labour for the execution of construction tasks, resulting in a stagnant industry in terms of improving productivity,

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safety and quality, however the implementation of technology and robotics into construction has been a very slow.

The construction industry is regarded as one of the leading industries in the creation of employment, both formal and informal, directly and indirectly because of its reliance on manual labour (Klinc and Turk, 2019). However, over the centuries the construction industry has seen some major technological advances which led to construction processes becoming easier and faster to execute. These advances range from software applications like Computer-Aided Design (CAD), computer software that produce cost estimates and construction schedules such as WinQS, to tangible construction equipment, plant and machinery like cranes, tractor loader backhoes, and other bulk excavation tractors. These technological advances perform different tasks in different stages of construction processes, from the initial planning and design up to the actual construction. They move material quicker, with greater reliability and precision than human labourers. Heavy equipment for use at the job site, such as cranes, conveyors, and earth movers, continue to become more efficient as technology advances (Yates, 1988).

The adoption of robotics and automation within the construction industry has been slow, and it is a problem facing many construction industries around the world, the South African construction industry being one of them. To better understand the underlaying factors to this low adoption of automation and robotic technologies, this study investigated the intention of adopting bricklaying robots in the South African construction industry and to determine the willingness and readiness of construction companies to adopt this robot as a step in automating their work processes.

Construction automation is the utilisation of robots to improve production and minimise risk of accidents on construction sites. By shifting and re-assigning work originally performed by humans to robots, construction automation helps firms achieve better quality using less resources and in a shorter period of time. Oke, Aigbavboa and Mabena (2017) further establishes that construction automation is a self-controlling procedure that operates by using computerised machines to perform different construction tasks. Construction automated machines are designed and developed to function in conformity with a programme that regulates the behaviour of the machine and ensure efficiency at all times without imposing any risk to people operating or working besides it.

**The Bricklaying Robot**

The introduction of more automation and robotics is needed to overcome the challenges faced by the industry such as declining productivity and quality and on-site accidents (Oke, Akinradewo and Aigbavboa, 2019). Japan was the first country to produce the first real world single task construction robots manufactured by the major construction contractor, of Japan, Shimizu to be tested in the market (Bock and Linner, 2016). Over the past few years there has been major improvements in the industry with new technological innovations slowly being implemented.

It is through these technological advances that the world of construction has seen the introduction of the semi-automated mason (SAM), the bricklaying robot, developed in the United States by the New York based robotics and automation equipment manufacturer, Construction Robotics (Dormhel, 2017).

Bricklaying robots are single task construction robots (STCRs), which assembles brick walls with minimal input from humans. They almost totally take over the

manual labour that would be needed from human workers to lay bricks. They were developed to achieve more productivity while using less resources (Bock and Linner, 2016).

Over the years technology and machines and robotics have beensimplified, their design incorporates simple systems which are easy to work with and operate. This makes it easier for people and construction companies to be open to the idea of utilising bricklaying robots in construction and replacing human workers. The integration of innovative technologies such as SAM on construction sites has a great chance of improving the productivity, safety and quality aspects of the construction industry (ManLi, 2018).

The adoption of construction automation and robotics would be beneficial to construction industries by increasing production, reducing construction duration, improving quality, lower risks of injuries and fatalities and reducing labour and production costs (Akinradewo, Oke, Aigbavboa and Mashangoane; 2018; Bock and Linner, 2016; Dormhel, 2017).

### Challenges of Adopting Bricklaying Robots

There are drawbacks identified with the implementation of automation and robotics, which includes job loss, the cost of acquiring the bricklaying robot, the uniqueness of construction sites, technical and work-culture factors and a weak business case (Bock and Linner, 2016).

## RESEARCH METHOD

For this study, the researchers wanted to collect information and opinions of experienced and knowledgeable construction industry professionals about their views, attitudes and beliefs on adopting automation and robotics in the South African construction industry. Therefore, the qualitative research method was adopted because in a qualitative research process, the researcher focuses on learning the meaning, that the participants hold about the problem or issue, and gives high importance to their point of view as this would form the basis of their analysis and research conclusion (Creswell, 2020). The non-probability purposive sampling method was adopted in this study as it allowed the researchers to seek out information-rich respondents to best address the research purpose and questions (Leavy, 2017), and this was done through the use of semi-structured interviews which were conducted telephonically. In order to ensure that the respondents knew what SAM is and how it works, they were provided with a link to a tube video to ensure that they had a good understanding of what they were being asked about. Prior to conducting the interviews ethical clearance was obtained. Twenty respondents based in Durban, KwaZulu-Natal registered with the KwaZulu-Natal Master Builders Association participated in this study. Leavy (2017) suggests that 20 is an appropriated sample size for a qualitative research.

The data collected from the interviews were analysed using NVivo-12. This entailed coding all the data to accumulate and increase the understanding of the respondent's perceptions, attitudes, and beliefs in a format that is easy to read, use and understand.

## FINDINGS

Sixty five percent of the participants were male and a majority of the participants (40%) were quantity surveyors. Over 40% of the participants had more than 11 years'

experience with 45% of the companies they worked for were in existence for more than 15 years.

Three clear themes emerged from the analysis of the findings which were the benefits of using SAM, the disadvantages of using SAM and the willingness to adopt the use of SAM.

**Theme 1: Benefits of using SAM**

There is currently no construction company in South Africa that has adopted the use of the semi-automated mason. This is also true for most construction industries throughout the world as construction robots are still being researched and there are only few practical construction robots developed and used (Kangari, 2015). The first theme provided an analysis of what the participants perceived would be the major benefits if the semi-automated mason (SAM) was to be adopted by construction companies in South Africa. The benefits of adopting SAM would be improved quality of construction works, faster construction time, increased productivity and reduced labour costs. Other benefits were the creation of new skills and improving the skills level of the current manual labourers and improving the safety in construction sites.

*Improved quality*
The standard of quality one achieves using manual labour is never consistent as it depends on the skills, experience and competency of the workers, therefore, this was the strongest attraction of SAM. A majority of the respondents, stated that the movement from manual methods of construction to using construction robots would eliminate factors such as human error and unskilled labour which compromise the quality of works in construction projects. Participant 20 stated that "robots are programmed to carry out a specific job and do exactly what they are told, so by that I think the precision and quality of laying of the bricks would be greater". Participant 19 supported this view by providing that "I think the technology within the robots allows them to precisely lay a brick without any error so I think they would really improve the quality without any human error involved, …more people would want to work with us as result of the quality we will be producing".

*Faster construction time*
The second most mentioned benefit was faster construction time. Ninety five percent of the participants were of the view that construction projects would be completed much faster if bricklaying robots were implemented. Participant 2 stated that "I believe a semi- automated machine would complete the work much quicker as compared to the most experienced worker …", Participant 8 added that the "construction duration would reduce as the works would be executed faster because the SAM can lay more bricks a day as compared to human and it never gets tired or needs any breaks".

*Increased productivity*
Fulford and Standing (2014) provided that one of the major challenges that are currently facing the construction industry is low productivity as compared to other industries. The respondent's believed that automating the construction industry would be a solution to this challenge. Fernando, Mathath and Murshid (2017) stated that many industries around the world like manufacturing and the automotive industries were able to increase productivity and realise greater profits after they were automated. This supports the views held by the respondents that if the semi-automated mason is applied properly and efficiently in executing construction tasks, it would greatly increase productivity in the construction industry. Participant 7

commented that the adoption of SAM by construction companies would "increase productivity by being able to start work on time, work through breaks and work longer shift hours". Participant 5 added to this view by stating that by adopting SAM, "the company could get more recognition, more people would be talking about the company that has such technology and therefore reaching more potential customers". The participants believed that the adoption of SAM would attract more clients, which would mean getting more projects and therefore increasing the productivity of the company, and the industry. Participant 10 stated that "in extreme circumstances like during the COVID-19 pandemic SAM would have been a viable asset…".

*Reduced labour costs*

The participants believed that the adoption of SAM into construction working processes would affect the running costs of a construction company because the adoption of SAM would lead to a lot of manual workers losing their jobs. The participants believed that this would lead to construction companies saving a lot of money on labour costs as there would be fewer manual bricklayers employed. Participant 13 stated that "another obvious value of using SAM would be the running costs. Despite the fact that SAM would be costly to purchase, it will be cheaper to run in the future when compared to having a masonry team". Participant 1 stated that "construction companies, or any other company in a labour-intensive industry such as the construction industry spend large amounts of money on salaries, wages and employee benefits. Having automatic bricklaying robots would help save on these costs", and participant 18 added that "I think it (SAM) would make the construction of buildings become cheaper as it would be replacing a lot of manual workers and finishing the work faster".

Creation of new skills and improving the skills level

The South African construction industry is a great employer of unskilled labour, people who specialise in bricklaying usually do not hold any qualification or tertiary education. Some participants were of the view that the adoption of the semi-automated mason would provide opportunities for the manual labourers to be retrained to be able to operate and maintain the robots. Participant 8 stated that "unfortunately, people would lose their jobs, but also this would be a great opportunity to learn new skills and learn how to operate the robots", Participant 3 also added that "… there would also be a lot of new job opportunities presented by the implementation of the bricklaying robots". The participants believed that even though the number of people retrained to operate would not even be close to the number of people who would lose their jobs, there would be an increase in the skills level and the retraining of workers.

*Improve Health and Safety*

Construction robots relieve workers of tedious jobs, as humans tend to get bored and lose focus while working, making them prone to accidents or mistakes. Since the robot works without mental or physical fatigue, it can perform the job consistently and safely. In commenting to the question of safety, most of the respondents responded in the positive and stated that having less people, would mean less risk of human error on construction sites and this will therefore minimise the chances of accidents and injuries because they believed that most accidents on sites occur due to human error or recklessness from human workers. Participant 1 stated that "… construction sites will no longer be as crowded and there will be enough space for everyone to perform their duties without risk of causing accidents".

Two of the participants believed that even though the use of the semi-automated mason would improve the overall safety of construction sites, there would still be the risk of danger from the robot itself if not properly maintained and operated by a fully qualified person. Participant 11 stated that "the robot itself can cause danger if not used appropriately …". Participant 9 stated that "in terms of accidents caused by human error I think the bricklaying robot would limit those, but the system itself could impose its own risks, like if it breaks down, loses control or is operated by an unqualified person".

**Theme 2: Disadvantages of using SAM**

The second theme developed from the participant's interviews was the disadvantages of using SAM in the South African construction industry. The most recurring and common answers from the participants were the increase in unemployment and loss of jobs and the cost of SAM. An additional disadvantage in SA is the possibility of riots.

*Increased unemployment and job loss*
The p increase in unemployment was one of the factors that would be disadvantageous in the adoption of SAM by the South African construction industry. Furthermore, the participants commented that "there would be fewer job opportunities for informal labour within the construction industry" adding to that, "some people would be laid off, hence contributing to an increase in unemployment."

Bock and Linner (2016: 156) stated that having the semi-automated mason on construction sites would mean that construction companies no longer need too many bricklayers on site and the participants believed that the introduction of SAM would lead to bricklayers losing their jobs. Participant 2 also mentioned that "… trades will become irrelevant and skills will be lost."

*Costs*
Construction companies willing to adopt automation and robotics are usually limited by economic factors such as all the elements that identify to the costs of acquiring, using and maintaining the robotics. The participants felt that the introduction of bricklaying robots would cost them a lot of money and time to train their employees to operate and work with SAM and after training them they would now need pay a higher rate as the employees now have a 'scarce skill'. It was also believed that there would be the additional costs of "maintaining and servicing the robot, the insurance, training and salary of the operator". Participant 1 stated that "since they are manufactured abroad, they would have to spend on the cost of the robot plus shipping costs and levies and import tax so the cost would be much higher than the retail cost". Therefore, many construction companies would feel discouraged to adopt the robots due to affordability issues.

*Riots*
The participants also thought that the public will not be too pleased with the introduction of SAM in South Africa because they are currently looking to the construction industry to improve the employment rate of the country. Therefore, the participants thought that having SAM in the construction industry would add to the frustrations of the society, "thinking that the robots are here to replace them, there will be a violent disturbance of peace by the society, i.e. riots." Participant 3 also added that the "unions would oppose the idea, as it would disrupt the usual work flow of the sector. Basically, SAM wouldn't be worth it in the end". The participants further added that "the robots definitely won't be used on public or government works because the contracts used stipulate that you have to use labour intensive construction

methods, sometimes you are not even allowed to dig a hole using a machine, you have to use manual labour".

**Theme 3: Willingness to adopt the use of SAM**

The willingness of the construction industry to adopt the semi-automated mason will be greatly influenced by the interest shown by the key role players, stakeholders, directors and the government. This theme allowed the respondents to comment on their willingness, or lack thereof to adopt the semi-automated mason in the South African construction industry.

Almost all the participants shared the same view in that South Africa is not keeping up with and is still far behind in the implementation and use of technology in the construction industry. They therefore believe that SAM will aid in "South Africa becoming more technologically advanced." Participant 5 stated that "I believe that the South African construction industry is only keeping up with the software and programming side of technological development, when it comes to the tangible technology, we are stuck with the original labour-intensive methods of construction."

*Would SAM be a good investment for construction companies?*
Eighteen of the participants believe that, looking at the potential benefits, adopting the semi-automated mason would be a great investment for them. But most importantly, they would have to look at cost implications, meaning "adopting SAM would have to make good business sense in that it would have to help cut costs and save money". If the costs of operating and maintaining the bricklaying robot would prove to be higher than having manual labours then the robots would not be a good investment". They believe that if adopting SAM would improve the quality of works, increase productivity, help cut down on labour costs and create safer construction sites then having the robot would be a big advantage. Some of the respondents also stated that having the semi-automated mason would be beneficial in extreme circumstances like during the COVID-19 pandemic when manual labourer were unable to work, then it would be a viable asset.

However, Participant 11 stated that "adopting the semi-automated mason would be more costly than manual labour in South Africa today, when, taking into account the cost of the robot together with its programs and the maintenance cost which would be the major issue when calculating the payback period." The respondents also believe that it would depend on the size of the company and the type of projects they usually do whether having the semi-automated mason would be a great investment or not. Participant 4 added that "for big construction companies who normally work on big development structures it would be a good investment, but for small companies who specialise on small residential projects it could be a loss".

*Choosing between SAM and manual labour*
Sixty percent of the participants stated that given an opportunity they would choose to use SAM over manual labour as they believed they would be able to increase productivity, reduce salaries and construction work would be executed faster with more accuracy and better quality. Participant 14 stated that "I would choose the semi-automated mason because it is fast paced, meaning more of the project can be covered in a short time", and Participant 9 added that "I would take the semi-automated mason any day, because that would mean I would work with less manual labour which results in paying less salaries, and the work is executed faster with more accuracy and better quality". The participants believed that most issues that come with having manual

labour like strikes, human error, incompetency would be avoided if they adopted SAM therefore, increasing their revenue which is what any company wants.

But forty percent of the participants stated that they would prefer using manual labour because they understand the state the country is currently in. To empower people, they would continue using manual labour, and because manual labour has been used for a long time, they are guaranteed it works, unlike SAM. Participant 17 stated that "I would choose the manual labour, I think we need to do everything to keep our people employed."

*Assisting construction companies in adopting SAM*

The participants believed that to help construction companies adopt the use of SAM, the government would have to take some proactive steps. They believe that the government's involvement would be the leading factor in ensuring the success of implementing automation and robotics in the South African construction industry. "Educating the general public of the benefits of adopting SAM, making training to use SAM affordable, offering incentives to companies that adopt SAM like a percentage cut in taxes and making SAM available in the country" are actions that the government could take to assist in the adoption of construction robots. Participant 10 added that "a trial phase may be needed where it (SAM) would be used in specific sites. Reports may be taken during of its operation by different members involved for circulation".

The participants further provided that the unions together with the current regulations in the construction industry would not facilitate the adoption of SAM, stating that "most companies are quite happy to adopt SAM however the unions are against them (less labour less fees)". They believe that changing the structures of regulations and unions to not force companies to utilise labour would make the adoption of SAM much easier.

Participant 2, however stated that "I don't think there currently is anything that the government or anyone can do to encourage the use of machines over manual labour. We have regulations that demand employing local labour on government projects, so if the government were to give incentives for adopting bricklaying robots that would defeat the purpose of trying to create employment".

## CONCLUSIONS

The construction industry has been slow in adopting new technological innovations. The introduction of bricklaying robots will reshape how the construction companies approaches designing, planning and execution of construction projects. The adoption of the semi-automated mason will have a huge impact on the South African economy as a whole as the introduction of bricklaying robots on construction sites will affect the profitability of construction companies and the number of projects completed within a given period of time.

Human error, inconsistency and incompetency of manual labourers is believed to be the main cause of quality, safety and productivity challenges faced within the construction industry. Therefore, the adoption and use of alternative construction building methods, such as the semi-automated mason (SAM) would address these problems and improve the overall production process of construction companies and the construction industry as a whole. The advantages in the use of construction automation and robotic technologies include higher productivity, process improvement, product improvement and higher quality.

The research found that the participant's believed that that the benefits of adopting SAM outweigh the disadvantages and therefore, given an opportunity they would adopt the bricklaying robot because the adoption of SAM would be a step in the right direction towards the automation of the construction industry.

However, the participants believed that even though the semi-automated mason would be a good investment, and h benefit construction companies who adopt them, the South African construction industry is not ready to implement innovations of this kind yet. The cost of acquiring the semi-automated mason, lacking the necessary skills to operate the robot, and the uncertainty of the running costs which include regular maintenance costs and the salary for the operator, are among the barriers to construction companies to consider adopting SAM. But the main barrier to the adoption of SAM in the South African construction industry is the issue of the high unemployment rate because the adoption of SAM would cause a lot of bricklayers to lose their jobs causing dissatisfaction in communities and eventually leading to riots that interrupt ongoing projects.

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# ATTITUDES TOWARDS USING WOOD IN THE DANISH BUILDING SECTOR

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The Danish political strategy aims to reduce 70 % CO2 emissions by 2030. One way to achieve this goal is by choosing alternative building materials, particularly by using more wood in buildings. Research shows that wood is still not used broadly in the Danish building sector, compared to neighbouring countries, due to design traditions, legislation barriers, and lack of experiences and solutions. Thus, this study investigates the Danish construction sector's current status and attitudes towards using wood in buildings, identifying the perceived barriers and benefits. A nationwide survey was collected from 155 respondents, including engineers, architects, municipalities, and professional building owners. The results indicate that actors have a positive mindset towards using wood and recognize its benefits, revealing that 15 % of actors use wood frequently in their projects, and 52 % are interested in this transition. However, numerous technical aspects must be solved, e.g., risk of fire and moisture. Building owners are the most prominent influencers to promote using wood and are responsible for progressing broader sustainability goals. Furthermore, a knowledge gap among designers was detected.

Keywords: wood; buildings; sustainability; attitudes

## INTRODUCTION

Denmark aims to reduce 70 % CO2 emissions from buildings by 2030. One way to achieve this goal is by choosing sustainable resources and energy-efficient building materials by promote using more wood in buildings. Accordingly, the Danish building regulations are currently regulated by including a new sustainability building class to promote sustainability in buildings, ready in summer 2022 (The Danish Housing and Planning Agency, 2020). A recent national strategy for sustainable construction calls for using more wood in construction (Danish Ministry of housing, 2021). Wood is an environmentally friendly material and a renewable resource that provides neither waste nor pollution (Danmarks træportal, 2021). In new construction, wood is a substitution of materials produced under greater CO2 emissions (Rasmussen *et al.,* 2020), contributing to an improved indoor climate quality (Institute, 2021). It is a necessary structural material in modern construction, offering the potential for cost-efficient and high-quality, sustainable construction

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(Harris and van de Kuilen, 2016). In Europe, a growing interest in wooden construction as a sustainable building solution calls for strengthening the positive image of wood. There are plenty of forests in the Nordic region, and wood has always been the dominant material for low-rise construction (Martin Einfeldt, 2020). In Denmark, 8 % of the buildings are constructed from wood. Assuming that it is possible to convert 10% of the buildings each year to construction with a high proportion of wood, buildings will contribute to the sustainability transition by saving 1.2 million tons of CO2 from 2020 to 2030. It corresponds to an increase in the net climate impact of 22 thousand tons of CO2 per year, corresponding to building 631 more wooden buildings with a high proportion of wood instead of conventional construction (Rasmussen *et al.,* 2020). There is a boom in multi-story wood construction (MWC) in Europe, but not yet in Denmark as we are behind other countries. The Danish construction sector has had a tradition of bypassing wood, giving uncertainty and misunderstandings about methods, fire protection, legislation, and economic aspects of wood construction. Also, in countries with as little forest area and wood tradition as Denmark, such as UK and Netherlands, huge wooden houses have been built (Martin Einfeldt, 2020). Thus, this study investigates actors' attitudes towards using wood in Danish construction, exploring the current national status and pointing out factors that impact actors' decisions, aiming to increase the proportion of wood in construction by highlighting wood benefits and tackling challenges.

## LITERATURE REVIEW

Wood is an attractive material with a low carbon footprint; each cubic meter of wood binds one ton of CO2. It uses less energy and water and is 100% renewable from sustainably managed forests. In construction, wood is highly flexible, light, and robust. It is well-suited for prefabrication and can significantly reduce construction time. When well-engineered, wood constructions are perfectly fire-safe (Danish Technological Institute, 2021). Life Cycle Assessment (LCA) research in Norway and Sweden compares the environmental impacts of substitution between wood and alternative materials, confirms that wood is a better alternative material regarding CO2 emissions (Petersen and Solberg, 2005). Climate impact data from LCAs were presented for 60 Danish buildings with various construction and building materials, shows that buildings with wooden loadbearing structures have the lowest climate impact (Zimmermann et al.,2020). The ecological and environmental benefits of wood constructions are indisputable, providing healthy housing (Švajlenka and Kozlovská, 2020). A Danish case study of 40 hybrid timber construction apartments provides a vision of what sustainable social housing can look like, has 70% lower CO2 emissions and 28% lower life cycle costs than buildings with traditional materials (Craig, 2021).

Wood must be a natural choice of building material for multi-story construction (Danish Technological Institute, 2021). Finland, Sweden, and Norway work proactively with wood in more extensive structures and focus on developing solutions but still lack knowledge in MWC (Rasmussen *et al.,* 2020). There are sufficient wood resources to increase the use of wood substantially, but several factors hinder this. An analysis of wood substitution is a complex issue since the substitution influencing factors are found along the entire wood supply chain and involve several industries, socio-economic and cultural aspects, traditions, price dynamics, structural and technical change (Gustavsson *et al.,* 2006). Enhancing wood in construction requires strengthening its orchestration of partner networks and capabilities (Toppinen *et al.,*

2018). The wood's aesthetic appearance in buildings is appreciated most by frugal and responsible consumers, whereas comfort, environmental friendliness, and longevity are important to consumers (Kylkilahti *et al.,* 2020). A study shows that most building owners believe that wood buildings, compared to concrete and steel buildings, are more aesthetically pleasing, create a positive living environment, and use materials that regrow (Larasatie *et al.,* 2018). A survey among 373 architects in Southeast European countries reveals a positive perception of using engineered wood products (EWP) in all countries. Most respondents believe that EWPs will increase in the future. Results indicate knowledge gaps between respondents and, conversely, where awareness and willingness to use EWPs exist (Kitek Kuzman *et al.,* 2018). Architects in Sweden can be good advocates for the increased use of EWP. The low environmental impact is the most common reason to select EWPs. The influence on material selection, knowledge, experiences, and architect's attitude in using EWPs affect the prospect of increased use (Markström *et al.,* 2018). Prospects for timber frame multi-story buildings in England, France, Germany, Ireland, the Netherlands, and Sweden shows that the main driving forces are environmental concerns. The potential for MWC hinges on architects, developers, and contractors' attitudes (Jónsson, 2009). The share of MWC is still limited in Denmark, lacking experience in this field (Martin Einfeldt, 2020). The most considerable potential of increased use of wood in Danish buildings is climate, environment, and economy. Building with wood is efficient regarding construction and assembly speed (Rasmussen *et al.,* 2020).

The European building sector has an achievable potential for net carbon storage of about 46 million tons CO2-eq./year in 2030. To unlock this potential, a bundle of instruments is necessary for increasing the market share for EWPs against the backdrop of existing policy instruments such as the gradual introduction of stricter rules for carbon emissions trading or more incentives for the voluntary use of innovative wood construction materials (Hildebrandt, Hagemann and Thrän, 2017). Timber engineering is vitally crucial to the sustainable development of society. However, it lacks research funding, both historically and today (Harris and van de Kuilen, 2016). In recent years, wood has rapidly developed into high-tech construction material, and the market for EWPs is rapidly grooving every year in European countries (Klarić and Obučina, 2020). The spread of wood-based constructions in the Central European region is hindered by insufficient knowledge of potential and actual users (Švajlenka and Kozlovská, 2020). In Finland, the MWC diffusion is heavily dependent on the regulatory framework and the construction industry structure. The risk-averse nature of the construction value chain resisting the uptake of new practices appears to be a more significant hindrance for the future market potential of MWC. It requires increasing competition within the MWC sector and co-operation between wood product suppliers and the construction sector to attract investments, reduce costs, and make MWC practices more credible throughout the construction value chain (Hurmekoski, Jonsson and Nord, 2015). In Norway, challenges involve a lack of developers' and constructors' knowledge and experience in MWC. Lack of local producers of wood-based construction materials and infrastructure challenges in material delivery (Danish Technological Institute, 2021). Building with wood has a slightly lower cost for acquisition, operating, and maintenance. However, the market situation and investment horizon are crucial factors (Rasmussen *et al.,* 2020). Having practical experiences with wood buildings helps professionals realize the benefits of wooden construction and deconstruction phases (Li and Xie, 2013).

Humidity affects the durability of wood, and the long-term exposure to moisture accelerates the decrease in mechanical properties and long-term strength of wood with a certain degree of deterioration in the process of exposure (Wang, Cao and Liu, 2020). The potential of a biological attack, ultraviolet light degradation, and dimensional stability in EWPs to produce a durable material requires developing technologies that resist biological and physical damage. Some technologies already exist but remain too costly (Morrell, 2017). Fire safety can be as high in timber-frame buildings as in other types of buildings when suitable construction methods are used (Karlsson, Gudnadottir and Tomasson, 2020). A Canadian study highlights wood density's influence on the percentage of wood failure and shear strength (Morin-Bernard *et al.,* 2020). In Denmark, solutions for wood load-bearing structures must be developed to support buildings up to five stories and requests examples of how wooden buildings with more than five stories can be built, focusing on acoustics and fire challenges (Danish Ministry of housing, 2021). Challenges remain in fire and height limits for wooden buildings. Individual technical assessments are needed in planning due to a lack of pre-accepted solutions, which should be addressed. On-site acoustic testing during the construction phase is required instead of acoustics simulations to meet regulations in the design phase. These factors have hindered wood construction development, as they create greater risk and costs for developers. A limited policy has been introduced to develop wood construction competencies. Teaching competencies within Danish institutions could be more vital to meet this demand and equip the next generation with wood skills and knowledge. The industry must take greater responsibilities to achieve competencies in wood construction (Craig, 2021). According to Rasmussen *et al.,* (2020), Denmark's most significant barriers are the lack of knowledge and experience in using wood as a building material and constructing wooden buildings. Challenges in fire safety, the acoustics of floor slab partitions, and moisture impregnation. In construction sites, it is challenging to protect wood materials from moisture. In the operation phase, moisture management, durability, and maintenance costs are challenging factors. Also, building regulations fire requirements hinder advisors from recommending the use of wood (2020).

## METHODOLOGY

A mixed research approach was applied, including a quantitative and qualitative online survey questionnaire according to Dillman (2007), distributed to 640 organizations within the construction industry with more than ten employees specifically targeting engineers, architects, municipalities, and professional building owners, collected from 155 responses. The survey aimed to investigate the construction sector's current status and attitudes towards using wood in buildings, identifying the perceived barriers and benefits. The survey was conducted by using Microsoft forms, consisting of closed-ended questions with multiple-choice options, yes/no questions, and rating questions according to the Likert scale (Likert, 1932), along with open-ended qualitative questions to extend in-depth some of the respondents' answers, elaborating the perceived benefits, experiences, and challenges of wood construction. Colleagues tested the survey to evaluate the clarity of questions. Organizations were obtained from the Danish Central Business Register (CVR virk, 2021). The survey was available during December 2020, and a reminder mail was sent two weeks after the initial mails, where the research objectives and values were highlighted to motivate actors to respond. The results indicate the general state of organizations' attitudes towards using wood in buildings with a response rate of 24%. Based on similar studies, a response rate of 15-35% is considered adequate

for analytical purposes for surveys, considering an expected response rate in this range and a sampling error of 10% (Dillman, 2007). The questionnaire firstly includes introduction questions describing the respondent's role, organization location, and general status of implementing sustainability in building projects. Then, substantive questionnaire items follow, including the perceived benefits, experiences, attitudes, and challenges when using wood in construction.

## ANALYSIS AND DISCUSSION

Responses covered the whole country with a satisfactory response rate from all targeted actors, as 23 % of responses were professional building owners, 26% architects, 28% engineers, and 23% municipalities. Respondents were asked about their status for implementing sustainability in building projects and readiness to apply building regulations new sustainability class, where 52% observe sustainable development but are not ready yet, 34% already include sustainability significantly in their projects, and 14% have no or minimal knowledge in sustainability. Results show that the actors who have a big focus on sustainability are architects, meaning that they play a significant role in promoting sustainability in buildings. However, results show that they do not always use wood in their projects despite focusing on sustainability.

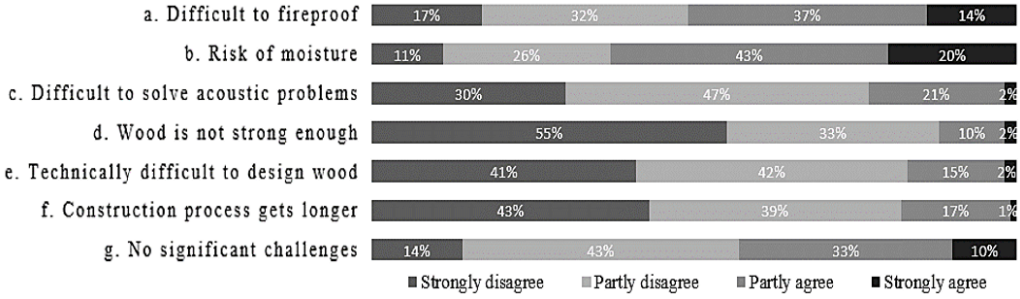
Fig 1 (a-g) illustrates challenges in wood load-bearing structures (WLBSs) Challenges in fireproofing are shown in Fig 1-a, revealing that 37% of respondents partly agree on the presence of fireproofing challenges in WLBSs, and 32% partly disagree, 14% of actors strongly agree, while 17% strongly disagree. Reflecting that despite the fire challenges, there is a possibility to solve them, but only a limited group of actors are experienced in this area. It is found that consultant engineers partly disagree on fire barriers and are more positive towards using WLBS, indicating that engineers are more experienced in finding proper fire safety solutions.

This reflects the knowledge gap among designers in fire protection strategies. According to the Danish Technological Institute (2021), wood construction is perfectly fire-safe when well-engineered. Thus, fire challenges in WLBSs can be solved by using proper solutions. Ensuring fire safety is a design prerequisite in wood construction with the necessity of integrated engineering (installations and structure) and architectural expertise. Fig 1-b refers to moisture challenges; 43% of respondents partly agree, and 20% strongly agree, indicating moisture problems in WLBS and lack of technologies and solutions to prevent moisture. Fig 1-c shows difficulties in solving acoustic challenges where 47% of responses partly disagree, and 30% strongly disagree, meaning that the building sector is positively developing in finding soundproofing solutions for WLBS and have already found suitable solutions.

Fig 1-d refers to the robustness of WLBSs, showing that 55% strongly agree that wood is a robust material and 33% partly agree, meaning that wood is perceived as a solid and robust material used in buildings' load-bearing structures. Fig 1-e shows that most actors (83%) confirm that it is technically easy to design WLBSs. Most responses (82%) in Fig 1-f show that using wood will not prolong the building process. Finally, in Fig 1-g, 44% of actors confirm challenges in WLBSs. Thus, moisture and fire are the most challenging aspects. Factors that can hinder this are the building regulations' strict fire requirements. Similarly, Rasmussen *et al.,* confirm that the most significant perceived challenges are lack of knowledge, fire safety, and building regulations fire requirements that hinder using wood, moisture impregnation, and acoustics for partition slabs (2020). However, acoustic challenges were not

highly rated by respondents in this survey. It also appears that there is a knowledge gap among designers in finding technical solutions.

*Fig 1 (a-g): Respondents challenges when using wood as a load-bearing structure*




Besides, other challenges were optionally defined by 43 respondents. New wood suppliers must be aware of the challenges that wood construction poses to be more effective. The stiffness of wood is less than steel and concrete, creating challenges in deformations and wood import challenges. Maintenance is a problematic and risky aspect compared to traditional buildings. Building owners must accept that wood construction requires more maintenance as the influence of moisture and temperature in both construction and operation phases is challenging. It is revealed that the long-lasting properties of wood as load-bearing elements are unknown. Designers and constructors lack experience in WLBS. There is also a need to clarify the concepts early in the design and tender phases. Also, the need for regulatory adjustment, especially according to fire regulations. Generally, authorities and advisors are not familiar with wood, which provides resistance. Other challenges expressed by respondents are economy, conservative building traditions, municipality approval, lifetime concerns, and finding the correct wood type and construction system.

Results reveal that 58% of responses confirm the presence of challenges when using exterior wood cladding, mostly fire challenges, followed by maintenance cost and sensitivity to climate conditions. Other challenges collected from respondents' comments reveal that architectural and technical solutions are essential for service life and maintenance. Also, drying must be ensured, and moisture must be minimized, besides limited possibilities for facade expressions that suit big cities' architecture. Thus, architecture and building traditions are significant factors. Fire conditions and exterior wood cladding treatments are considered problematic factors. Fire impregnation and lack of fire documentation are challenges, and few actors can deliver the required fire classes. Documentation for fire impregnation can extend the entire life of buildings according to building regulations. Untreated wood changes appearance and becomes less consistent over time. One has to expect that the building envelope is a sacrificial garment and can get expensive in the long run. Besides, unequal patination depends on overhangs and façades orientation. The operation, maintenance, and service life of wood cladding are primary issues. It also requires craftsmen experience, which is partly sunk into oblivion. In the design phase, the replacement of some building elements parts when using wood must be considered. Moreover, there are several exterior wood cladding types, so actors must choose the right approved type. Today, we lack usable labelling schemes that can be used in tenders, obstructing promoting wood construction.

Fire safety and sensitivity to moisture remain the most significant challenges, as confirmed by 50 % of respondents. Comments from respondents reveal that building regulations hinder the use of wood for interior cladding in high-rise buildings as wood

surfaces must comply with fire requirements. The appearance of wood surfaces may change if treated incorrectly. When using raw cross-laminated timber, it shrinks by drying, leaving cracks that will be seen if not coated or surface treated, then repairs will be visible. Also, the patina varies depending on how much light it receives.

Results reveal that 89% of respondents confirm the environmental benefits, 92% agreed that wood improves the indoor climate and is also aesthetic, while 66% of respondents acknowledged economic benefits, indicating that the economy is still a challenging issue. According to construction effectiveness benefits, 68% of respondents agreed that using wood benefits the construction process using less construction time and 85% agreed that it is easy to construct with wood. Generally, 83% confirmed significant benefits linked to wood construction, indicating actors' positive attitudes towards using wood in buildings and a tendency to use more wood.

Results show that 63% of respondents have worked with wood construction instead of traditional construction, and 21% have not, while it was not relevant for 16% of them. Also, 40% of respondents claim that the biggest reason for choosing wood is building owners' wishes, while 31% of respondents choose wood according to advisors' recommendation, and 29% choose wood due to their significant focus on sustainable development. This indicates that building owners have the greatest impact on material choices in the design phase. Advisors, including architects and engineers, have a significant role in influencing builders' decisions, promoting the use of wood. Respondents were asked how frequently they have used wood in their projects in the last five years; 61% answered "sometimes" and 15% "mostly," while 24% answered "rarely," indicating that the building sector is tending to change its construction traditions towards more wood in construction with developing experiences. According to Craig, the industry must take greater responsibility to achieve competencies in wood construction (2021). Results show that wood is used in various types of projects, including new construction and renovation. It appears that wood is used mainly in single-family houses and residential buildings up to three stories but less in commercial buildings. Respondents' ongoing wood project typologies varied, involving daycare institutions, multi-story residential buildings, senior housing, culture houses, and renovation of schools, indicating the broad and flexible use of wood despite the various type of buildings. Consequently, high-rise wood construction is not expanded yet in Denmark, indicating fewer experiences and difficulties to comply with building regulations fire requirements.

Respondents who use wood in their projects were asked where they most often use wood in their projects. For the WLBSs, results reveal that 25% use wood primarily for the load-bearing structure, 67% use it sometimes, and 8% have never used it. Regarding using wood as exterior cladding, results show that 39% of actors use wood often as exterior cladding, 52% use it sometimes, and 9% have never used it as exterior cladding. Regarding using wood as interior cladding, 24% of respondents use it frequently, 53% use it sometimes, and 23% have never used it as interior cladding. Generally, actors use wood mostly for the load-bearing system and exterior cladding, while less used as interior cladding followed by decoration purposes. Results reveal that architects use wood mostly for interior and exterior claddings and less for the bearing structure due to economy, clients' wishes, lack of experiences, and technical challenges. In contrast, engineers use WLBSs more than claddings. Here client wishes are the influencing factor. Thus, wood is a solid building material that can replace concrete in bearing structures. It also indicates that actors choose wood as exterior cladding due to its aesthetic appearance. According to the Danish

Technological Institute (2021), this must be combined with a wood surface treatment to protect against moisture and temperature variation. Building owner's wishes and decisions are the main barrier in choosing WLBSs, followed by lack of experience and knowledge in wood construction, then by economic considerations and technical challenges. Respondents were asked about who is responsible for promoting wood in construction. According to their responses, the biggest responsibility is directly linked to building owners and their architect advisors, followed by engineering consultants. It is revealed that architects have an essential role in proposing wood and providing efficient solutions, supported by engineers to solve the technical and construction challenges. Research by Markström *et al.,* (2018) addresses the influence on material selection, knowledge, experiences, and the architect's attitude in using EWPs. Thus, results confirm architects' essential advisory and facilitating role. Regarding learning and gaining knowledge in wood, 82% of respondents are interested in learning more about wooden construction, indicating their positive attitudes and tendency towards using it more.

## CONCLUSIONS

The green transition, reducing the climate impact of buildings, calls for strengthening the positive image of wood construction. Wood must be a natural choice of building materials. An authoritative contribution to this growing movement arises from the Danish governmental strategy on climate change, which identifies a substantial increase of wood in buildings as a top priority. However, an encouragement of such a strategy raises some challenges giving the urgency of practical solutions for continued wood growth in construction. This paper emphasized actors' perceived benefits, experiences, and challenges of using WLBSs and claddings. Challenging issues remain on moisture risk and fire safety for high-rise buildings, calling for regulatory adjustment. Most respondents confirmed the environmental and social benefits gained from wood construction. The study reveals that building owners have the biggest impact on choosing wood in construction, and advisors, especially architects, have a major facilitating role in promoting wood. However, engineers are more experienced in solving technical solutions, revealing an experience gap between designers, and hindering wood progression. Here, it is revealed that the building industry has a great need for further education in wood construction. Thus, educational institutes need to address this need and educate future architects, engineers, and relevant professions to focus on wood construction solutions and methods to promote more wood buildings.

Additionally, the paper findings contribute to international research and practitioners by adding some experiences to learn from when using wood in construction, assisting in promoting this sustainable building material, which has a real potential for further adoption in construction globally. In addition, the paper contributes to construction management theory in terms of the industry's general poor adoption of innovation, new and uncommon practices, which is also realized as a challenging matter when calling for increased use of wood in buildings. Here a common thread can be drawn with adoption behaviour in other cases, such as digital technologies. Finally, the authors suggest further research to investigate the potential of industrialization and prefabrication of wooden construction to promote the use of wood in buildings and eliminate the various challenges. The survey's limitations include uncertainty in respondents' answers, especially organizations without significant experience in wood construction. Also, the survey did not include organizations with less than ten employers.

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# THE DESIGN AND CONSTRUCTION OF PUBLIC SERVICE BUILDING IN DEVELOPING RURAL REGIONS DURING THE POST COVID-19 PERIOD: CASED ON A CHINESE VILLAGE CENTRE

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The spread of COVID-19 has caused an increasing demand for public medical room. Cases of Chinese Huoshenshan Hospital and mobile cabin hospitals proved the effectiveness of constructing emergent medical buildings. However, these cases, usually with strict requirements on technology and infrastructure, are hard to implement in developing rural regions. Therefore, there is an urgent need for adapting industrial construction to the rural situation. This research introduced an adaptive approach for rural projects delivery during COVID-19. It is based on a longitudinal case study, recording and analysing the construction process of a village centre in Jiangsu, China, from 2019 to 2020. By comparing the construction process of actual operation and traditional method, the advantages in a shorter building period and lower labour density were verified. This research pointed out neglected risks in developing countries and provided a practical construction approach in these areas. It supported the prevention of COVID-19 global wide.

Keywords: public service building; rural regions; post COVID-19; design

## INTRODUCTION

COVID-19 had spread to 221 countries by 11th March 2021, with 118,006,153 cases (Coronavirus Resource Center of Johnes Hopkins University 2021). Its rapid expansion and extreme high transmission rate have triggered an urgent demand for medical space (Gbadamosi *et al.,* 2020), i.e., wards and treatment rooms. The number of visiting patients exceeded the maximum hospital load by 40% in Wuhan during the first month of 2020 (Cao *et al.,* 2020). The increasing demand for medical never subsided as the infection ratio increased from 29 per 100,000 (3215 in 11.2 million in Wuhan, 2020) to 8,900 per 100,000 (29 million in 328 million in America, 2021). As pointed out by the Epidemiological Report of the World Health Organization (2021), the developing area is facing a growing threat because of the scarce medical resource.

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Zhu, K, Xiang, Y, Bu, J and Zhang, H (2021) The Design and Construction of Public Service Building in Developing Rural Regions During the Post COVID-19 Period: Cased on a Chinese Village Centre *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 37th Annual ARCOM Conference,* 6-7 September 2021, UK, Association of Researchers in Construction Management, 56-65

Outbreaks in several developing countries further indicated that these regions deserve special concern.

Current solutions aim at establishing treatment space within a short period, relying on modern construction equipment and skilled labours. For instance, during the construction of Leishenshan Hospital, which took less than 12 days, there used to be over 1,500 workers and more than 800 construction machines working simultaneously (Luo *et al.,* 2020). Whilst this approach would not be effective in less developed regions because of the weak industrial fundamental (Sun *et al.,* 2019). Although the adequate workforce used to be an alternative in rural regions (Mostafa *et al.,* 2016), the social distance constraint of COVID-19 has prevented delivering projects rapidly with such a labour-intensive construction approach. Therefore, there has been an urgent need of developing adaptive industrial construction methods for these places. It could promote worldwide prevention and global economic resilience. Moreover, the construction approach with limited labour source and equipment adapts to the requirement of current prevention operations (e.g., social distance) well, which may also support medium-sized and small enterprises to survive in such a severe environment.

This paper proposed an adaptive industrial construction method appropriate for less developed rural areas, filling the need for both high efficiency and low labour density. It was tested for the effectiveness within a case study of a village centre located in Jiangsu Province, China. The construction process from December 2019 to January 2021 is recorded and compared with the conventional approach. The outcomes showed that it effectively decreased the labour density and construction quantity and proved it practical in a COVID-19 environment implementation.

## LITERATURE REVIEW

### Construction in Rural Areas

Rural construction varies across areas for diverse cultural and geographical features, economic levels, and resource availability (Hu *et al.,* 2021), e.g., residences with masonry structure in central China (Zhang *et al.,* 2019), huts of marl and branches in Africa (Von Seidlein *et al.,* 2019), and houses with beamed drywall in Turkish (Sağıroğlu 2017). Previous rural construction research focused on three fields, i.e., heritage preservation, sustainability improvement, and disaster reconstruction (Yuan *et al.,* 2021). Heritage preservation studies are characterised by employing local materials and traditional construction methods. For instance, Guan and Li (2002) constructed the foundation with local stones and filled the envelope with straw and bamboo. Picuno *et al.,* (2017) explored the possible restoration of traditional rural constructions in the Adriatic-Ionian Area based on the characteristic analysis. Sustainability improvement study optimises the thermal performance and energy efficiency through specific technologies like renewable energy (Zhu *et al.,* 2011), and sustainable envelope (Hu *et al.,* 2021). Although received the most concerns, studies in these two areas seldom considered construction efficiency and safety. They are, therefore, of limited meanings. Disaster reconstruction is the most relevant direction among these three fields. It aimed at providing projects with limited resources for afflicted areas. Zhu (2011) built two eco-schools in the quake-hit area of Sichuan with a lightweight structured system. Hsieh (2016) employed a similar structure in the 2015 Nepal reconstruction. Ban (2017) explored the implementation of paper structure since 1995 in temporary project delivery. These studies provided abundant experience in rapid rural construction, but they seldom considered the limitation on

the workforce. Local labours were gathering at a close range, according to their records. It is undoubtedly a powder keg during the spread of COVID-19.

**Conventional Construction During COVID-19**

As the largest industry in the global economy, the construction industry experienced a strong impact of COVID-19 (Ribeirinho *et al.,* 2020). The coronavirus-induced recession crushed or significantly delayed construction plans (Ecker 2020), causing a wide-range job loss in the construction industry in **2020(**Currie 2020). Governments have declared rules and regulations to relieve such threats since 2020 (Gostin and Wiley 2020). Specific self-protection solutions concerning construction including 1) wearing masks, 2) staying a distance from others, 3) avoid crowds and poorly ventilated space (American CDC 2021; Chinese CDC 2020). However, implementing these solutions in construction is challenged due to the inherent labour-intensive nature of construction projects (Zheng, Chen and Ma 2021) and the heavy financial pressure (Johnson *et al.,* 2021). Araya (2021) simulated the spread of COVID-19 on construction works by agent-based modelling. He reported a 90% workforce reduction in the worst situation. The number was even more than 30% within the optimised solutions.

**Industry's Adaption to COVID-19**

Although the industry is directly exposed to the risk of COVID-19, it is vital to provide structures and infrastructures to recover from the epidemic. Many researchers considered construction efficiency the most significant criteria to evaluate suitable construction approaches during this specific period. Luo *et al.,* (2020) made a detailed introduction of Leishenshan Hospital. It pointed out that BIM and the Product, Organization, and Process (POP) model contributed to the ultra-rapid delivery. The modular and offsite construction has been highlighted by (Gbadamosi *et al.,* 2020) for its rapid delivery. However, these industrial approaches rely on a reliable supply chain and transport system. Considering the current situation in which the epidemic is raging in underdeveloped areas, adaptive method carted to limited technologies deserves more consideration.

On the other hand, scholars put efforts into the personal monitor to alleviate the risk of aggregated infection. Araya (2021) managed to delay the spread among labours by maximising the low-risk construction activities. However, the approach is limited implemented for difficulty in risk classification. Pavón, Alvarez and Alberti, (2020) used a mathematical model to simulate occupant distribution among the building. By BIM integration, the approach is proved effective in personnel density prediction. Although not construction-oriented, the model is an excellent example of labour management. However, no standard concerning specific solutions (e.g., a numerical criterion on the labour density) was observed. It led to subjective and loose management in practice, which left the industry at risks.

In conclusion, previous research pointed out the current challenges of the construction industry and possible approaches to project delivery. Existing rural studies improved the quality of construction but remain labour-intensive. COVID-19 presses on both labour safety and resource supply. A trade-off between the labour density and resource dependency demands to be achieved in developing an appropriate approach to rural project delivery. Therefore, the following sections introduced an adaptive approach that realised industrial construction by local labours, equipment, and retrofitted agricultural machinery.

# METHOD

This study is based on an actual project in a rural district in Jiangsu province, China. The technology integration developed by a case-study organisation (CSO) was studied, including a series of management events and development work within the project. A two-storey building was considered a technology integration due to its application of specific production techniques and organisational effects in the construction process. A longitudinal case study using data collection was employed and revealed technologies synthesised to alleviate the negatives caused by COVID-19. The researched project stretched from the detail design phase that led to the construction and included onsite building until the end of the project, a period of 5 months. The effect and advantage of integrated technology were studied through the comparative analysis of data collected during the project and the simulated data.

As for construction analysis, construction efficiency, precaution performance, and technology dependency are selected as the main criteria. The construction duration and labour amount are considered two related indicators of construction efficiency. Because a construction time reduction usually has the same effect of labour amount reduction, they were considered synonymous in the specific operation evaluation within the Case Study section. A detailed elaboration on the other performance analysis was given in the Data Analysis section.

## Case Study

The proposed construction approach was implemented in a village centre, as shown in Fig 1. It is a two-storey residential service centre with an area of 574.44 m2 (319.29 m2 for 1F and 255.15 for 2F). Its construction was monitored and observed for four months. A summary of the site record is shown in Fig 4.

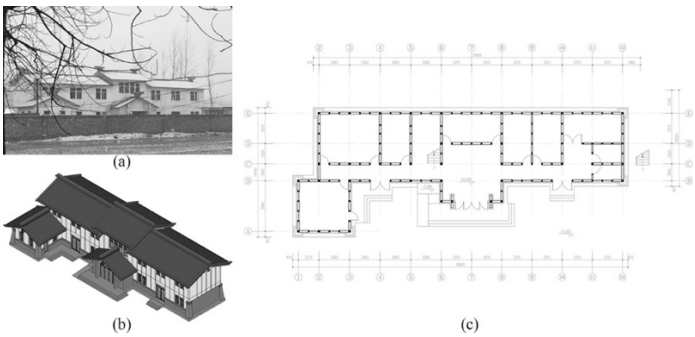


*Fig 1. Photograph (a), 3D models (b), and the plan (c) of the study case*

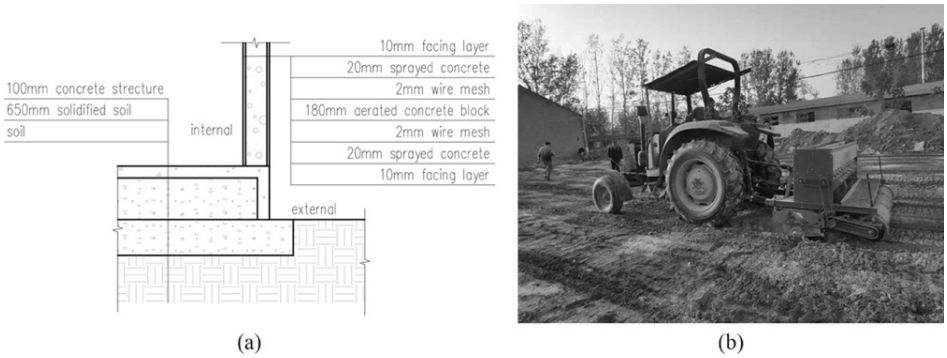


*Fig 2. Construction detail (a) and the construction process (b) of the foundation*

Adaptive construction methods were used in the foundation and structure. This project integrated the approach of roadbed construction, as shown in Fig 2. Firstly,

labourers excavated the earth to the height of -0.75m with a small-type excavator (8t). The excavated soil was then mixed with quick lime and curing agent for 4 to 8 hours to remove moisture and increase the strength. After that, preliminary treated soil was stirred with cement and compacted to form the foundation to the height of -0.10m. A 100-mm cast-in-situ reinforced concrete was constructed on it as the floor to the height of 0.00m. As no masonry or reinforcement foundation is needed, it saved time for masonry (masonry foundation) or formwork, reinforcement construction, and concrete curing (reinforcement foundation). Additionally, Fig 2-b gives information on how local labourers adapted the local scarifier to construction equipment for soil stirring, reducing the dependence on professional equipment.

The structure is similar to a masonry one in which the load-bearing walls work as enclosure components. Fig 3 gives a detailed description of the construction process.

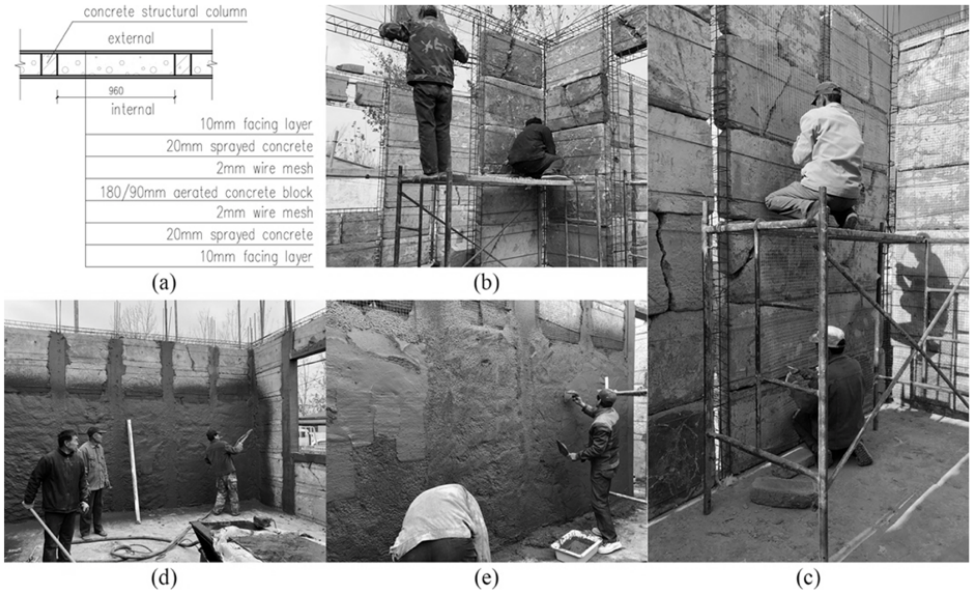


*Fig 3: Construction detail (a), and the construction process (c-e) of the wall*

The building block is the size of 960mm×180mm×600mm (length × thickness × height). The mix of aerated concrete and straw proves a weight at approximately 25Kg per block. Therefore, labourers could assemble the blocks at a higher speed than before (with blocks of the size of 240mm×115mm×63mm) without lifting equipment. The structural column (130mm×220mm×3600mm in the middle or 220mm × 220mm × 3600mm at the corner) distributes every 960mm, consistent with the size of blocks. Before the construction, the structural columns' reinforcement cages were prefabricated in the size of 130mm×180mm×3500mm. They were directly weld to the foundation's embed parts at first, during which the time for reinforcement cutting and binding was reduced. Labourers then formed the wall with blocks and fixed them with steel bars (Fig 3-b). The 2mm bidirectional mental mesh is attached to both sides of the wall after that (Fig 3-c). The concrete was poured following the sequence of the structural column, wall, and floor. Apart from the floor, paved by a pump truck, concrete was pumped and sprayed by a mobile concrete pump, as shown in Fig 3-d. It was more efficient than manual construction. Labourers only need to smooth surfaces manually at the end (Fig 3-e).

**Comparative Construction Simulation**

To testify the performance of the proposed approach, a comparative construction simulation of the same building that is masonry structured was chosen as the candidature. The majority of differences between these two structure designs was the design of foundation and wall system, and it could be distinguished from the construction approach. The construction process of a comparative candidate was built based on the empirical data provided by the original project team and organised corresponding to the local construction criteria. Discreet-Event Simulation (DES) was adopted in this section for its ability to capture interaction and interdependence among complex construction processes (Feng *et al.,* 2019). A detailed summary of the construction process is given in Fig 4.

**Data Analysis**

Many governments have adopted social distance control in COVID-19 prevention, but the indicator is hard to calculate in construction analysis. As an alternative, labour density, i.e., the number of people per unit area, was employed in data analysis. It is calculated in the following equations:

$$D_{i,j} = N_{i,j}/S_{i,j} \quad (1)$$

$$D_{max,i} = \max_{j} D_{i,j} \quad (2)$$

Where $D_{i,j}$, $N_{i,j}$, and $S_{i,j}$ is the labour density (person/m2), number of the labour, and the area of the working place (m2) in the working area j at time i, respectively. $D_{max,i}$ is the maximum labour density onsite (person/m2) at the time i. In this section, the standard working labour density will be 0.60 and 0.32 (person/m2). The former refers to the Chinese government's requirements of crowded places management, and the latter is considering a 2m social distance (3.14 m2 per person).

It is possible to say that reducing the labour number of distributed tasks would alleviate the prevention pressure by adjusting the social distance. However, a low labour density avoids infection but affects work efficiency. Therefore, besides the precaution performance, the production efficiency is also included in the assessment. By setting a limit on the simultaneous working labour, the time consumption would be an evaluation indicator, as shown in Fig 4.

## RESULTS AND DISCUSSION

The actual construction lasted 49 days, in which the foundation was built in the first four days. With a 14-day nature curing, the first floor's construction was conducted from the 18th day to the 33rd day. That of the second floor took another 13 days after a 3-day nature curing started by the 34th day. Constructors employed a synchronous construction approach. They divided the project into six areas (i.e., axis 1-5, 5-8, and 8-12 on each floor) and followed a standard procedure (i.e., methods mentioned in the case study) in each area.

The construction schedule (Fig 4) directly compares the construction with proposed approach and two limited conventional approaches. Their process was divided into five categories, i.e., foundation, reinforcement, masonry, formwork and pouring, and cladding, each taking a row in the graph with a unique colour and corresponding labour amount. The Fig shows that the conventional approach had to employ 5-10

more labours in masonry assembly and about four more labours in cladding if required to finish the project within the same period. But less workforce needed for formwork assembly and pouring because the conventional structure consists less constructional columns. Theoretically, it needed to employ 100 and 33 labourers for foundation construction and cladding, respectively, to fill the need. However, these numbers were meaningless in practice indicating no possibility of matching the proposed schedule by conventional construction.

On the other hand, with a same-level workforce amount, the five projects took 143, 12, 41, 36 and 33 days, respectively. The whole process would last for approximately 178 days which was 129 days more than actual. A significant workforce reduction in formwork assembly and pouring was partly for the same reason mentioned before. Another reason was that less work was conducted simultaneously because of a lower masonry assembly speed. In summary, the construction quantity reduction in foundation construction (25-35%), masonry assembly (85%), and cladding (30-40%) indicated significant advantages of industrial construction in rural area. However, more workforce was consumed in the reinforcement construction.

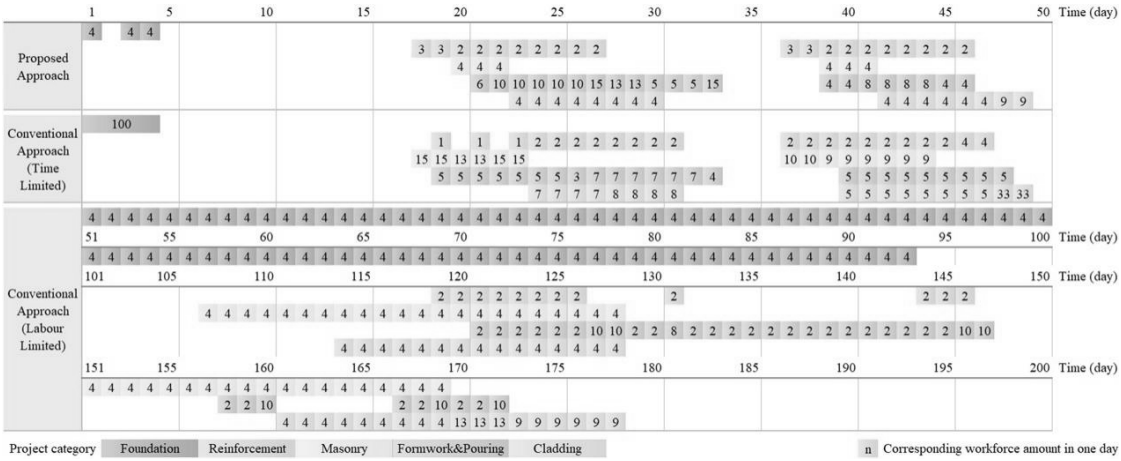


*Fig 4: Gantt chart of the construction schedule*

Fig 5 gives information on the labour density variation of the proposed approach and the time-limited conventional approach. The period of the foundation was excluded as an impractical scenario. Fig 5 (a) is the line graph of $D_{max,i}$ distribution with time. In general, the labour density was lower when employing the proposed approach. The most significant difference was observed in the first six days, during which 11 more labours were employed in masonry assembly by the conventional approach. The maximum value of the proposed approach was 1.57 on the 12th day when eight workers assembled the formwork and poured the concrete at the southeast corner. That of the conventional approach (2.55) appeared on the 6th day when 20 workers worked at the same place for masonry and formwork assembly. With a threshold of 0.60 (Fig 5 (b)), it was observed that both values distributed at a safety level (below 0) for most of the time. However, the line of the conventional approach was closer to 0 than that of the proposed approach, which indicated a smaller range of labour management in conventional construction. In other words, fewer labours could be added for a shorter construction period if the density is required to below 0.60. Its weakness was magnified when setting the threshold to 0.32 (Fig 5 (c)). The labour density of the conventional approach was higher than the requirement for about half of the time, while that of the proposed approach remained below. It meant that a 2m

social distance is harder to keep by conventional construction than the proposed method.

Peaks of the density appeared periodically in Fig 5 because of the synchronous construction by which different operations could be conducted in various parts simultaneously.

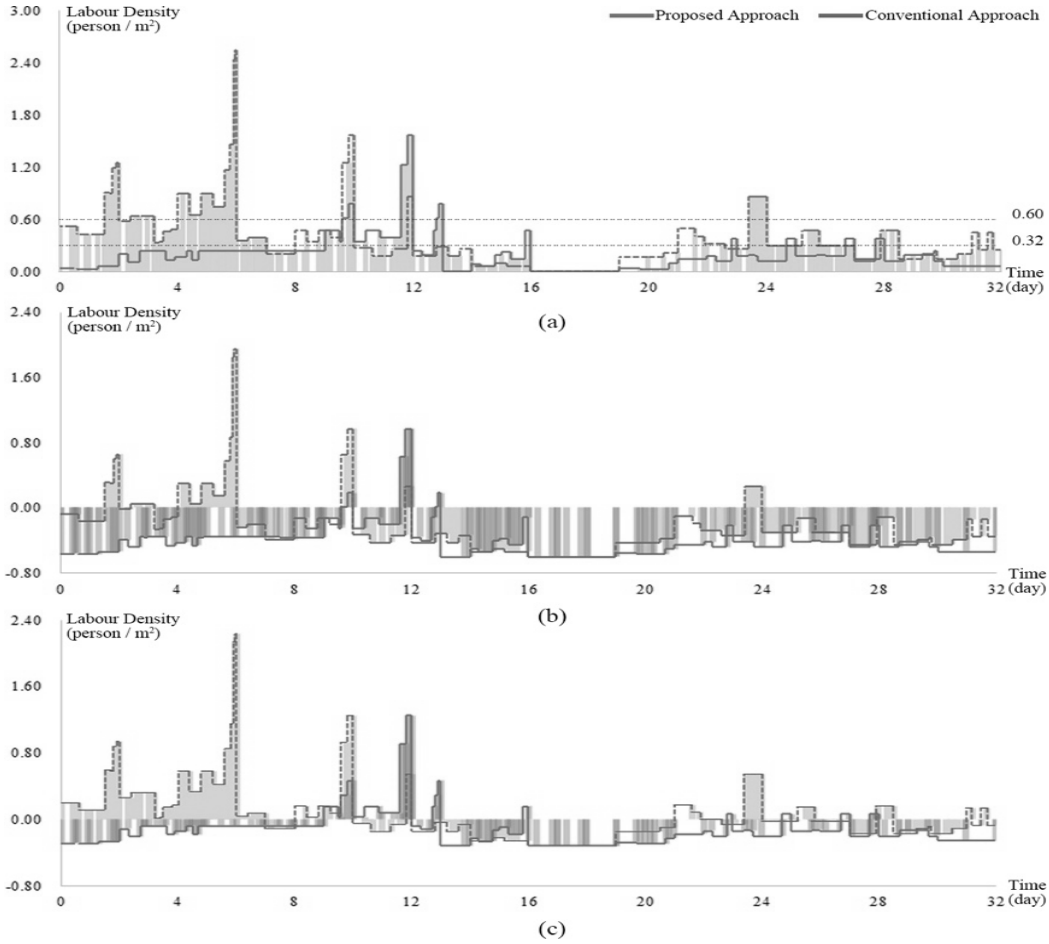


*Fig 5: Variation of the $D_{max,i}$ (a), the difference between $D_{max,i}$ and 0.60 (b), and the difference between $D_{max,i}$ and 0.32 (c).*

Locating the downstream of the construction process, the east part (i.e., the area of axis 8-12) periodically gathered multiple operations, resulting in a high labour density during the period. Here describe operations during peak periods (i.e., periods in which the labour density was higher than 0.60). As for proposed construction, the formwork assembly and pouring were conducted from the 9th to the 12th day, and four labours were cladding within a limited area simultaneously during another peak period, the 13th day.

Regarding the conventional approach, 15 labours were assembling the masonry from the 2nd day to the 6th day, and 9 of them were conducting the same projects from the 23rd day to the 24th day. The peak periods of the proposed approach can be eliminated by distributing those projects to a longer period, i.e., increasing the labour amount before or after the period. However, it is less possible for conventional construction, as mentioned before. Therefore, the gathering of workers, i.e., the risk of contagion, is more likely to be avoided by adopting the proposed approach.

## CONCLUSION

The outbreak of COVID-19 has generated significant pressure on the public medical system and marked an urgent need to provide the medical area for the rural. This paper introduced an adaptive industrial construction approach and documented its application in a public service centre. The construction schedule and labour density were selected as major indicators in comparative estimation. It was found that the proposed construction approach reduced considerable construction quantity in the foundation and structure projects. With a relatively low-level labour density, contractors were more likely to avoid contagion in the construction site. However, this approach has strict demands on the soil condition. The conventional foundation will be inevitable if the soil quality is poor. Moreover, it is suitable for developing regions with basic industrial basis because of using several industrial products and construction equipment. Despite all this, the experience of the studied case can be used as a reference for developing rural areas that are still facing the threat of COVID-19. Additionally, small-type enterprises can employ the methods mentioned to deliver projects with limited sources and technology. Future studies are expected to provide more comprehensive data analysis and implement the method in more cases.

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# COVID-19 Research

# DESIGNING FOR NEURODIVERSITY: REIMAGINING THE HOME FOR A COVID NORMAL LIFE

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As cities went into lockdown in response to COVID-19, for many, the role of the home in everyday life expanded. Activities that would normally occur at another venue, including work, study, recreation, and health appointments, were reconfigured to be done in the home. Among the legacies from this experience is a clearer understanding of the spatial and phenomenological quality of the spaces in which we live. Housing design already assigns private and public areas within dwellings, such as bedrooms and living rooms, but these are often rigidly defined and largely inflexible for alternative uses. Research on designing housing suitable for people with cognitive disabilities, including autism spectrum disorder (ASD), (such as a 'sensory design' approach, where it is necessary to move beyond public vs private, and recognise other dicotisms, light/ dark, warm/cool, loud/quiet, hard/soft, work/rest, and so on, and the transition between modes), may provide lessons for more general COVID-normal housing design. This study analyses three case studies of residential accommodation for people with ASD as opportunities for developing more responsive housing that can adapt to the demand for a greater range of activities to be fulfilled in the home.

Keywords: housing, COVID-19, sensory design, disability

## INTRODUCTION

Whatever form COVID-normal takes, the COVID-19 experience has, for many, forced a re-evaluation of the home environment, as more is demanded of our homes. In response, there are valuable lessons to be taken from the experience of neurodiverse people's engagement with the built environment. The three design principles advocated for in this paper—sensory zoning, spatial sequencing, and escape spaces—offer a way to view a dwelling as a sensory moderating machine that acts in a way to calm and prepare residents for changes in sensory intensity, and the likelihood of physical and social interactions that require mental and physical effort. Like all good design, a well-organised dwelling should make things easier and require less mental effort to complete day-to-day tasks, now expanded to include work, study, health, and social interactions previously undertaken mostly outside the home. Spatial constraints in apartments, often coupled with limited access to external walls (and light and air), make designing with neurodiverse principles more challenging, but also rewarding and impactful. Transitions, sequences, and escape zones need not be large in spatial terms, but they should be considered.

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As lockdowns were implemented globally to contain the spread of COVID-19, activities that would normally occur at other venues—work, study, recreation, and health appointments—were reconfigured to be done in the home. Established patterns of living were interrupted, including extended periods indoors, cohabitation with other people for extended times, or alternatively, isolation from social networks. The places where we live were designed with specific residential functions in mind—the kitchens, dining/living rooms, bedrooms—and so were challenged by the necessity to accommodate workspaces, study spaces, pets, and exercise spaces. The apartments that we produce are a product of a particular procurement system—a commodity in Australia and the UK, developer-led and driven—with a focus on cost, investment return, and compliance with the minimum regulatory requirements. Quality of space is therefore seen as something marketable rather than a genuine experience of space.

Building codes and energy rating systems mandate minimum performance levels for ventilation, sound, light quality, as well as spatial requirements controlling circulation spaces and entrances and exits, but these are determined by measurable (and absolute) physical characteristics like air movement, dB, lux, and meters squared (Allman 2021). In contrast, best practice guidelines for designing for people with a disability, in particular for people who identify as being neurodiverse such as those diagnosed with Autism Spectrum Disorder (ASD), focus more strongly on individual experience of space (Ahrentzen and Steele 2009).

In the literature on designing for people with ASD, there are two competing schools of thought. Recognising the particular tendency for people with ASD to experience sensory overload, and spatial disorientation, on the one hand, sensory design theory, advocates 'altering the sensory environment using specific design interventions' (Mostafa 2015) whereas the neurotypical environment school promotes the idea of people with ASD needing to 'adapt to the day-to-day reality of the world' (Henry 2011).

This paper moderates that discussion by asking how the implementation of sensory design theory in apartment design can improve outcomes for everyone, neurotypical and neurodiverse alike, rather than accept the 'day-to-day reality' of current apartment design. By analysing designs for neurodiverse clients using a small sample of case studies to demonstrate some applications of the principal design drivers, the intention is to turn the focus back to contemporary design for a primarily neurotypical housing market, particularly for apartments, so as to highlight the areas where design intervention can provide the most benefit in terms of privacy, security, and safety, but also dignity, wellbeing, and mental and psychological calmness. In this way, lessons from the lockdown might stimulate a greater dialogue between neurodiverse and neurotypical design.

## REVIEW OF THE LITERATURE

Designing in the built environment for people with a disability has come to focus on the idea of the 'person-environment fit', a concept first introduced by Alexander (1970). Iwarsson and Stahl (2003) have discussed the relationship between person-environment fit and three terms common to the literature around disability-design (and often used interchangeably)—accessibility, useability, and Universal Design. In their terms accessibility is an "environment in which an individual with any impairment can function independently" (2003:58). As such, accessibility is a relative concept that includes a personal component and an environmental component in determining the person-environment fit. Useability is where "the built environment has to allow any

individual, in spite of impairments, to be able to perform daily activities within it" (2003:59). Hence useability is subjective in nature, a measure of effectiveness, efficiency, and satisfaction. The determination of the person-environment fit requires a personal component, an environmental component, and an activity component. Universal Design is "based on the principle that there is only one population, comprised of individuals representing diverse characteristics and abilities" (2003:61). Therefore, Universal Design, or design for all that can be used by everyone, is a process more than a result. While Universal Design (sometimes also called inclusive design) has been recognized to have many positives for people with a disability, it has been critiqued, most notably by Imrie (2012), as being underpinned by a belief in technology and technological solutions. This references the medical-model of disability long discredited, a propagation of market-based discourse, and a defence of universalism with a particular ambiguousness towards particularism and the individual nature of a person's abilities (2012:880). In contrast to Universal Design, design that focuses on the needs of people diagnosed as having autism spectrum disorder (ASD) places emphasis on individuality and the ability to perform in particular environments, and so have more in common with the notion of useability, in Iwarsson and Stahl's terms.

Design guides that deal specifically with the needs of people with ASD and their interaction with the built environment are relatively recent. While initial research focused on schools and children (Baumers and Heylighen 2010; Mostafa 2014; Vogel 2008; Whitehurst 2006), this has broadened to include consideration of the home. Driven in part by the centrality of the home in the constitution of 'a life', and the increasing focus of governments and autism support service organisations on the deinstitutionalization of housing for people with ASD, and a resolve to encourage people to live in the community (Bonyhady 2014). This exposed the near total lack of available, appropriate, and affordable housing for people with ASD in the private housing market.

Housing design research, notably by Ahrentzen and Steele (2009) with 'Advancing Full Spectrum Housing: Designing for Adults with Autism Spectrum Disorders', identified key areas of design that included: safety and security, maximizing familiarity, stability and clarity, minimizing sensory overload, opportunities for controlling social interactions and privacy, providing choice and independence, fostering health and wellness, enhancing dignity, assuring durability, achieving affordability, and ensuring accessibility and support in the surrounding neighbourhood. Work by Nagib and Williams (2017), 'Towards an Autism-friendly Home Environment' examined home modification strategies employed by families with children with ASD in Canada and the USA. A similar study was carried out in Australia by Owen and McCann (2018). Several design guides have since been built on the principles highlighted by Ahrentzen and Steele, with adaptations to reflect National or State-based circumstances (see Brand *et al.,* (2010) for the UK, and Araluen (2020) for Australia).

Starting with the above-mentioned best-practice design guidelines for people with ASD, the methodology developed in this paper to assess apartment design has three focus areas adapted from Mostafa (2015); the alignment of appropriate sensory levels for different parts of a dwelling, the organising of space for predictability which includes spatial proximity but also the transition between spaces, and (most radically) the provision of space to mitigate sensory overload—that is, an escape space. This is consistent with a useability approach to dwelling design that, in addition to the

technical response to noise, light, temperature and so on, recognizes a degree of subjectivity and the importance of an individual's ability to perform necessary tasks. In Mostafa's words "...that to design the built environment for autism, one must calm it down, break it down into manageable experiences in discrete spaces, organise those spaces in a sensory and temporally logical flow and accommodate for sensory overload escape" (2015:58).

# METHODOLOGY

This research was conducted as a desktop study that analysed existing case study housing developments. This was necessitated by the lack of recent purpose-built housing development for people with ASD in Melbourne, Australia, where the researchers were located with (continuing) bans on Melbourne residents travelling internationally. Search guidelines included that the developments be 10 years old or less (as Ahrentzen and Steele's research into design guidelines was published in 2009).

Further, the developments had to be specifically designed for and occupied by people diagnosed with ASD. Several candidate developments were identified across the United States, the UK, France, Denmark, and Singapore. Only developments where architectural plans and sections were available, along with photographs were accepted, as physical site visits were not possible, but the architectural experience of the researchers allowed partial assessments to be made. Some elements of Mostafa's ASPECTSS were not able to be determined by this method, for example around acoustics. Therefore, a simplified assessment and rating system was developed that enabled an existing, or proposed, dwelling to be assessed across three criteria:

- Sensory zoning—is the level of sensory experience in a space appropriate for the use of that space?
- Spatial sequencing and transitions between spaces—is the dwelling's layout logical and are there transition zones between spaces of different sensory intensity?
- Escape spaces—does the dwelling provide a space of retreat and seclusion that is not in a bedroom?

In recognition of the space constraints on this paper, three case studies were chosen that in the researcher's perspective, represented different typologies, scales, urban settings, and approaches. It should be noted that methodologies for assessing building quality are many and varied, ranging from purely qualitative and subjective to attempts at more rigorous and quantitative formats. Design assessment tools are often described as 'performance-based' or 'prescriptive', or a combination of the two. The intent here is to promote a dialogue between the designer and the dwelling, taking our clues from the neurodiverse experiences of the built environment, and so the outcome is an assessment of the likely performance of a dwelling, with all the subjectiveness that implies. Ideally, this initial phase will be followed-up with interviews of the dwelling's residents to gauge their experiences and cross-check the predictions of performance.

## Case Studies

This study implements comparative analysis using three case studies of medium-density residential projects designed for people with ASD. The selection criteria

implemented sought equivalence of typology/scale, and the intentional use of ASD guidelines in the design of the residential project.

**First Place, Phoenix, Arizona, USA**

First Place is a new 55-unit apartment complex in central Phoenix. Opened in July 2018, the 55-unit apartment complex was designed by RSP Architects. The building is an intentional community designed to cater to adults with autism with a focus on independence and community integration (Curley 2018). First Place uses "The Six Feelings Framework" as part of their design strategy (Saltzman 2018).

*Fig 1: Typical one bedroom unit First Place (Image: firstplaceaz.org)*

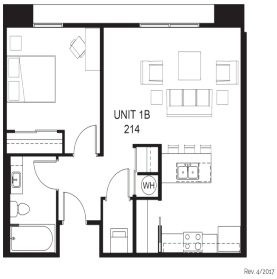
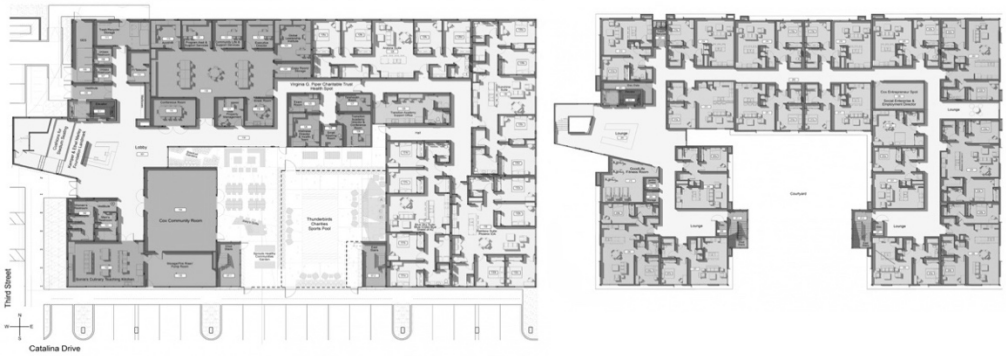



*Fig 2: First Place Ground [Left] and First Floor [Right] (Image: Firstplaceaz.Org)*




**Sweetwater Spectrum Residential Community, Sonoma, California, USA**

Sweetwater Spectrum Residential Community is a new development providing supportive housing for adults with autism that opened in January 2013. The project was designed by Leddy Maytum Stacy Architects using Ahrentzen and Steele's work as the design guide (Tortorello 2013).

*Fig 3: (Left) Sweetwater Spectrum Residential Community: Design concept guidelines. (Right) Plan of typical residential unit Sweetwater Spectrum Residential Community*

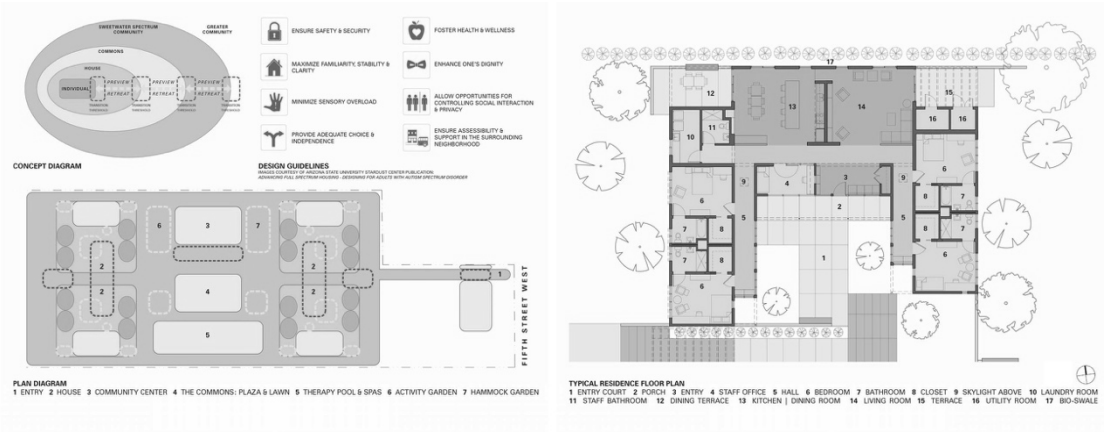


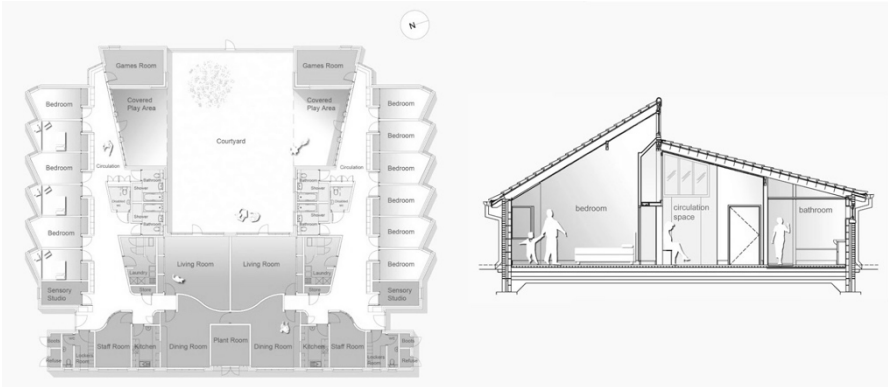
*Fig 4: Sweetwater Spectrum Residential Community (left) view into kitchen [13], (centre) view into living room [14], (right) reading space at end of corridor [5].*

**Rowan and Oak House Clent, England, UK**

The Rowan and Oak House is a residential building designed by GA Architects. Completed in 2012, it is part of the larger estate of Sunfield Children's Home and School. The school supports children with complex learning needs including ASD. GA architects use the following themes in their design: Layout, Personal space, acoustics, heating, health and safety, sustainability, supervision, colour, and patterns (GA Architects 2021).

*Fig 6: Rowan and Oak House [Left] Detail of bedroom with window seat. Different bedrooms have different colours. [Centre] View along corridor. [Right] Detail of high-level window. Windows in different locations use different colours to assist with wayfinding. (Images: Autism-architects.com)*

*Fig 8: [Left] Plan of Rowan and Oak House. [Right] Section through Rowan and Oak House (Images: Archdaily.com)*




## RESULTS

*Sensory Zoning*

Whereas the aim of sensory design theory is to reduce sensory experience throughout a dwelling, the approach here is to determine an appropriate level of sensations commensurate with the likely tasks or activities that are undertaken in that space. Table 1 describes key spaces within a dwelling, including kitchens, bedrooms, front

entrance, etc., and the likely tasks undertaken in those spaces. It then provides an assessment of optimal (or acceptable), sensory conditions based on a series of sensory dichotomies such as light/dark, warm/cool, hard/soft, and so on. In this way, individual spaces within the dwelling can be assessed for their sensory appropriateness. The more information a designer/assessor has, such as floor and wall materials, window heights, or building orientation, the more accurate an assessment can be made.

Table 1: Room description relative to activity and optimal sensory conditions

| Location | Tasks | Optimal Sensory Conditions |
|---|---|---|
| Front door | The transition point between outside and inside | The transition from high stimulus to low stimulus, public, quiet, light, warm |
| Corridor | Transition zone | Public to private, the transition from different stimulus points in the dwelling, quiet, dark, hard |
| Living | Entertainment, relaxation | Public, Loud, Potential for different levels of stimulus, public, loud, light, warm, soft |
| Dining | Eating | Public, loud, light, warm, work |
| Bedroom | Resting/sleep | Private, Quiet, dark, soft, cool, rest |
| Bathroom | Ablution | Private, Quiet, light, hard |
| Balcony | Relaxation | Public, Sound determined by location, light, rest, |
| Kitchen | Food preparation, Food storage | Public, loud, light, warm, hard, work |
| Escape space | Retreat/respite from environmental overstimulation | Private, Quiet, Low stimulus, soft |

*Separation of intensity*

The residences at Sweetwater and Sunfield Children's School clearly separate areas of high sensory intensity including the kitchen and living areas from lower intensity zones such as bedrooms and bathrooms. In both cases the high intensity zones are brought together and centralised, while two wings of bedrooms are situated to the sides to enclose a centralised courtyard space. Corridors act as a link and transition zone between the different sensory zones, and in the case of Sweetwater the entry area and staff office act as a buffer. Sweetwater uses the ceiling profile to further differentiate the zones. The one-bedroom apartment highlighted from the First Place case study is much smaller therefore a literal separation is harder to achieve. However, the transition zone between the front door, bedroom, bathroom, and laundry acts to differentiate the higher intensity (kitchen and living) zone from the lower intensity one. Note that exiting the bedroom or the bathroom, the resident goes through this zone before entering the living-kitchen space. This provides both privacy and a chance to prepare for the change in sensory experience. Movement between the bedroom and the bathroom (both low intensity zones) does not need to go through the high intensity zone of the apartment.

*Diffusion of light*

Both Sweetwater and Sunfield use articulation of ceilings and window placement to diffuse direct sunlight into occupied space. Interestingly, in Sweetwater the diffused light is concentrated in the high sensory intensity areas of the dwelling, whereas at Sunfield it is directed into the bedrooms—a low intensity zone. All three case studies utilise a courtyard typology and so natural light and ventilation are available to most zones of the dwellings. Figs 3 and 8.

*Spatial Sequencing and Transitions*
After analysing individual spaces, the next set of questions for the designer concern the sequence of spaces throughout the dwelling—what adjacencies of use are appropriate and which are not, how are the different sensory zones moderated across the dwelling and critically, what transition zones (if any) are there between spaces of different sensory intensity? When assessing spatial sequencing, concerns such as privacy, safety, surveillance (or site-lines), and acoustics will be central. Predictability and perceptibility are also important, especially when considering transitions between spaces.

The Sunfield example demonstrates two spatial sequences mediated by transition spaces. The first—from the privacy of an individual bedroom to the public open courtyard (a journey from left to right on the plan). Starting from inside the bedroom, the first transition space is immediately adjacent to the bedroom door (note that the built-in robes in the bedroom, and seating in the corridor, create a small entrance space near the door). Then entering the corridor with its double-height space, then proceeding to the covered play area (with lower ceiling) and then out into the open courtyard. Each step represents an increase in public display and likely social interaction, with a corresponding increase in sensory intensity. The second sequence is along the corridor (from top to bottom of the plan). This also marks a journey from the privacy of the bedroom to the high intensity zones of the living and kitchen areas. Here, the private bedroom is mediated by the shared bathroom facilities and shared laundry, before approaching (at an angle) the kitchen, dining and living zones. Note that there is a small transition zone immediately before the choice of which door (kitchen, dining or living) and associated sensory levels the resident chooses.

At Sweetwater, the concept diagram (Fig 3) makes explicit the spatial sequence from individual privacy to the larger community through five transitions. With the apartment at First Place, the sequencing is condensed, as noted, but follows a similar logic in going from bedroom/bathroom to kitchen/living through a transition space. In the Sweetwater and Sunfield examples, the staff offices have been positioned to allow observation of the transition between low intensity to high intensity zones within the dwellings.

*Escape Space*
Assessing sensory conditions and spatial sequences are effective strategies for the design of most built environment spaces intended for use by multiple user groups. The inclusion of an escape space for all dwelling designs is something more specific to a user group likely to experience sensory overload and discomfort. However, increasingly stressful lifestyles and the encroachment of work and other activities into both homes and non-traditional work hours in the evenings and weekends, suggests that the design of a sensory escape space in every dwelling may be worthwhile. It may be that this space is linked to concentration and work or be a place to escape work and other life stresses. Ideally, an escape space would be personalised by the occupant or user, and so the assessment need only indicate whether suitable and sufficient space is provided within the floorplan. Of three case studies, only Sunfield provides a dedicated sensory room (the Sensory Studio) as a common space aligned with each bedroom wing. However, in the Sweetwater model, each bedroom contains a large walk-in robe (Room 8 in Fig 3) that links to the bedroom and potentially the outdoor courtyard space as it includes an external wall to the corridor. The central node/transition space identified in the one-bedroom apartment in First Place also can potentially access space from the laundry and storage cupboard that may be modified

to include a small, secluded escape space (Fig 1). However, a sensory escape space need not be a completely enclosed space, careful design around thresholds and boundaries can also generate spaces to calm and relax. Fig 8 showing the small triangular seat near the window in a bedroom from the Sunfield case study is a good example.

## CONCLUSION

The COVID-19 experience has shown that the role of the home in everyday life is an expanding one. In responding to this expectation, accessible design is not enough, and that while Universal Design has its virtues it is insufficiently adaptable to personal particularities. A useability design approach that captures the creativity and uniqueness needed to design successfully for ASD requirements offers a pathway to a COVID-normal approach to housing that recognises sensory intensity, transitions and escape alongside more conventional technical considerations such as light and warmth and air.

This research began to explore how a neurodiverse perspective on the adequacy of home environments might influence how we design the homes of the future, adaptable and appropriate to the changing way we use our homes. A critical next step in moving forward needs to include the perspectives and input of people on the ASD spectrum in the design conversation.

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# COVID-19 CRISIS MANAGEMENT LEFT TACIT KNOWLEDGE BEHIND

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As the COVID-19 pandemic raged throughout New York City and its surrounding suburbs, more than 500,000 positive cases and 30,000 deaths were recorded between early March and early May 2020. In response, built environment firms were forced to confront uncertainty, shift mindsets, and embrace new workflows to remain viable in the face of city and state mandatory stay-at-home orders and curfews. This required the creation of new internal processes for document dissemination. Firms focused on alleviating clients' concerns and boosting productivity by providing information, a hierarchy of business processes, and new codes of conduct. Utilizing case study methodology, this evolution at one architecture firm was tracked. Semi-structured interviews prior to and after the early wave of the pandemic clarified and verified findings. Participants were asked probing follow up questions to better understand the impacts, especially regarding tacit knowledge. The firm's efforts were optimized, but tacit knowledge sharing disappeared. Once this form of knowledge sharing was highlighted, participants acknowledged the loss and speculated about how to address this critical activity moving forward.

Keywords: architecture; COVID-19; information management; KM

## INTRODUCTION

New York City's building boom spanned more than six years, leading to widespread optimism. The New York Building Congress - an inclusive, membership-based organization representing more than 250,000 professionals and tradespeople - forecasted an almost 10% increase in construction spending from 2018 to 2021 (New York Building Congress 2019). Construction employment increased; 2019 was the eighth consecutive year of growth. At the end of 2019 more than 161,000 individuals were employed (New York Building Congress 2019).

In January 2020 no one predicted this growth would come to an abrupt halt at the end of the first quarter and that by the end of June the American Institute of Architects would report a record drop in billings (American Institute of Architects 2020). *Construction Dive*'s June 30th daily report noted that New York Metropolitan Transportation Authority work, including a $51.5 billion subway modernization plan, was halted. A 350,000 square-foot mixed use development in Jersey City, New Jersey was cancelled. Yet simultaneously, work resumed on a 975,000 square-foot Amazon warehouse after a 45-day shutdown (2020). Volitivity was the order of the day.

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The impetus for this extreme plunge in billings was COVID-19, a global pandemic. The first U.S. confirmed cases were in mid-January in Washington State, quickly followed by Illinois. By March 1st it was in New York City (Axelson 2020). After reaching 76 confirmed cases a week later, Governor Andrew Cuomo declared a State of Emergency, but it was too late; New York City became the epicentre of the United States (House 2020).

Drastic changes followed. By mid-March, New Yorkers were under "stay-at-home orders," followed by enforced curfews, mandatory social distancing, and mask mandates. All non-essential businesses were closed, resulting in extreme levels of unemployment, lines at food banks, and mental health challenges (Axelson 2020),

Whether construction was considered "essential" was not clear. On March 20th, Cuomo issued "New York State on PAUSE," an executive order that defined "essential" infrastructure as public utilities, telecommunications, transportation, hotels, the skilled trades, and infrastructure that relates to healthcare, emergency repairs, and safety. The Empire State Development Corporation issued further guidance, adding affordable housing projects as well as projects that would be unsafe if left incomplete (Benarroche 2020).

Architects and engineers immediately transitioned to remote work, including those working on "essential" projects. On March 23rd, *Metropolis* published interviews with principals from the hardest hit cities. They were generally optimistic, noting the ease of transitioning to remote work, setting up Zoom or Microsoft Teams meetings, and attending "digital" lunches. One mentioned a uniform video "background" to bolster team cohesion. Another discussed the challenge of sending submittals to architects' homes, especially the difficulty of storing large samples. Previously "workflow" was assumed, but workflow discussions became daily occurrences (Metropolis 2020).

These changes were only the beginning. Firms continued to confront uncertainty, shifting mindsets, and new workflows. By mid-April, the city had reached the apex of the first wave; more than 700 people were dying every day. On June 24th, a 14-day quarantine became mandatory for those arriving from states with high infection rates. With each such shift in policy, organizations were forced to adapt (Parsnow 2020).

Using case study methodology, the evolution of one architecture firm's responses were tracked for six months; all firm emails were reviewed; internal and external announcements, procedural changes, business processes, particular events, and shifts in codes of conduct were saved and analysed with respect to knowledge sharing. Then semi-structured interviews with firm leaders and staff probed perceptions of the effectiveness of these measures. Responses were compared to semi-structured interviews from the previous year with the same subjects; these earlier interviews provided a baseline for comparison. The study provided a glimpse into crisis behaviour during and immediately following an uncontrolled, external incident of unprecedented magnitude. It also explored the efficacy of this firm's actions and attempts to both control and share knowledge during an uncertain, ambiguous, and uncontrollable event that placed the firm in existential peril.

## METHODOLOGY

### Research Context and Rationale

Although there is some research on crisis management and uncertainty management in the built environment, there is limited research on their impact on knowledge sharing,

especially within a crisis of the magnitude of a global pandemic (Walker, Davis and Stevenson 2016). Even though numerous studies that focus on COVID-19's impacts are emerging, they are neither concentrated on knowledge sharing within a design firm, nor did they employ case study methods.

When the opportunity arose for access to significant quantities of data that would allow an in-depth analysis of one organization's responses during the initial stages of the pandemic, the case study approach was selected. By focusing on one firm, and employing mixed methods, the research produced a detailed, more complete, and nuanced examination (Flyvbjerg 2011; Saunders *et al.,* 2016; Yin 2018) Concentrated on two questions: *How did knowledge sharing during the pandemic contribute to the firm's survival? and What tactics were successful in sharing knowledge under these new circumstances?*

This was primarily accomplished by plotting the patterns of interactions between the firm and its employees, focusing specifically on statements from leaders to staff pertaining to specific circumstances, work and administrative processes, and changes in policies - prior to the start of the pandemic, at the start of the pandemic, and as the first wave crested and subsided. These communications became the framework for analysing behavioural changes longitudinally.

**Data Collection**

The data collection process was multi-dimensional. Emails were the primary source of data; cataloguing emails prior to the pandemic provided a baseline, which were compared to emails after the pandemic to identify and track changes that occurred because of the pandemic. Emails were chosen because they are timestamped, quantifiable, and provide examples of formal and informal messages associated with specific actions at defined moments.

After the emails were analysed, retroactive semi-structured interviews with firm leadership and staff were conducted. The information collected in these interviews was then compared to earlier interviews exploring knowledge sharing with the same subjects conducted pre-COVID by the researcher. By comparing the two sets of interviews, evolving perceptions of the efficacy of policy changes, procedural changes and other interventions were brought into stark relief.

**Staffing Matrices**

Additional data emerged. Starting years previously, firm management would populate a spreadsheet (a staffing matrix) Of all billable employees' staffing assignments for the week in advance of a Monday morning coordination meeting between project managers (PMs). These staffing meetings are based in collective decision-making. After the transition to remote working, staffing matrices became more widely disseminated and consulted. Individual staff were to use them to guide their remote work - and at the end of the week, before the next staffing meeting, PMs would compare the staffing plan to timecards before initialling them to record review and approval. Major deviations would precipitate uncomfortable phone calls.

When such deviations began to impact project delivery and project quality, PMs instituted End-of-Day (EoD) Reports. Staff were to outline their efforts each day and email it by the end of the day so PMs could monitor progress and identify roadblocks on a daily basis. Timely interventions with clients or consultants - or requests for additional resources in consultation with the Principal-in-Charge - were proactively

pursued. Staffing matrices proved to be a treasure trove of information. Data included:

1. Number of projects billed to - on a weekly basis
2. Number of fully utilized employees (scheduled/authorized for 40 hours)
3. Number of employees with utilization rates less than 100%
4. Total number of staff (sum of numbers 2 and 3 above)
5. Total number of billable hours per week (aggregated)
6. Utilization percentage (number 5 divided by number 4, to two decimal places)
7. How non-billable hours were allocated

*Table 1: Staffing Matrices Summary Data*

| Week Ending | Sum of Utilization | Average Percent Utilized | Fully Utilized | Less than 100% | Total Staff |
|---|---|---|---|---|---|
| 01/03 | 4020 | 91.36 | 33 | 11 | 44 |
| 01/10 | 4210 | 95.68 | 38 | 6 | 44 |
| 01/17 | 4300 | 97.73 | 40 | 4 | 44 |
| 01/24 | 4275 | 97.16 | 38 | 6 | 44 |
| 01/31 | 4155 | 94.43 | 38 | 6 | 44 |
| 02/07 | 4180 | 95 | 39 | 5 | 44 |
| 02/14 | 4145 | 94.2 | 38 | 6 | 44 |
| 02/21 | 4150 | 94.32 | 38 | 6 | 44 |
| 02/28 | 4220 | 95.45 | 39 | 5 | 44 |
| 03/06 | 4200 | 93.33 | 38 | 6 | 44 |
| 03/13 | 4320 | 98.18 | 41 | 3 | 44 |
| 03/20 | 4300 | 97.73 | 41 | 3 | 44 |
| 03/27 | 4540 | 98.7 | 44 | 2 | 46 |
| 04/03 | 4635 | 98.62 | 45 | 2 | 47 |
| 04/10 | 4293 | 93.33 | 42 | 4 | 46 |
| 04/17 | 4400 | 95.65 | 42 | 4 | 46 |
| 04/24 | 4460 | 96.96 | 43 | 3 | 46 |
| 05/01 | 4555 | 96.91 | 44 | 3 | 47 |
| 05/08 | 4150 | 88.3 | 41 | 6 | 47 |
| 05/15 | 4250 | 90.43 | 42 | 5 | 47 |
| 05/22 | 4050 | 86.17 | 40 | 7 | 47 |
| 05/29 | 4110 | 87.45 | 40 | 7 | 47 |
| 06/05 | 4170 | 88.72 | 40 | 7 | 47 |
| 06/12 | 4215 | 89.68 | 40 | 7 | 47 |
| 06/19 | 4230 | 90 | 37 | 10 | 47 |
| 06/26 | 4330 | 92.13 | 42 | 5 | 47 |
| 07/03 | 4290 | 91.28 | 42 | 5 | 47 |

Table 1 'Week Ending' dates fall on Fridays but cover the Sunday previous until the Saturday following. The office was closed between Christmas Eve and New Year's Day, thus such poor utilization during week 1. The firm strove to, and managed to maintain, 96% average utilization through week 18. Starting week 19, utilization dropped more rapidly than the levers available to firm leadership to reign in utilization rates.

**The Management Response**

In response, firm leadership instituted a salary deferral program for employees earning $100K+ per annum to address cash flow. 50% furloughs (one week on, one week off,) Which allowed unemployment claims during 'off' weeks, were next. Delays in receiving a 2020 CARES Act PPP loan contributed to both partial salary deferrals and partial furloughs. Eventually, layoffs were necessary, as they were the only way the firm could survive.

A special all-office virtual meeting was held on 7/15/2020 to announce the measures taken, and that the layoffs would allow the firm to remain viable since the PPP loan had finally been approved and the funds would shortly be received. A significant number of accounts receivable that were in arrears were also collected. The principals deferred 100% of their salaries until all consultants were paid. The PPP loan allowed the deferred salaries to be repaid between 7/9 and 9/3 in five equal increments.

50% furloughs remained in effect for those the firm especially valued but whose projects had still not restarted. A feature of the PPP program - keeping people employed in the short term until cash flow improved - is also a condition for PPP loan forgiveness, meaning that staff paid through PPP could not be laid off without the firm forgoing the possibility of loan forgiveness. This is a very strong incentive structure. Please note that the study period ended July 4th, so the events above do not fall within, and will not be included, in the data analysis.

**Quantitative Data Analysis**

Table 1 data generated three graphs, which will be described in turn.

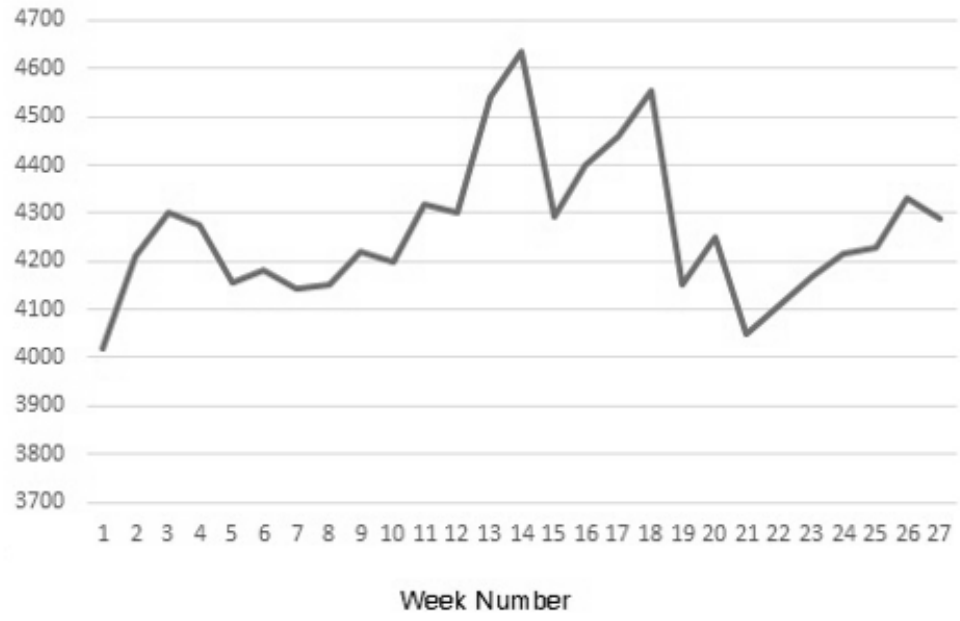



*Fig 1: Aggregate Billable Hours during the First 6 Months of 2020*

The Y-axis represents the aggregate number of authorized/billable hours for the week, based on staffing matrices (assignments) Not actual time billed on timecards.

When the aggregate number of billable/authorized hours is divided by the total number of employees, Average Percent Utilized results. The divisors vary and the results correspondingly vary from Fig 1.

*Fig 2: Average Percent Utilized during the First 6 Months of 2020*

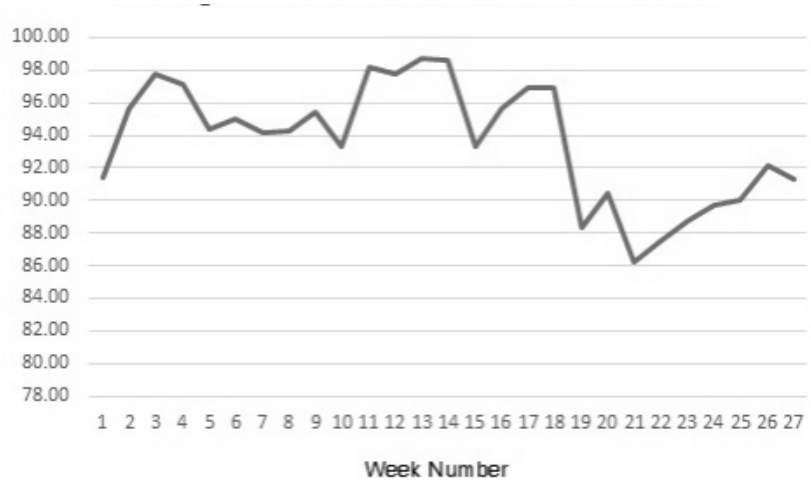
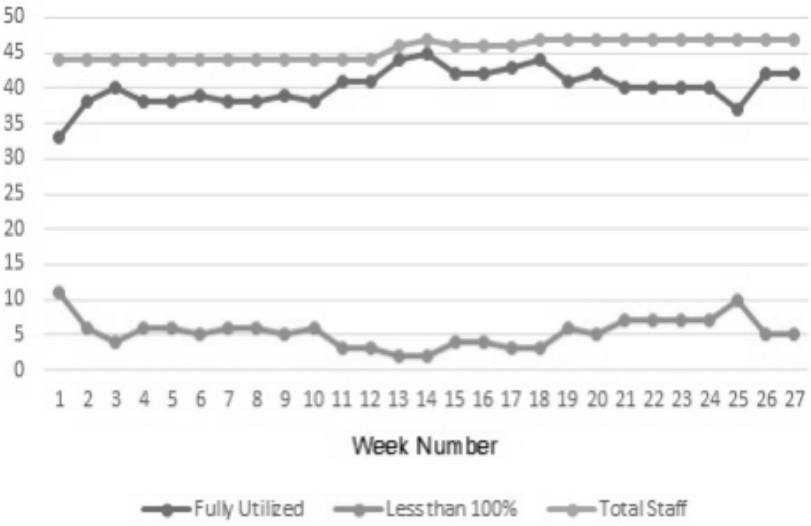



*Fig 3: Staffing during the First 6 Months of 2020*




This *Stacked 100% Line Graph* depicts the number of employees not fully utilized (lower line) Fully utilized (middle line) And total number of employees (upper line) The novel information that can be gleaned from this data is that *in the face of the pandemic* the firm *did not* decrease staffing during the first 27 weeks. Not cutting staff represented a heroic effort to mitigate the impacts of the pandemic upon employees; layoffs were avoided until after week 27. Also notable is that the number of underutilized employees hovered around five or fewer until week 19, which correlates with projects being placed on hold or cancelled earlier in the year by the NYC School Construction Authority (SCA) And the NYC Department of Citywide Administrative Services (DCAS), among others. Existing contract provisions and delays inherent within demobilization caused these staffing impacts to be delayed.

**Exceptions to the Drive for Maximum Utilization**

Town Halls were introduced by firm leadership in 2017. They were initially to be quarterly events (every 90 - 92 days), but best intentions did not prevail, and the number of days between Town Halls, pre-COVID-19, was 229. During the study

timeframe, time between Town Halls dropped to 121 days. The urgency of communication and cultural challenges related to the pandemic clearly contravened the pressure for maximum utilization, even as the firm struggled to survive the emergency. When a firm of close to fifty professionals (not counting non-billable staff) Attend such events, it represents between 45-68 billable hours at an average billable rate of $120/hr. The opportunity cost of such events therefore equals between $5,400 and $8,160 of unearned fee. For a firm seeking week-over-week average utilization of 96%, a Town Hall week takes a -2.2% to -3.2% hit. In the face of this, mean time between these meetings *actually decreasing* during COVID. This evinces their perceived importance to firm leadership.

Town Halls follow a specific agenda: 1) An *Introduction*, 2) *Project Highlights*, 3) *Firm Financial Status*, 4) *Projects Booked / Status of Current Project Pursuits*, and 5) An anecdote about *The History of the Firm*. The implicit messaging during each of these agenda items was: 1,2) Firm projects are substantial and make a difference in the world, 2) *You* could be presenting *your project* in the future, 3) Firm leadership are actively dealing with financial pressures to ensure firm survival and everyone's continued employment, 4) Projects are being won even in the face of increased competition and even more are being pursued, since business development is a high priority, and 5) The firm advances talent from within, as evidenced by anecdotes about scrappy young architects performing mundane and sometimes ridiculous tasks who eventually became principals in the firm. In person Town Hall meetings lasted about 1.5 hours, but once they went virtual dropped to about an hour long.

On a much more regular basis, the firm would host “Friday Lunches” where lunch was sponsored by vendors giving presentations or employees would present projects. Prior to COVID-19, these events were held an average of three times a month but did not represent the same level of investment as Town Halls, since lunch hours were not billable time. Post-COVID, they were as much for morale as they were for ongoing professional development, and the formula flipped; employees had to ‘invest’ their time without the reward of “free” food or the real camaraderie of a shared meal around a large conference table.

Friday Lunch frequency dropped off exponentially to the point where Friday Lunches "…began to feel pointless." They still occurred when there was real interest, such as the April 24th session on Construction Documents, a topic that all architects are interested in and have an opinion about. But by June, Friday Lunches had dwindled to one per month or fewer.

Beer Fridays on the company tab were regular occurrences prior to COVID-19. To compensate, the principals staged ‘social events’ or ‘happy hours’ via Zoom where they requested everyone be on camera and share an alcoholic or non-alcoholic drink at 4:30 pm on a Friday. The invitations for the virtual simulacrums were simultaneously touching and ridiculous (but quite revealing): One noted that "It’s a poor excuse for a social event, but it’s the best we can do under the circumstances" while another said "I hope you all remember who I am." There is a kernel of truth in such asides.

Eventually these events, which never quite jelled as social events, likewise petered out. They may have exacerbated remote workers' feelings of isolation; more and more staff sent their regrets in advance or did not even acknowledge receipt of the invitation. It is possible that everyone realized that when not talking business they no longer had anything to say to each other.

Interviews revealed that *unplanned moments* such as before and after meetings, conversations in the kitchenette, or walking around the office and dropping by someone's desk - that previously had been opportunities to get to know fellow employees on a more personal level - had disappeared, yet few took the time to pick up the phone to chat. Those that acknowledged making or receiving such calls even expressed guilt about talking about things other than work - or how to be more effective or productive - given the circumstances. Yet such “in between” moments have value beyond the social. They are opportunities for the exchange of the most valuable long-term resource for professional service firms: tacit knowledge.

### Tacit Knowledge

Tacit knowledge is context-specific and often involves heuristics (Koen 2003). Informal, it is often drawn from personal experience, thus it is hard to communicate or manage, (Chen *et al.,* 2019). It is important to those in the built environment because much of the industry's knowledge is experiential, is based on lessons learned, and is grounded in intuition. This is primarily due to the project-based nature of the industry. When teams change with each project, tacit knowledge fragments and becomes decentralized, (Yang *et al.,* 2020).

As work became remote during the pandemic, communication and documentation trended towards being centralized and formalized; its frequency increased, increasing everyone's workload. As workload increased, and opportunities for "in between moments" decreased, tacit knowledge sharing evaporated. This was not evident in the documents reviewed. Participants were not even cognizant of the opportunities missed. Only when answering probing, follow up questions such as "were there opportunities to share lessons learned" did it become evident that opportunities were being missed. Participants' reactions ranged from acknowledgement to regret, with one subject speculating about ways to increase informal interactions with staff.

## FINDINGS

The documents analysed fostered information exchange and established alternative business processes. Project-focused, quantifiable knowledge sharing (Staffing Matrices and EoD Reports) Resulted in improved management and productivity. Implicit messaging reassured employees whose worlds had been turned upside down. Tacit knowledge sharing deficits were not evident to the subjects interviewed. Management tactics were considered largely successful - and they *were* successful in the short term - but the competitive advantage of an architecture firm is its people and without tacit knowledge exchange a firm cannot sustain competitive advantage. Since tacit knowledge exchange deficits were not recognized until the researcher's probing questions prompted it during the second round of interviews, this speaks to the 'stealth' qualities of tacit knowledge exchange, and how it was not dealt with in any systematic way by this firm.

This may be the case because those sharing tacit knowledge have difficulty explaining how or what they do. Even if Town Halls and Friday Lunches provide increased opportunities for conventional knowledge exchange, the loss of in-between moments during the pandemic *eliminated an ecosystem for the exchange of tacit knowledge* and did not foster deeper personal relationships between more experienced and less experienced staff that eventually promote tacit knowledge sharing. Participants acknowledged the loss and speculated that integrating new processes to address the

shortfall moving forward should be a goal. Unfortunately, no one had a clue what form such processes might take.

## CONCLUSION

Outstanding employee-centric crisis management of professional service firms can soften the blow of the worst of externalities. COVID-19 changed the playing field completely and required immediate and heroic efforts to shore up the firm. In the end, managerial interventions cannot change the harsh reality of clients who do not pay, place projects on hold, or cancel them. Given that the worst case (laying off staff) Eventually becomes inevitable, the firm's fostering of a robust culture and implicit messaging must emphasize belonging, caring, stewardship, and hope, otherwise it will become less likely employees will elect to 'ride out the storm' with a firm. Fostering opportunities for one-on-one interactions could go a long way toward mitigating tacit knowledge exchange deficits that threaten the long-term competitive advantage of any professional service firm - its people.

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# DEVELOPMENT OF ECONOMIC NATIONALISM IN AUSTRALIA AND IMPLICATION FOR THE CONSTRUCTION SUPPLY CHAIN

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Despite rapid economic globalisation, economic nationalist measures such as a local content policy for the construction sector that has gained favour in recent years is now being promoted as a tool for rejuvenating the Australian economy. This study aims to conduct a structured literature review on the historical development of economic nationalism in Australia and its implication for the construction supply chain. The findings indicate that economic nationalism was strong with protectionist policies of tariffs and the rejection of foreign capital prevalent before 1990 but became more open from the early 2000s, with increasing import penetration from lower cost producers leading to declines in Australian manufacturing capacity. Policies such as 'buy local', subsidies to manufacturers, and strategic restrictions on foreign investment were put in place during this period. The disruptions caused by the pandemic and recent global trade tensions have resulted in a resurgent economic nationalist sentiment to sustain the declining Australian manufacturing sector to maintain a capacity to produce essential items. Construction companies that have previously sourced a large proportion of their materials and products overseas are now encouraged to increase their local content requirements to support the domestic manufacturing sector.

Keywords: Australia; supply chain; economic globalisation; economic nationalism

## INTRODUCTION

Economic nationalism has always gained prominence after major global crises such as the Great Depression in the 1930s, the oil crash in 1973, the global financial crisis in 2008 and the recent pandemic in 2020 (Hesse 2020). The pandemic has not been an exception in triggering another wave of economic nationalism. Globally, concerns for domestic availability of medicine, critical health equipment and consumables exacerbated by the initial shutdown of manufacturing in China led to introduction of 110 export restrictions on medicine and other medical products, 68 of which have no termination date (Evenett and Fritz 2020). The pandemic also exposed the weakness in supply chains that were over-reliant on imported goods which was a wake-up call for governments as massive shortages persisted (Ibn-Mohammed *et al.,* 2021).

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Apparently, governments are taking economic measures to preserve local supply chains as countries look forward to post-pandemic economic recovery.

One of the policy options to protect the economy and guarantee economic recovery after global crises is Keynesian-esque government demand which is largely dominated by major infrastructure and building projects, tax concessions and subsidies for building projects. For example, the Government of Victoria in Australia has budgeted AUD50 billion for social housing, infrastructure, and school projects; land tax cuts, widening the eligibility for stamp duty rebates, and a subsidy-for-equity scheme for home buyers which is expected to create 400,000 jobs by 2024 (Durkin and Wootton 2020). Most of this budget is expected to be spent on the domestic construction supply chain to stimulate the local economy based on an existing local content law in the state of Victoria.

Despite criticisms of economic nationalism by Saunders (1982) for lacking statistical justification, economic policies by the government will play a critical role in post-pandemic economic recovery (Nicola, *et al.,* 2020). Some of these policies will carry varying degrees of economic nationalism. The Australian government needs to secure essential domestic manufacturing capacity and transit from sole reliance on global markets to deliver national prosperity and security (Hameiri 2021). These policy interventions by governments have reawakened interest in economic nationalism which has been observed to follow global or regional economic crises (Hesse 2020). Therefore, this study aims to review literature on the historical development of economic nationalism in Australia and its implication for the construction supply chain.

The following are the contributions of the study. First, is to present a consolidated account on the development of economic nationalism in Australia. Second, is to compare economic nationalism in Australia up till 1990 with the current forms of economic nationalism. The remainder of the paper is organised as outlined. The next section is literature review which is followed by research methodology and results of the structured literature review, discussion, and conclusions.

## LITERATURE REVIEW

Although Helleiner (2020) advocates the expansion of the intellectual roots of economic nationalism; understanding the ideas of List and Hamilton, the renowned pioneers of economic nationalism, will be helpful in properly defining economic nationalism (Harlen 1999). They supported the principle of free trade but argued that the necessary conditions for free trade were absent in Germany and USA, the two economically weak and political divided countries they analysed; consequently, they promoted limited versions of infant industry protection in agrarian countries (Ibid). They asserted that their nations were not yet developed to participate in free trade; hence, if free trade were to promote global prosperity, developing agrarian nations should be afforded time to build their industries before embracing free trade, this argument expanded Adam Smith's argument that national security should warrant protection (Helleiner 2002). Both List and Hamilton criticised the protectionist Corn Laws in Britain as ardently as David Ricardo (Harlen 1999). Perhaps, because they saw Britain as an industrialised nation that will benefit more from free trade.

In 18th century America, Hamilton cautiously endorsed industry protection and contended that subsidies and not trade restrictions will better develop domestic manufacturing; he also appreciated foreign investment (Helleiner 2020). List has been

typified with infant industry protection which does not represent his central view on how economic nationalism should be defined; in contrast, his aim was to formulate a "science which limits its teaching to the inquiry of how a given nation can obtain (under existing conditions of the world) prosperity, civilisation and power"; thus, List's ideology was targeted at serving the interests of a nation as a collective group (Helleiner 2002: 312).

Furthermore, the great depression of the 1930s and Britain's departure from the gold standard forced a chaotic and incoherent adoption of nationalists' policies (i.e., currency inconvertibility and import restrictions) to cope with the global economic crisis, albeit not backed by theory (Pryke 2012). John Keynes, an economic liberal, provided a scholarly argument for economic nationalism by advocating for national self-sufficiency to express English innovative aptitude; and inward-looking capitalism which would trap the producer and consumer within the same national, economic and financial entity (Ibid). Matsunaga (2021) argues that Keynes foray into economic nationalism was not a doctrine of necessity but rose from a contradictory coexistence of economic nationalism and economic liberalism as liberal producerism emphasised the importance of the manufacturing sector.

Generally, economic nationalism is the utilisation of national resources to realise economic benefits for a nation's citizens from the global economy (D'Costa 2009). In times of economic crises, nations often adopt economic nationalism to recover from these predicaments (Nakano, 2004). In this study, economic nationalism is defined as a group of practices by governments, businesspeople, trade unions and other actors designed to create, boost and protect national economies as opposed to allowing the nation's fortune to be dictated by the forces in the global markets. This is in line with the definition proposed by Pryke (2012).

Measuring economic nationalism empirically has not been an easy task, perhaps because of the conceptual and descriptive ambiguity previously associated with it. The leading empirical study of economic nationalism was conducted by Baughn and Yaprak (1996) who developed eight items for measuring economic nationalism. These eight items, later adopted by Lee and Lee (2015), are: buy local policies; restrictions on foreign firms; restriction on immigration of workers; intellectual property; formal barriers to foreign products; domestic production by national firms; a general nation-first orientation in trade and inter-firm competition; and restrictions on foreign investments.

## METHOD

For the debate on economic nationalism in Australia, the aim of the search was to select peer reviewed journal papers that analyse economic nationalism in Australia. The search key words used were "economic national*" and "Australi*" on "article title, abstract and key word" which produced 42 combined results in the Scopus and Web of Science databases. A total of 37 papers were reviewed for relevance after five duplicated were eliminated. Ten papers were selected after titles were checked against the criteria. After reviewing the abstracts, these were further reduced to six (Bryan 1983; Joseph 1984; Bryan 1991; Evans 1999; Pokarier 2017, Sadlier 2017). A backward citation search revealed two additional articles relevant to economic nationalism in Australia and was added to the list. The selected papers were analysed in a chronological order to show the development of economic nationalism in Australia.

# FINDINGS AND ANALYSIS

## Economic Nationalism in Australia

Threat of Multinational Corporations (Post-War Period to the 1970s)
In the years after federation, Australian nation-building was based on a large immigration program from the UK and Europe with an obvious open door to foreign investment as an engine of growth and investment into technology for a growing nation (Pokarier, 2017). Before World War I, foreign capital initially came from Britain, post-World War II foreign investment came from US which was followed by a third wave from Japan (Wheelwright 1997). Thus, Fitzpatrick, through dependency theory, postulated that Australia was a victim of international capital (Bryan 1983). This was because of the middle position of Australia in the imperialist capitalist chain, foreign direct investment was targeted at the agriculture and mining industries, dwarfing the growth of the declining manufacturing industry (Bryan 1991). This argument holds that Britain, US and Japan wanted Australia to always import advanced manufactures from them which resulted to the lack of investment in Australian manufacturing sectors.

While economic nationalism in the 1960s and 1970s was preoccupied with the threat of multinational corporations (MNC) to Australia; this shifted to a focus on industrial policy in the 1980s (Bryan 1991). Wheelwright (1981: 4) captures this nationalist concern - "One result of this corporate re-structuring is that Australia is being de-industrialised. Companies are relocating to South-east Asia, using the latest equipment and paying wage rates 10% of those in Australia, in countries where there are no free trade unions, and which often are a police state, of some kind". This nationalist concern, championed by the opposition Labour party, translated to the identification of Australia as a victim of Britain, US and Japan, the then major global economic powers; the panacea was restriction of foreign investment and ownership to prevent loss of national control and autonomy; strict regulatory control of the financial system; and high tariff protection of labour-intensive manufacturing industries, parts of which were implemented by the Whitlam Government (Sadlier 2017; Evans 1999; Bryan 1991; Bryan 1983).

*The Era of Industrial Policy (1980s)*
In the 1980s, Australian economic nationalism adopted a post-Keynesian approach that advocated for intervention to promote the manufacturing sector because of its critical role in securing a globally competitive national economy; and a progressive labour union involvement in economic decision-making (Bryan 1991). The Federal Government announced industry assistance to support high technology industries in March 1983 (Joseph, 1984). This nationalist approach, heavily backed by trade unions, rejected comparative advantage, and argued that it led to de-industrialisation; and promoted industrial policy with four fundamental agenda:

1. Selective industry protection to achieve competitive economies of scale based on theory of strategic trade policy (e.g., 1983-1988 Steel Plan).
2. Implementation of separate industry plans in strategic industries to effectively utilise state resources and pick winners in global competitiveness.
3. Import substitution by the government through local content procurement policy and advertising of Australian made products; and
4. Increase of investment in research and development, and provision of funds for capital investment by the state to achieve an unassisted expanding manufacturing sector (Bryan 1991).

These measures were designed to entice footloose capital, especially foreign capital to remain in Australia which was a shift from the strong economic nationalist opposition to foreign capital pre-1980 (Ibid). Nevertheless, Evans (1999) contends that Australian economic nationalism, based on a perceived international economic threat and use of domestic capital produced deteriorating economic and social outcomes such as recurring high unemployment, misallocation of investment and decline in growth rate of GDP per employee. This was followed by liberalisation of the Australian economy starting from the mid-1980s as economic nationalism took a back seat in economic policy.

*Rapid Globalisation and Retreat of Economic Nationalism (1990s)*
In the 1990s, economic nationalism was still primarily concerned with the inflow of foreign capital into Australia, especially private capital which was over 80% of total capital inflows; these concerns were captured in the statement of Geoff Kitney, a policy columnist - "As the internationalisation of the Australian economy proceeds, public confidence in its benefits is receding. Public support for economic nationalism is growing to the point where the major parties cannot ignore it" (Wheelwright 1997: 92). Economic nationalists argued that this intrusion of foreign capital promoted global consumerism especially on mass media which undermined Australian national identities, caused a fall in manufacturing output for the domestic market as export production remained flat (Ibid).

**Economic Nationalism in a Globalised Economy**

Despite rapid economic globalisation, Australia has initiated and implemented a range of economic nationalist policies in the construction supply chain since year 2000 with broad consensus across policy makers of both nationalist and liberal tendencies. Three components of economic nationalism from Baughn and Yaprak (1996) were apparent in the last two decades. These were the buy local policies, an increased emphasis on domestic production and restrictions on foreign investments. Other components from their list were observed but were not portrayed as being driven by economic nationalism.

*Buy Local Policies*
The state of Victoria is the only state or territory in Australia with a very high and mandatory 90% local content (materials, labour, and service) policy for capital projects of the state government that are worth AUD50 million and above (Department of Jobs, Precincts and Regions 2020). The local jobs first policy is backed by the Local Jobs First Act 2018 which supports SMEs in Australia and New Zealand that are exempted from free trade agreements and under WTO rules. The law states that only building materials that cannot be sourced from Australia and New Zealand should be imported for use in these public projects. For the post-pandemic economic recovery, the Victoria State Government will spend AUD6 billion in housing projects and AUD19.6 billion in infrastructure projects until 2024 to recover 180,000 lost jobs, and add another 280,000 jobs (Durkin and Wootton, 2020). This is a Keynesian-style demand policy (Pryke 2012) which is one of the tools employed by government during times of global crises (Nakano 2004).

*Emphasis on Domestic Production*
The two primary steel producers in Australia, BlueScope and InfraBuild, have been assisted by Federal and State Governments to preserve that strategic supply chain to the construction industry. In 2016, when Arrium Steel fell into administration, the Federal Government brought forward the Adelaide to Tarcoola rail upgrade project

worth AUD252 million to help sustain the company before it was acquired by Liberty House Group (Department of Infrastructure and Regional Development, 2017). The rail upgrade project utilised about 73,000 tonnes of steel. Also, the Federal Government of Australia and the Victoria State Government will deliver a AUD150 million electricity subsidy to Portland Aluminium to keep the plant running till 2026 (Miles 2021). The company's output is 20% of Australia's aluminium production and over 500 jobs will be saved. This subsidy will guarantee the continuous domestic production of aluminium doors, windows and panels which are vital inputs in the construction supply chain. This aligns with the view of Hamilton that government subsidies and not blanket trade protection will better promote domestic manufacturing (Helleiner 2020).

*Restriction on Foreign Investments*

The Federal Government has tightened restrictions on foreign capital in strategic sectors important to national security by expanding the scope of the Foreign Investment Review Board (FIRB). The FIRB will now approve all foreign investments in any business deemed sensitive to national security irrespective of the value (Clarke 2020). Also, another restrictive layer of the law gives the Treasurer power to veto a foreign investment pre-and-post acquisition, and to order a divestment if national security risks arise after approval by FIRB (Ibid). The FIRB recently rejected a AUD300 million Chinese takeover of South African-owned Probuild, a Tier-1 builder, for economic and security reasons (McGuirk 2021). This conforms to the idea of List that economic policies should serve the interests of the nation (Helleiner 2002).

**Comparing Economic Nationalism Pre-and-Post Economic Globalisation**

Before the rapid economic globalisation of the 1990's, economic nationalism was aggressive, tariff-inclined, opposed to foreign capital and adopted a coherent industrial policy (Sadlier 2017; Bryan 1991; Bryan 1983). In contrast, post-globalisation, economic nationalism is subtle, non-tariff inclined, relatively more receptive to foreign capital and is not inconsistent with economic globalisation. As asserted by D'Costa (2009), economic nationalism seeks to derive maximum national benefits from the global economy. For instance, Australia has 15 free trade agreements in force and 14 under negotiation which is mixed with various inward-looking economic nationalist policies. This is particularly evident in the 90% mandatory local content procurement policy in state of Victoria for public capital projects despite the availability of lower cost imported materials. There seems to be an unwritten consensus across political party lines and policy circles that economic globalisation is inevitable; nonetheless, assistance to industries is also acceptable. This contrasts economic nationalism before 1990 which was more about creation, development and protection of the national economy which aligns to the assertion of Pryke (2012).

Also, there are similarities between economic nationalism either side of globalisation. Both subscribe to local content procurement, government-assisted investment in research and development, and selective industry assistance to strategic industries to achieve a competitive and unassisted manufacturing sector. The federal government has attempted to make a very subtle distinction between a hand-up (assistance to improve competitiveness) and a hand-out (unsustainable gift). The recent grant of AUD8 million for an upgrade to British-owned Whyalla steelworks in September 2020 was a clear demonstration of this 'hand-up' offered to a foreign company employing more than 1,500 local workers. (Government of South Australia 2020).

### Implication for the Construction Supply Chain

The discussion of strengthening the declining Australian manufacturing sector has returned to the fore due to the recent disruptions in supply of construction materials from overseas. In practical terms, favouring the local supply chain over the foreign one is interpreted as economic nationalism, but this may also form part of the road map for post-pandemic economic recovery. Businesses should not have to choose between economic nationalism and economic liberalism, but a merger of global and nationalist endeavours can maximise benefits for the firm (Waldman and Javidan 2020). A very strong globalist approach could lead head contractors to miss local opportunities while an extreme nationalist approach can limit the ability of the business to seize foreign opportunities (Ibid). Although the Australian construction industry may return to international supply chains due to the cost savings, adoption of local supply chains for resilience purposes could be a big game changer in the event of another pandemic.

Moreover, head contractors that decide to bid for public projects of the state of Victoria must show a commitment to the local industry by using at least 90% local content. Due to the declining competitiveness of the Australian manufacturing sector, many building components like curtain wall and lifts for high-rise buildings are no longer produced locally. This implies that head contractors must maintain strong local and foreign supply chains into the future. There is also considerable support for a revival of domestic manufacturing capacity from the community in response to the shortages of medical supplies, personal protective equipment and other essential manufacturing inputs (Lucadaou-Well 2020).

## CONCLUSIONS

The structured literature review reveals that while the motivations for economic nationalism in Australia has remained the same, it has adopted several new approaches to the same issue. Before 1990, economic nationalism was very aggressive, tariff-inclined, hostile to foreign capital and used an articulate industrial policy. However, from the 2000's, economic nationalism became less protectionist, subtle, non-tariff inclined, relatively more receptive to foreign capital and compatible with economic globalisation. Local content procurement policy, government-assisted investment in research and development, and selective industry assistance to strategic industries were discovered as similarities between economic nationalism pre-and-post economic globalisation. Post-economic globalisation, economic nationalism takes the forms of buy local policies, subsidies to manufacturers and selective restrictions on foreign investment. Post-pandemic, the implication for the construction supply chain is that head contractors, especially those engaged on public projects must develop both local and foreign supply chains to satisfy the increasing local content procurement requirements in Australia and also to build resilience to cope with future disruptions.

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# TAKING THE PULSE: DEVELOPING A MODEL OF RESILIENCE CAPITAL FOR ARCHITECTURAL FIRMS

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In Australia, during 2020, the COVID-19 pandemic led to disruptions in architectural workplaces. These disruptions led to project cancellations and the need for many architects to work from home. This paper aims to trace how architects responded to these disruptions and then utilise their responses to propose a model of resilience suitable for architectural firms. What lessons can architects learn from these changes regarding resilience within their profession and workplaces? In a series of industry surveys, the Architects Consulting Association of Australia (ACA) Tracked the pandemic's impact on firms. Five national surveys were undertaken beginning in March 2020. Detailed selected results from the five surveys are presented, and the surveys' design is critiqued. With over 3000 respondents, the surveys represent a comprehensive snapshot of data gathered from architects in Australia. In examining these membership surveys, what constitutes resilience in architectural firms is explored and developed. From these results, firm resilience is reframed, and an integrated model of resilience is developed. This integrated model of Resilience Capital (RC) extends previous understanding of architecture firms based on limited indicators of psychosocial measures of well-being and professional identity conflicts. The developed model will enable further industry development and further studies of resilience in architectural and other small professional service firms.

Keywords: Australian architects; resilience; well-being; global pandemic

## INTRODUCTION

For architects working in small professional service firm's resilience is a critical issue. This concept is vital because many firms are small, operating with low-profit margins in a highly competitive environment. Firm resilience is critical if firms are to recover from external disruptions. Concepts of resilience have been employed across population health, developmental psychology, ecological and climate studies. Evidence of the concepts wide-ranging application can be seen in its integration across the UN Habitat's Sustainable Development Goals (SDG). However, as a concept, resilience is not often applied to studies of the professions. Indeed, architects themselves have long been concerned with applying resilience concepts in wide-ranging studies across community development and urban design (Barton *et al.,* 2018; Roggema 2018). However, few architects have thought about resilience within their firms, nor have they considered how resilience is operationalised.

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The paper traces how Australian architectural firms responded to disruptions resulting from COVID-19 outside of their standard operating context during 2020. This will be done by analysing a series of nationwide surveys. The Architects Consulting Association of Australia (ACA) tracked the impact of COVID-19 lockdowns and project disruptions on firms (ACA, 2020). Five national surveys were undertaken beginning in March 2020 as a national lockdown due to COVID-19 was instituted. The overarching aim is what lessons about resilience can architects learn from pandemic induced disruptions? Moreover, in a post-pandemic profession, how might resilience be reframed in strategic and operational terms so a model of resilience can be developed for architectural firms.

## LITERATURE REVIEW

### The Focus of Previous Studies

In studies of the architectural profession, ideas of firm resilience have been overlooked in favour of examining the well-being and mental health of employees in architectural firms. For example, Bowen *et al. (*2013), in a study of construction professionals in South Africa, found that "Architects, more than engineers, quantity surveyors, and project and construction managers; and female, more than male professionals feel stressed." In a similar vein, Raidén and Räisänen (2018) cite the architects diminished work-life balance, unpaid or excessive working hours, precarious employment and "low professional worth." They argue that well-being and mental health is critical to knowledge workers like architects who can "simultaneously demonstrate creativity and compliance." Perhaps as a result of these concerns, the UK Architects' Mental Wellbeing Forum tool kit was developed "to tackle the all-pervasive problem of mental health issues within architecture schools and practice." Topics range in the tool kit include "Office Culture and Overtime, Technology, Monitoring Staff Wellbeing and Championing an Active Mindful Approach." In Australia, this tool kit was championed by Parlour, the advocacy group working to improve gender equity. This impetus has led to, more recently, an Australian Research Council (ARC) grant for Australia entitled "Architectural Work Cultures: professional identity, education and well-being" was funded in 2020. According to its proponents, the ARC study will "address the question of how workplace cultures and professional identity affect subjective well-being in architecture." The above imbalances identified in the working lives of architects appear, as some have suggested, to be a global phenomenon (Raisbeck, 2019).

There has also been a focus on well-being in Construction Management—perhaps more so than in architecture. Again, psychosocial notions of well-being have been the focus: Kotera *et al.,* (2020) explore psychological outcomes in construction workers related to work-life balance. Chan, Nwaogu and Naslun (2020), in a literature survey of construction workers and mental health research, identify 16 psychological risk factors. Cheung *et al.,* (2019) develop a psychological "Shortened Stress Evaluation Tool" to highlight project professionals' stress levels. In related research, Clarke *et al.,* (2020) note that construction— and the same could be said for architects— is "a highly competitive market with low-profit margins and tight time frames, all of which is in a sector that is temporary in nature." Consequently, "the mental health and well-being of those within microenterprises may therefore be compromised." All of the above studies point to the need to develop accurate well-being measures such as the PERMA measure—rather than simply asking people how they feel (Butler &Kern, 2016).

The focus on the individual mental health, professional identity and individual resilience of architects in their workplaces is undoubtedly critical. Many researchers, as indicated above, have isolated well-being and mental health concepts, not linking these to industry, firmwide or organisational resilience. Moreover, this assertion is underscored by the fact that notions of individual identity and its professional conflicts in architecture (creative vs. suit) have been extensively examined (Bos-de Vos and Volker 2017). As noted in the field of Social Work 'Well-being' is a "contested issue, for both policy and practice" and one that is primarily "self-defined" by researchers and participants (Lelkes *et al.,* 2021). Self-definition suggests that a broader consideration of firm resilience is needed. In prevailing well-being studies, self-identifying tropes of the architect may have been reinforced: the architect as creative genius; a knowledge worker who must be "kept" or "made" well; a worker as an atomistic commodity. As Fraile-Marcos (2019) asserts, individual resilience is also reliant on "the social and physical" context enveloping an individual "far more" than individual "traits, cognition or talents."

**Definitions of Resilience**

Many of the normative definitions of resilience have been focused on the engineering capacity to absorb shocks or perturbations and yet still maintain function (Folke, 2016). However, the concept has also evolved since its emergence in ecology studies of the 1970s. As a result, integrated definitions rather than functionalist definitions have prevailed as resilience has been seen to be a socio-ecological construct (Fraile-Marcos, 2019). In contrast to engineering, ecological resilience has been defined as the "ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist." Zampieri (2021). Not surprisingly, this definition aligns with the Intergovernmental Panel on Climate Change (IPCC) definition: "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organisation, and the capacity to adapt to stress and change." Zampieri (2021).

In multi-lateral organisations, ideas of multifarious resilience have also taken on an integrated tone. For example, in research centred on the Sustainable Development Goals, Assarkhaniki *et al.,* (2020) note the many different types of resilience emerging in the SDG literature. In a literature review from 1970 onwards, they identify five dimensions of resilience: "social, economic, institutional, infrastructural, and environmental." As the World Health Organisation (WHO) states, for resilience to be "meaningful in operational terms", three things need to happen: Firstly, "the causes of the vulnerabilities that the strengthening of resilience should tackle." Secondly, the context or level of application of the measures needs to be identified." Thirdly, identifying the positive impact of any measures and processes advocated for resilience. Moreover, WHO argues that overall resilience must have "absorptive, anticipatory and adaptive capacities" (Ziglio, 2020).

Similarly, essential definitions of resilience have also emerged in Disaster and Emergency Studies. For example, after the Canterbury earthquake, the Resilient Organisations Research Group concluded that essential factors in building resilience are: care for staff, effective leadership, employee engagement, wide-ranging stakeholder communication, and "open communication" along supply chains. In two studies after the Christchurch earthquakes, Wilkinson *et al.,* (2016) and Sapeciay *et al.,* (2017) Argued that to help in post-disaster environments, contractors themselves

need to be resilient. They note the difficulty of this given that 'smaller companies struggle to achieve a reasonable level of resilience"—likewise for architectural firms.

There have also been many calls to consider the resilience construct in Construction Management studies as an integrated concept by extending it into design, project and organisational contexts (Anderies, 2014). Banahene *et al.,* (2014) set out the difficulty of maintaining resilience in temporal organisations, finding that the "dispersed, temporary and unique nature of projects: impairs the "communication and knowledge sharing" required for resilience in project organisations. Blay (2017) Examines resilience in both projects and temporary organisations, finding that diversity is critical to organisational resilience, concluding that inclusiveness, "the process of valuing, respecting and supporting members of an entity," is important in maintaining resilience in temporary organisations. Blay *et al.,* (2019) goes on to extend her work and concludes, " resilience in organisations should be seen as both the capability to prepare and respond to disruptions and the capability to respond to, prepare for and reduce the impact of disruption caused by the drifting environment and project complexity."

Despite the above impetus to bring notions of resilience into construction studies, as Kurth *et al.,* (2019) argue, operationalising the concept of resilience across construction is problematic. Firstly, they note the inability of risk management factors to be correlated with resilience measures and the "limitations for mainstreaming resilience into building industry processes and actors." This claim is because the full range of "Climate extremes, emerging human-caused hazards, system vulnerabilities and interdependencies can erode the capability to profile risks and apply risk management techniques." They go on to warn that the barrier to integrating resilience concept in construction is resilience analysis is "immature in terms of predicting or estimating what enhancements will yield greater resilience." To offset this, they suggest that the resilience curve and National Academy of Science (NAS) defined stages are useful analytical tools. The stages of resilience in this model are Plan, Prepare, Absorb, Recovery and Adapt (Kurth *et al.,* 2019; Ayyub 2014).

The above definitions indicate that conceptions of resilience for architects need to shift away from the proxy conceptions of retained—or "snapback"—functionality or a delimited psychosocial focus on individual well-being or professional identity.

## RESEARCH METHOD

The Pulse Check (PC) Surveys were membership surveys intended to gather information from ACA members as the pandemic progressed to inform ACA decision-making (ACA, 2020). Before the pandemic, few extensive surveys or analyses of immediate business conditions for Australian architects had been undertaken. The ACA's strategic aim was to position itself as an influential advocacy group by understanding its membership. The survey design was primarily formulated by the executive committees and members of the ACA. This participatory context led to each survey containing different questions as external events unfolded. No two surveys were precisely the same. However, in this study, survey responses were downloaded for each survey. Aggregate statistics related to project cancellations, work pipelines, casual workers and redundancies were collated for each jurisdiction. This aggregation was done in Excel. These results were then ordered chronologically and compared to the corresponding staff well-being indicators (also collated in Excel) as set out in Tables 1 and 2 below. The resultant comparative analysis of the descriptive statistics is discussed below. Through a process of inductive interpretation

of concepts of firm resilience are also discussed below; from this discussion, a general model of firm resilience is developed. Further research would be needed to conduct correlation and regression studies on the data presented below.

## The Pulse Check Surveys

*Survey Responses and Questions*

Table 1 summarises surveys and responses. The surveys covered a range of issues: office culture, changing working arrangements, roles, reduced hours, reduced pay, remote working, carer duties, seconding staff, well-being and stand-downs vs. forced redundancies. Broad financial indicators were also canvassed in the surveys, such as questions concerning work pipelines, revenue declines and the impact of cancellations in different sectors. It can be seen that the first survey gained the most respondents. By the time of PC4, the number of respondents decreased to be about 38% of PC1.

*Table 1: Survey Summary*

| Survey and Date | Responses | % of Small firms (1-5). | % Casual to FTE | Projects cancelled or delayed | Standowns (%): Forced redundancies (%) | No. Rating mental well-being in as Very Good? |
|---|---|---|---|---|---|---|
| PC1:15-17 March | 1,341 | 51% | 16% | 17% | Not asked | Not asked |
| PC2: 29-31 March | 777 | 59% | 15% | 66% | 12:12 | 15% |
| PC3: May 31 -3 June | 453 | 60% | 13.2% | 79% | 118: 166 (no.) | 34% |
| VPC: Aug 20-27 | 196 | 67% | 13.2% | 75% | 15:12 | 7% (43%) |
| PC4: 12-19 October | 511 | 52% | 12.3% | Not asked | 19:12 | 16% |

## Survey Results

*Pulse Check 1 (PC1). Taken 15-17 March 2020*

The 1341 responding firms in survey 1 encompassed 15873 staff and 2542 Casual staff. At this point in 17% of firms had had projects cancelled, and 41% of firms anticipate this would happen. Respondents thought managing both stand-downs (24%), and Redundancies (25%) would be “Very Challenging”. At this time, any offices were shifting to remote working at home, and the most critical challenge appears to be "software and networking file-sharing issues. With 18% of respondents saying this might result in substantial difficulties. However, 23% felt that remote workers' carer duties (working at home) would also be “Very Challenging.” Only 8% felt that there would be a “Very Challenging” impact on office culture.

*Pulse Check 2 (PC2). Taken 29-31March 2020*

As the pandemic circumstances unfolded, the second survey came quickly after the first. The 770 responding firms in survey 2 encompassed 7040 staff and 1072 Casual staff. At this time, 33% of firms stated they were changing work arrangements. 65% of firms noted that with the shift to remote working, productivity was down by 30% or more, but 47% expected this to improve quickly.

Pulse Check (PC3). Taken May 31 to June 3 2020

This Pulse Check also reported on the Federal JobKeeper wage subsidy program. Of the 271 respondents, 94% of firms had applied for it, 89% had been approved to receive it, and 10% were still awaiting approval. Overwhelmingly respondents stated JobKeeper had both prevented redundancies (79%) and stand-downs (74%). In response to how mental well-being in the firm had been since the beginning of the

pandemic: 49% of firms said it was the “About the Same”, while 24% said it was “Worse” (20%) Or “Much Worse” (4%).

*Victorian Pulse Check (VPC). Taken August 20-27, 2020*
Victoria's extended second wave lockdown prompted the VPC survey. In this survey, there were also questions regarding well-being. Notably, this survey also sought information about which sectors of cancelled or on-hold projects had impacted architects. The majority of cancelled or on-hold projects was in the residential sector (66%). More worrying was the response that 26% of office's had only up to 2 month's work.

*Pulse Check October 4 (PC4). Taken 12 -19 2020 (refer to Table 2)*
By this time, 43% of architects stated some projects had restarted, and 17% felt it would restart but not yet. 36% of office’s had put to 2 Months of work whereas 25% had three months of work and 39% had six months or more of work. The ACA used the results of PC4 to call for substantial fiscal stimulus from the state and federal governments in the construction sector.

## DISCUSSION

To what degree Australian firms were resilient in the first place is an open question. The above results suggest that Australian architects absorbed and partly recovered from the 2020 lockdowns. PC1, PC2, PC3 and VPC can be seen to undertake in the absorption phase. PC4 suggests the beginning of a recovery phase. Arguably, the decline responses from PC1 to PC4 might increase the surveys' increasing disinterest as business conditions picked up. On the one hand, the surveys appear to indicate an agile profession easily absorbing the pandemic shock and quickly adjusting to remote working, sensitive to carer duties during lockdowns, and able to change and adjust labour arrangements quickly. Throughout the surveys, except VPC, it was reported by employer firms that mental health and well-being were either "Good" or "Very Good"; although respondents, as managers, may have had optimism bias with no actual knowledge of their worker's well-being.

While the above results suggest a resilient profession, a profession with the agility to quickly cope with exogenous shocks, there are also contrary notes. This apparent agility may only reflect flexible labour arrangements and architects’ ability to weather boom-bust cycles in neoliberal service markets. The Federal government's wage subsidy JobKeeper program was the primary source of resilience for many architectural firms. Arguably, many more architectural employers and employees would have had drastic changes in their employment and conditions without this support. The work pipeline questions point to the architectural practice's precarious nature, with many firms having less than three months of work. For employees, there were reduced pay, reduced hours, stand-downs and redundancies. As direct measures of resilience, the surveys are limited because the elements of firm resilience read through the surveys are imprecise. In part, this is due to the limited resources of the ACA despite their best efforts. Measures of financial resilience in all the surveys did not account for initial financial reserves in smaller firms. In Australia, this data is not collected at all by membership bodies. It was also difficult to know more precisely how many staff had been stood down from one survey to the next. Or the percentage of people working remotely in each firm, working remotely whilst caring for others and to what degree reduced wages and hours were in play. In addition, anecdotal evidence also suggests that many architects feel they have survey fatigue. Indeed, the ACA's employer architects seemed to "selectively" answer some questions and not

others. For example, in PC4, only 297 out of 511 skipped the decline in revenue questions, and 360 skipped questions regarding changing working arrangements. Arguably, the higher the uncertainty in the external environment at the start of the pandemic, the more likely architects would respond.

*Table 2: ACA Pulse Check No. 4 Comparison by States*

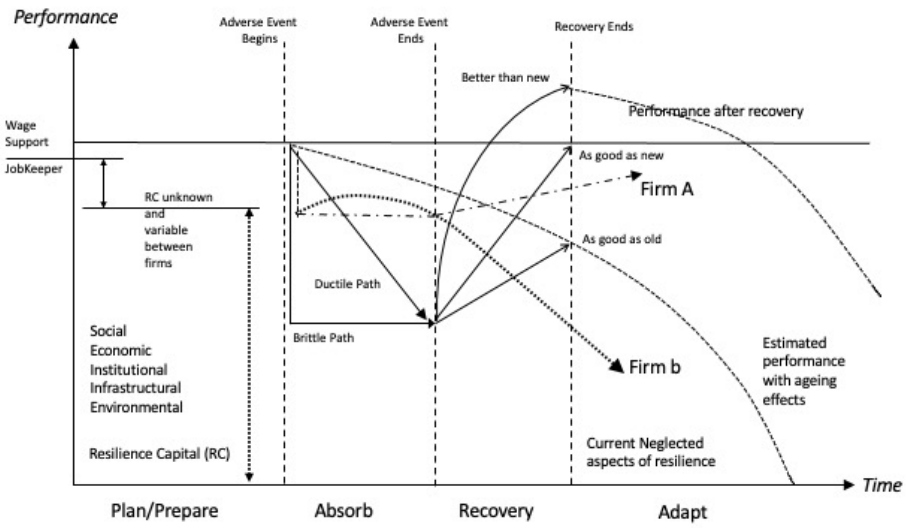
| | SA | NSW | QLD | Vic |
|---|---|---|---|---|
| Cancellations or on Hold | | | | |
| Yes | 71% | 70% | 77% | 77% |
| No | 23% | 21% | 17% | 15% |
| Pipeline of Work (Average all firms) | | | | |
| Work needed now | 12% | 23% | 0.0% | 4% |
| 1-2 Months | 7% | 13% | 20% | 24% |
| 3 Months | 28% | 19% | 20% | 35% |
| Decline In Revenue | | | | |
| Yes | 46% | 67% | 70% | 80% |
| No | 42% | 27% | 28% | 18% |
| Well-being: Current: Very Worrying (1), Neutral (3) Very good is (5). Compared: Much Worse (1), Same (3), Much Better (5) | | | | |
| Current Mental Well Being | 3.95 | 3.79 | 4.02 | 3.44 |
| Well Being Now Compared to Start | 3.37 | 3.17 | 3.23 | 2.59 |
| Job Keeper Prevented Redundancies | | | | |
| Yes | 41.7% | 48.1% | 42.7% | 50.0% |
| No | 10.4% | 10.1% | 5.3% | 14.6% |

In Fig 1, Resilience Capital (RC) is that capital available to firms to enable their performance over time as a result of disruptive events. Reserves of RC allow a firm to absorb and adapt after an external shock. This diagram has been adapted to indicate how the ACA member surveys' information might be interpreted and future surveys improved (Kurth *et al.,* 2019, Ayyub 2014). The RC framework is divided into four stages: Plan/Prepare, Absorb, Recovery and Adapt. Some firms will enter the absorb stage with more RC than others. This RC is built on an integrated mix of the firm's culture, finances, infrastructure, institutional support (e.g., industry and govt policy) And spatial and environmental factors in workplace settings.

The surveys were taken in the Absorption stage; many firms reported a sudden drop in projects between PC1 and PC2, suggesting a more brittle path than a ductile one. The financial support of JobKeeper helped all firms with different degrees of RC at the outset of the disruption. But arguably, how firms employed this support determines how well they do in the recovery phase. For example, in Fig 1, two model firms are contrasted. Firm A uses the wage support and other measures to maintain reduced operations in a competitive environment.

In contrast, Firm B uses wage support to extend operations, for example, using the support to price its fees to win work aggressively. In the Absorb stage, both firms look very much alike; firm B, because of increased activity and the quick expenditure of the wage support, may appear to have more outstanding performance. However, Firm B's strategy fails in the Recovery stage because it has expended too many of its resources on unsustainable and low fee bids in the previous stage. Appearing to do well in the Absorb stage may not be a predictor of success in the following stages. The model thus points to why it is essential for firms to accurately consider RC in the Plan/Prepare stage, especially given the cyclical nature of the construction sector. The model also suggests what might happen if the Absorb and Recovery cycles were repeated due to sequential pandemic waves.

*Fig 1: Diagram of Resilience Capital (adapted from Kurth et al., 2019, Ayyub 2014).*




The above results suggest the need for architects to better index and measure RC in future surveys. Assarkhaniki *et al.,* (2020) Suggested that an integrated and strategic resilience model needs to address social, economic, institutional, infrastructural, and environmental contexts. However, they also suggest that this should account for the broader context of firms and their circumstances. In other words, RC should be measured to account for different scalar contexts. To this end, RC in the Plan/Prepare stage should account for both internal micro and external macro factors. Hence, firm resilience relies on a range of multi-scaled elements. These elements need to encompass "the interconnection and interdependence of social and ecological systems, their interplay between conservation and transformation, and the capacity of a given system for self-organisation" (Fraile-Marcos, 2019). As Casco-Solís, S. (2019) states, resilience must be seen as a "social process" that binds together individual actors and entities and broader social-ecological systems. The RC model developed here suggests further research is needed to determine how integrated Psycho-Social-Ecological conceptions of resilience can shape and be enacted in professional service firms. (Stroink, 2020).

## CONCLUSIONS

The above discussion contributes to our knowledge regarding architects by establishing how Resilience Capital might begin to be conceptualised as a dynamic

concept for their firms (Fig 1). As suggested by the preliminary framework, the concept of Resilience Capital should be defined, measured and developed across micro and macro different scales. All too often, people and organisations imagine they can quickly return to their "pre-earthquake" or "pre-pandemic" state. For architects working in a knowledge sector, there is a need to develop industry-wide resilience data and actions across social, economic, institutional, infrastructural environmental contexts. For architects, measuring, building and modelling Resilience Capital will prepare the profession for the exogenous and environmental shocks that will surely come in the future.

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# A FRAMEWORK TO MODEL THE SPREAD OF INFECTIOUS DISEASES ON CONSTRUCTION SITES USING HYBRID AGENT-BASED MODELLING AND MONTE CARLO SIMULATION

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The construction industry has been severely affected by COVID-19 restrictions resulting in several challenges in form of supply chain disruptions, performance loss, and limited workforce interactions. The construction industry initially needs to understand and quantify the impacts of COVID-19 on each aspect of the industry. Simulation techniques are powerful tools for this purpose, which enable modellers to run construction projects virtually and assess their performance under different circumstances, scenarios or settings. In this paper, a hybrid simulation framework is developed using agent-based modelling (ABM) and Monte Carlo simulation techniques (MCS) to evaluate the impact of the spread of COVID-19 on the performance of construction projects. The proposed simulation framework enables the construction modellers to capture the interactions between construction workers effectively and to determine the impact of restrictions on the overall project performance. It also helps practitioners in the post-COVID-19 era by testing multiple virus spread scenarios on construction sites and minimize the adverse impacts of restrictions on the project performance.

Keywords: agent-based modelling; automation; productivity; risk; simulation

## INTRODUCTION

The outbreak of COVID-19 pandemic forced many countries to place restrictions and take various risk mitigation measures including mobility restrictions, socio-economic restrictions, physical distancing, hygiene measures, communication and international support mechanism (Bruinen de Bruin *et al.,* 2020). It is evident that recovery from disruptive impacts of COVID-19 requires both strategic and detailed planning to address various aspects of COVID-19 impacts on businesses and people. World Bank (2020) emphasised that the labour productivity could be reduced for years following COVID-19 pandemic unless urgent policy actions are taken. The construction industry is one of the major industries that was significantly affected by the pandemic because majority of construction activities are physical and require human resources. Since the construction industry has significant contribution to the global economy, its success in addressing the consequences of the pandemic is crucial for faster economic

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recovery. Therefore, a comprehensive playbook to recover from COVID-19 adverse impacts and address each affected aspect of the industry is needed. The response of the construction industry to the COVID-19 pandemic is likely related to many factors including the features of the social system, government and policy frameworks, and the state of the economy that the industry operates in (Lingard *et al.,* 2021). Considering variation of these influencing factors, decision-making is challenging due to the inherent uncertainties and dynamics of construction projects. Simulation techniques are powerful tools for this purpose, which enable modellers to run construction projects virtually and assess their performance under different circumstances and settings.

This paper focuses on the impacts of the spread of COVID-19 on construction workers on jobsites. As the human interaction is a primary reason for the virus spread, this study aims to model workers' behaviour on construction sites using agent-based modelling (ABM). In addition, Monte Carlo simulation (MCS) is used to stochastically assess the influence of different strategies on controlling the spread of COVID-19 infections on the sites and minimizing its adverse impacts on the project staff performance.

In the next sections of this paper, first, research background on the COVID-19 impacts on construction and the different approaches for modelling and predicting various impacts of COVID-19 are discussed. After that, the research methodology and a framework for modelling human interactions on construction sites are explained. Then, the applicability of the developed framework is demonstrated in a hypothetical case study. Finally, the conclusions, limitations and directions for future research are discussed.

## RESEARCH BACKGROUND

Developing an effective industry playbook to mitigate the COVID-19 risks requires a clear understanding about the impacts imposed to the industry and accurate predictive models for assessing the potential recovery plans from those impacts. Kamal (2020) recognized two types of COVID-19 disruptions:

1) Transformational disruptions, which were a planned disruption for adopting digital technologies in response to the imposed restrictions.

2) Hostile disruptions (e.g., economic disruptions), which were unexpected from external sources. Some industries could manage this type of disruptions by the bailout packages offered in some countries.

For the construction industry, COVID-19 imposed some threats such as disruptions in material supply chain and lower productivity due to absenteeism, which could lead to potential claims from contractors to compensate the cost and schedule impacts of these disruptions. At the same time, COVID-19 provided the construction industry with some opportunities. Jones *et al.,* (2020) identified some problems as well as the potential positive impacts of COVID-19 on the construction sector including:

- Changes to the site layouts and working practices.
- Increased worker productivity and effectiveness by deploying workers in smaller groups than usual.
- Improved housekeeping and tidiness, which can lead to better productivity, material planning and motivation, and less risks of incidents.

- Increased advance planning, which demands more time from management but can improve productivity by providing more detailed planning for some tasks, and more detail liaison between trades.
- Social distancing, which could cause issues for communication between workers on the site while it could improve productivity by reducing chatting time.
- Distraction and less focus on ordinary health and safety.
- Improved safety by having fewer people on site and tidier sites.
- Increased working from home and remote meeting, which could increase productivity for some staff (e.g., management and admin staff), and decrease productivity for some staff due to reduced wellbeing and working in isolation.

Alsharef *et al.,* (2021) studied early impacts of COVID-19 on the construction industry in the United States and reported significant delays on projects, inability to secure materials on time, reduction in productivity rates, and material price escalations as the main adverse impacts. They also identified the new opportunities for the construction industry including new projects for building medical facilities and residential buildings, transportation-related work, and opportunities to recruit skilled workers.

Overall, COVID-19 imposed some threats and provided some opportunities for the construction industry. Mitigating the threats and taking advantages of the opportunities are essential to keep business continuity for the construction industry, which needs substantial efforts and planning at both high level (strategic level) and low level (project level).

**Modelling Approaches for Predicting the Impacts of Covid-19**

A number of studies attempted to model and predict different aspects of COVID-19 impacts. Some researchers (e.g., Tuan *et al.,* (2020) and Samui *et al.,* (2020)) used mathematical methods for COVID-19 transmission modelling. Amaral *et al.,* (2021) used a Susceptible-Infectious-Recovered-Deceased model to predict infections, recoveries, deaths, and viral reproduction numbers. Truong and Truong (2021) used a statistical method, i.e., time series, to forecast the travel behaviour of United States citizens by distance at the national level and found the patterns of daily trips and the COVID-19 spread.

Simulation is a suitable method for modelling, forecasting, and making decisions under uncertain circumstances. Depending on the nature of the problems, different simulation techniques such as MCS, ABM, Discrete Event Simulation (DES), System Dynamics (SD) and hybrid simulation can be adopted for modelling. There are successful applications of simulation techniques for modelling the impacts of COVID-19 on human societies, including: to predict hospital capacity needs during pandemic, Weissman *et al.,* (2020) used MCS for developing a susceptible, infected, removed (SIR) model, and providing insights into the dynamics of the infection spread. MCS was also used to compare two testing strategies for different infection prevalence and pooled group sizes (Deckert *et al.,* 2020). A study by Ghaffarzadegan and Rahmandad (2020) used SD to estimate the magnitude of outbreak and early spread of COVID-19 based on the Susceptible, Exposed, Infectious, and Recovered (SEIR) framework.

ABM has been widely used for modelling COVID-19 outbreak and decision-making. Covasim (Kerr *et al.,* 2020) is an open-source stochastic agent-based simulator that

was developed specifically for COVID-19 analyses and used by several researchers for modelling purposes. For instance, Li and Giabbanelli (2021) used Covasim for modelling two vaccination plans in the United States and experimented different non-pharmaceutical intervention scenarios to evaluate effectiveness of the plans. Cuevas (2020) developed an agent-based model to evaluate the COVID-19 transmission risks in facilities and simulated the spatiotemporal transmission process by modelling individuals as agents and their decisions based on their social characteristics and health conditions, spatial patterns and infection conditions. The model was used to experiment strategies for reducing the transmission risks of COVID-19 within the facilities.

Silva *et al.,* (2020) used ABM for simulating people, business and government, and experimented different scenarios of social distancing interventions to evaluate their health and economic effects. Similarly, Kano *et al.,* (2021) developed an agent-base model to simulate COVID-19 outbreak and find its interrelation between virus spread and economic losses. In another study, Mukherjee *et al.,* (2021) investigated reopening strategies for educational institutions during COVID-19 using ABM.

For the construction industry, Araya (2021) adopted the ABM technique for modelling COVID-19 spread on construction workers and found that construction workforce may be reduced by 30% to 90% due to COVID-19 infections. In the developed model, workers were modelled as agents, and possibility of the virus spread in a construction project was modelled by classifying construction activities into low, medium, and high risks for the virus spread.

## The Proposed ABM-MCS Framework to Model Covid-19 Impacts

The proposed framework utilizes hybrid ABM-MCS to model the impacts of COVID-19 on construction industry. The ABM component is used: (1) to model the performance of the construction labourers and to determine the project performance as the aggregated performance of the team; and (2) to model the spread of COVID-19 on the project site based on the specifications of jobsite, agents, and the disease. The spread of COVID-19 is extremely random, since it is be initiated by a random set of agents who enter to the construction site with infections every day and the virus is spread due to the proximity of agents that occurs by the random movements of the agents on the jobsite. Accordingly, the results for each simulation run can be significantly affected by the initial set of random numbers selected and the random seeds (Hadzibeganovic *et al.,* 2015). To address this challenge, the proposed framework integrates the MCS technique with the ABM component and runs the simulation model for several times (e.g., 100 or 1000 runs) and determines the simulation results as a stochastic variable rather than a deterministic one. For more flexibility and easier accessibility of the final research products, the proposed framework is developed in Python® programming language using Mesa library for ABM and upon the finalization of the framework, the open-source code for the framework will be released on GitHub®. Fig 1 presents the flowchart of the proposed framework and the flow of information between its different components.

*ABM component's settings*

The settings of the ABM component are specified by the modeller as follows. First, the specifications of the jobsite are entered, consisting of the dimensions of the jobsite assuming it is in a rectangle shape; and the location of material/equipment warehouse. Secondly, the characteristics of agents are specified by entering the size of project team (i.e., number of agents), the infection rate (i.e., the percentage of the agents who

are infected at the start of each day), and the length of each simulation time-step. Thirdly, the details of the infectious disease are specified by determining the minimum distance required for the transmission of the virus (i.e., two meters for COVID-19 in this research).

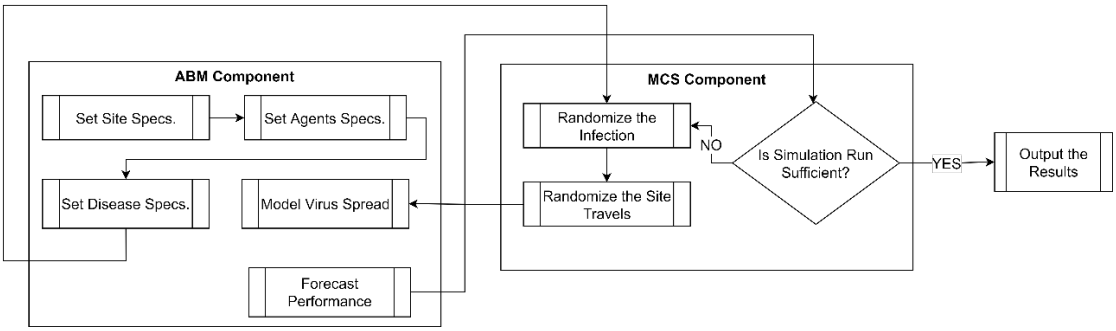


*Fig 1. The Proposed ABM-MCS Framework*

*ABM Simulation process*

The process of simulation starts with a drawing of the jobsite in a rectangle shape with the pre-specified dimensions locating the material/tool warehouse. Then, the jobsite drawing is further detailed by gridlines, where each grid is a square of two-by-two meters (i.e., the spacing of the gridlines is equal to the minimum distance required for the transmission of the virus). Next, a pre-specified number of agents are generated and randomly located at the project site, whilst it is assumed that an unlimited number of agents can be located at each grid simultaneously. Then, the ABM component simulates the behaviour of the agents within the project site in discrete time steps. For this purpose, each agent is randomly assigned to one of the three following states, which were extracted from the previous research by Tsehayae and Fayek (2016): (1) tool time/direct work with 60% probability, where the agent stays stationary at the same location for the length of the time-step; (2) tools/material handling with 15% probability, where the agent moves to the tools/material warehouse to pick-up or drop some tools and material; and (3) random walk with 25% probability, where the agent randomly walks within the project site. For the random walk state, each agent can only move to one of the six grids that surrounds its current position, meaning it can move up to three meters at each time-step. Then, the ABM component simulates the infectious behaviour of the virus by transmitting the infection from the infected agents to all the healthy agents within two meters of distance. Finally, the ABM model determines the number of infected agents at the end of each time step.

The infected agents are assumed to have a pre-symptomatic period of three days (Slifka and Gao, 2020) prior to developing any symptoms and hospitalization. During this period, agents are present at the jobsite and can transmit their disease to the other agents. In the proposed framework, once the infected agents develop symptoms, they are hospitalized (i.e., are not present on the jobsite anymore) for 10 days (Slifka and Gao, 2020) and then, will return to work once the hospitalization period is completed. In this framework, no mortality rate is considered for the virus, since in the context of construction projects, the construction labours are often healthy young individuals who have the lowest mortality rate for COVID-19.

*ABM simulation outputs*

The ABM component outputs a heatmap for the jobsite at the end of each timestep or at the end of simulation run, showing the number of agents located on each grid on the site. Fig 2(a) presents an example for the heatmaps generated by the ABM component

for one timestep and Fig 2(b) shows the heatmap generated for the whole simulation run of 10 timesteps. It should be noted that the yellow rectangle in Fig 2(b) with more than 70 occupants throughout the simulation run represents the tools/material warehouse location on the jobsite.

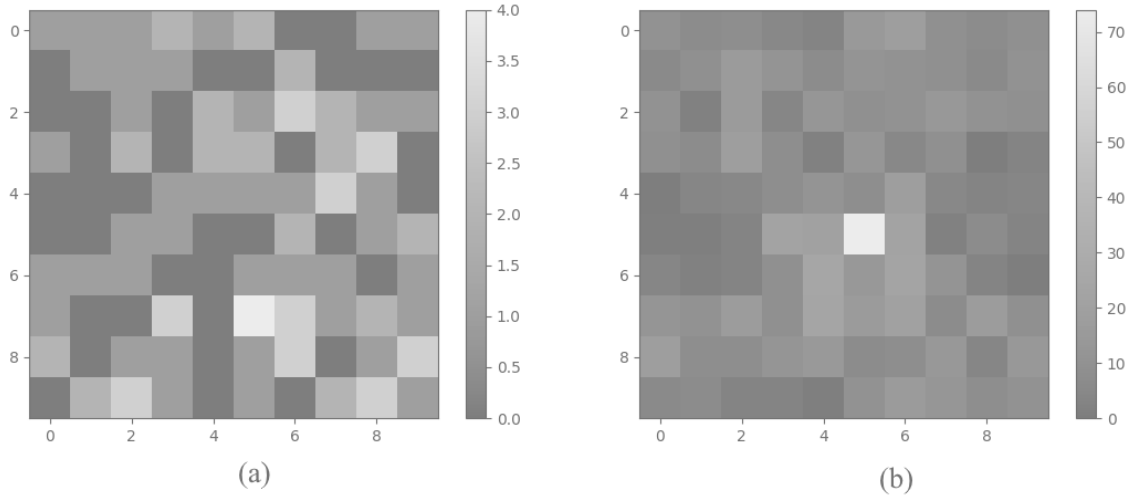


*Fig 2. Heatmap output of the ABM component*

In addition to the heatmap, the ABM component provides the following outputs: the total number of agents who are present on the jobsite; the state of each agent at each time step (i.e., direct work, material/tool handling, or random walk); the number of agents who are infected at each time step; and the number of agents who are hospitalized at each time step.

*The MCS component*

The MCS component of the proposed framework generates random numbers at each time step for the three following functions: (1) to randomly select a number of agents who are infected outside of the project site at the start of each workday; (2) to randomly select the state of each agent on the project site at the start of the workday; and (3) to determine the destination of those agents, who are in random walk state. Then, the MCS component runs the simulation for a pre-specified number of times and collects the selected outputs from the ABM component at the end of each simulation run. Finally, the MCS component develops the histograms of the results, implements the statistical analysis on the results and reports the mean value, standard deviation, the three percentiles (i.e., 25%, 50%, 75%), and the minimum and maximum value of the ABM outputs.

*Construction Case Study*

To assess the applicability of the proposed framework for simulating the spread of COVID-19 on construction project sites, the proposed framework is applied to a hypothetical construction case study, as its details are presented in Table 1.

To determine the impact of the spread of COVID-19 on the performance of the hypothetical project, the output of the ABM component is selected to be the number of agents who are directly working on the project tasks (i.e., tool time) at each time step. Moreover, the simulation model has been running by hourly time-steps for the total duration of 1040 time-steps, which denotes six months of project time with 5 days/week and 8 hours of work/day calculated as follows: $26(\text{weeks}) \times 5(\text{days}) \times 8(\text{hours}) = 1{,}040$ hours. The MCS component then, runs the project for 100 times

does the statistical analysis on the ABM component's outputs and the results are presented stochastically as presented in Fig 3.

*Table 1. Construction case study specifications*

| Project Site Specification | | Agents Specifications | | Disease Specifications | |
|---|---|---|---|---|---|
| Description | Value | Description | Value | Description | Value |
| Size of project site in meters (m × m) | 30 × 30 | Number of agents | 50 | Contagiousness radius (m) | 2 |
| Material/equipment warehouse location | 20 × 20 | Infection rate | 0, 5, 7, and 10% | | |
| | | Time steps | Hourly | | |

Referring to Table 1, there are four different scenarios for this case study to determine how the spread of the virus changes by changing the infection rate between 0% (i.e., no infection) 5%, 7%, and 10%. As the results indicate, the performance of the project drops significantly by the spread of the virus on the project site, where the mean value direct-working agents drops from 29.98 for the "No Infection" scenario to 11.76 for "5% Infection" scenario. According to the results presented in Fig 3, the performance of project does not significantly change by changing the infection rate, from 11.76 for "5% Infection" to 11.51 for "7% Infection" to 11.20 for "10% infection" scenarios.

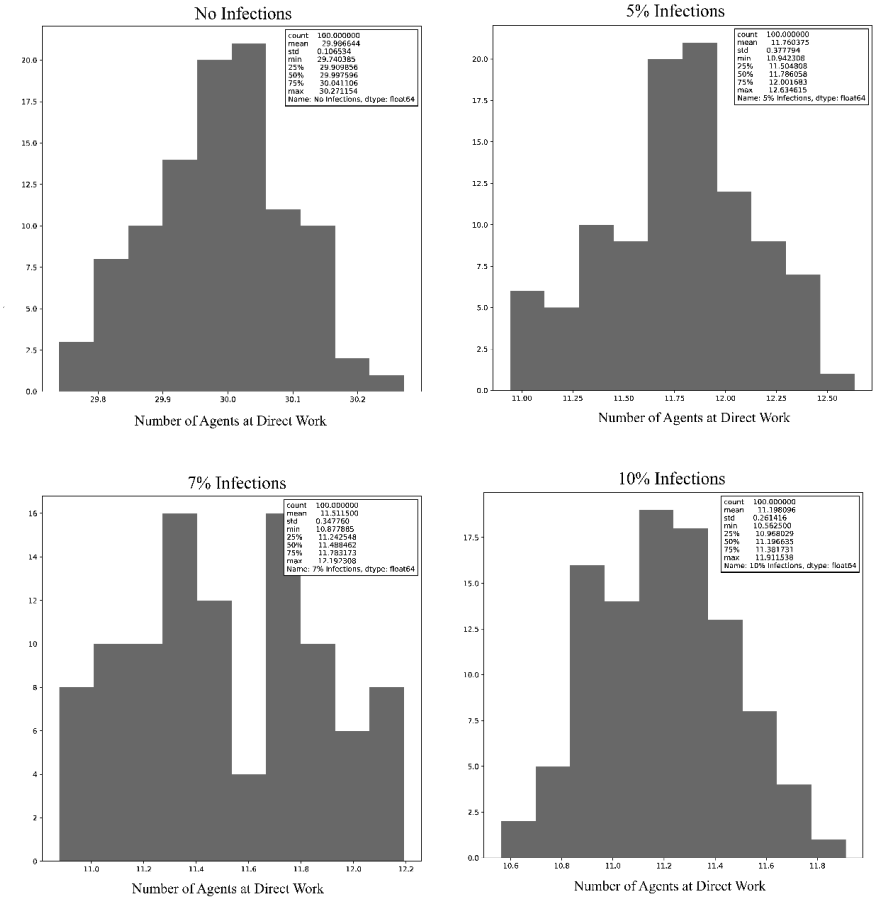


*Fig 3: Histograms of the project performance for four different scenarios*

This phenomenon indicates that the dominant cause of infection on the project site is the transmission of disease between the workers rather than being infected outside the jobsite.

## CONCLUSIONS

In this paper, a novel ABM-MCS framework is developed for simulating the spread of COVID-19 disease in construction sites and forecast the impacts of this disease on the performance of construction projects. The framework consists of two main components: (1) the ABM component that simulates the behaviour of individual agents on the project site and the transmission of the disease between the different agents; and (2) the MCS component that implements the statistical analysis and captures the random behaviour of the agents and disease transmission.

The results of simulation presented in the case study reveals that the transmission of the disease on the jobsite is the dominant cause of infection; and the changes in the infection rate from outside the jobsite does not significantly affect the spread of the virus unless the transmission on the site is controlled by some means.

Moreover, the simulation results show that the introduction of a few infected agents to the jobsite can significantly decrease the project performance, up to 61% drop in the project performance by the entrance of only 2 infected agents (among 48 healthy agents) to the jobsite daily. Accordingly, the monitoring programs on the jobsites can significantly alleviate the negative impacts of COVID-19 on construction projects. This research was conducted based on some assumptions due to the limitation of the available data regarding virus spreads on construction sites. In future research, this limitation will be addressed by collecting more data from construction sites. In addition, this framework can be extended to simulate the impact of COVID-19 on workers' behaviours such as stress and other mental impacts, and simulate the use of personal protective equipment, COVID-19 monitoring protocols and hospitalization to determine an optimum strategy for executing construction projects in the post-COVID-19 era. Moreover, a generic ABM-MCS framework developed in the Python® programming language will be released to determine the impact of infectious diseases on construction industry and to improve the resiliency of construction projects.

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# Disaster Management and Resilience

# WHAT IS REQUIRED FOR RECOVERING FROM DISASTER: THEORETICAL AND EMPIRICAL VERIFICATION

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The Great East Japan Earthquake, which occurred on March 11, 2011, had a magnitude of 9.0. The massive tsunami that followed caused extensive damage in coastal districts, resulting in 19,747 deaths and 2,556 missing persons. In terms of reconstruction, there are three main areas of focus: 1) support for the disaster victims (the number of evacuees has been reduced from 470,000 to 43,000 by responding in detail to issues that arise as reconstruction progresses), 2) reconstruction of homes and towns (housing reconstruction is progressing steadily, with most of the construction work completed; the relocation of housing areas to higher ground and the construction of public disaster housing is expected to be completed in FY2020), and 3) revitalisation of industries and livelihoods (production facilities have been mostly restored, production levels in the three affected prefectures have largely recovered, and support for tourism promotion is underway but is currently difficult due to COVID-19). This study examines the necessary and sufficient conditions for proceeding with this recovery, restoration, and revitalisation from an economic theoretical perspective and from public procurement data empirically, exploring their applicability in the post-COVID-19 world. Demand control measures are the first necessary condition to recover from significant damage, including that to infrastructure. Besides, supplier support measures are a sufficient condition to provide more effective and efficient construction services. As a tentative conclusion, an analysis of Japan's public procurement data shows that short-term demand-boosting measures have worked well. However, medium- and long-term supply stimulus measures need further efforts. In Japan, these practices are being applied in response to COVID-19. Specifically, it emphasizes productivity improvement through partnering and the use of new technologies.

Keywords: demand control; Great East Japan Earthquake; necessary condition

## INTRODUCTION

On March 11, 2011, the Great East Japan Earthquake of magnitude 9.0 followed by a massive tsunami caused extensive damage in coastal districts. Japan has learned lessons from this experience and has been quick to undertake all possible measures in the event of a disaster, as seen in the string of floods in recent years, the heavy snowfall of winter 2021. Disaster prevention and mitigation, as well as national land

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resilience, have been firmly promoted, and various reconstruction efforts have been realised.

Some argue that a low efficiency-oriented approach is needed to deal with natural disasters (Ingirige, 2016). In addition to such preparedness, efficiently rebuilding robust infrastructure in the event of a disaster is thought to be vital, and that the concept of pre-disaster recovery, which involves planning for a disaster before it occurs, is also being discussed (Otsuyama and Maki, 2018). Alternatively, there have been various studies about post-disaster reconstruction, and it is necessary to summarise how the market, including public procurement and the response of businesses to it, has evolved from the perspective of reconstruction (a so-called necessary condition). In addition, from the perspective of economic realities and management of the incentive structure of business operators, it would be an appropriate approach for construction management research to analyse the transition of such public procurement (considered to be a so-called sufficient condition). Based on these considerations, this paper analyses the role of the market and the impact of policy measures in the recovery from the earthquake, based on data.

In Japan, the Earthquake of magnitude 9.0 occurred on March 11, 2011. The massive tsunami caused extensive damage in coastal areas and destroyed many districts, resulting in 19,747 deaths and 2,556 missing persons. In terms of reconstruction, there are three main areas of focus: support for the disaster victims, reconstruction of homes and towns and the relocation of housing areas to higher ground and the revitalisation of industries and livelihoods but is currently difficult due to COVID-**19(**Data is based on Reconstruction Agency, 2021). This paper examines the impact of the Earthquake on public procurement of general civil engineering works, based on data from eight regional organisations in Japan from FY2006 to FY2019.

It also explores the potential applications of demand control methods in a post-COVID-19 world. To recover from the enormous damage including to the infrastructure, demand control measures are considered to be the first prerequisite. In addition, supply control measures that provide more effective and efficient construction services would be a sufficient condition. At the time of the disaster, the construction of emergency temporary housing and the reconstruction of infrastructure were vigorously undertaken as short-term efforts, and in the medium to long term, seamless support was continued according to the stage of reconstruction. Japan is applying these lessons in its response to COVID-19. Specifically, in the short term, stable orders are placed, and in the medium to long term, the focus is on partnering and improving productivity using new technologies to support businesses.

**Previous Research**

There is a dearth of research in the field of construction management on the changes in the economic conditions around construction projects in natural disasters and reconstruction. An analysis of the effects of public investment using a Keynesian model that examines endogenisation of inflation and deflation situations (Hino, *et al.,* 2012), factors that contribute to the speed of relief activities by local construction companies (Takeya and Ohashi, 2013), a comparative study on debt support measures for condominiums between Japan and Taiwan (Meno and Nakabayashi, 2018), and studies on risk assessment and economic damages from insurance payments (Kim, *et al.,* 2019), which have focused on individual factors. However, there are not many studies that critically examine these issues and how the entire market around the construction industry has responded to the earthquake and changed.

In fact, various studies have been conducted on the change in peoples' sense of trust due to natural disasters such as earthquakes (Crowley and Elliott, 2012; Naoi, *et al.,* 2012; Veszteg, *et al.,* 2014; Hanaoka, *et al.,* 2018). Research analysis and recommendations for various individual issues have also been conducted on topics such as pond embankment damage and rehabilitation (Suzuki, 2013), analysis of regional consultant orders (Sakamoto and Hara, 2018), change of motivation and impact of construction managers (Hori and Watanabe, 2019), preplanning for post-disaster relocation projects (Shioji, *et al.,* 2015), and the introduction of construction managers in reconstruction projects (Hosokawa and Minami, 2019).

Among the studies of disaster agreements involving responses to large-scale disasters in rural areas, one analysed the movements of companies that concluded agreements and examined the necessary conditions for building such cooperation systems, which is useful from the perspective of total response (Morizane, *et al.,* 2015). Furthermore, some studies have examined road administration in terms of overall infrastructure management from a broader perspective. One of them underscores the importance of building a framework for continuous improvement and developing a cross-organisational system for on-site management practices. It also specifies new measures for disaster response in addition to normal operations, focusing on maintenance and productivity, amid chronic staff shortages (Mori, *et al.,* 2017). As the reach of these studies, the need for preparedness and organizational readiness to respond to disasters is considered to be examined. In contrast, these papers summarise a number of factors though they do not examine how public procurement has been managed and what effects it has had. Based on this, this paper clarifies the actual situation of post-disaster recovery efforts from the perspective of public procurement.

## METHODOLOGY

This study shows how supply and demand are affected by shocks due to the earthquake and tsunami and how they respond to these shocks through model-based reasoning and empirical verification. The study focuses on the Tohoku Regional Development Bureau as this region was severely damaged by the 2011 earthquake. Inferences are drawn based on the model by critically examining previous studies, and theoretical analysis is verified by quantitative analysis based on the publicly available data of public procurement. The results are examined, and the implications and future actions summarised.

## FINDINGS

*Public procurement and business behaviour in post-disaster reconstruction*

The earthquake was an unexpected event, and a shift in the demand and supply curve is thus expected. Due to its unprecedented nature, both demand and supply were hit hard, and their curves expected to shift significantly to the left. As a result, while the equilibrium price could go either up or down, but the equilibrium quantity was expected to decrease significantly (Fig 1 and Fig 2).

In other words, the earthquake caused considerable damage, causing the supply and demand to shrink significantly. The demand curve shifts from D1 to D2 and the supply curve from S1 to S2. The equilibrium point E1 before the earthquake shifts to the equilibrium point E2 after it. This in turn, shifts the price P1 and quantity Q1 of the initial equilibrium to the price P2 and quantity Q2 of the new equilibrium.

Depending on the status of this shift in the demand and supply curves, Fig 1 or Fig 2 is realised.

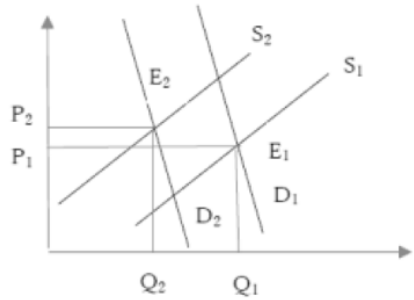


*Figure 1: Demand-supply curve shift (Large supply shocks)*

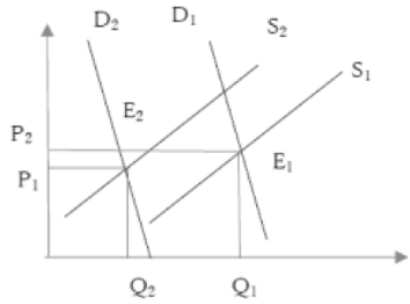


*Figure 2: Demand–supply curve shift (Large demand shocks)*

In terms of the Japanese public procurement market, there is a kind of ceiling price, set by the procurement authority as a scheduled price. What is considered to be the price can be considered as a ratio to this planned price, which is set for each project. The number of public procurements can be considered as a quantity. Also, although the earthquake occurred on March 11, 2011, the Japanese fiscal year ran from April to March of the following year. Hence, the period from FY2006 to FY2010 was considered as pre-earthquake, and the period from FY2011 to FY2019 as post-earthquake.

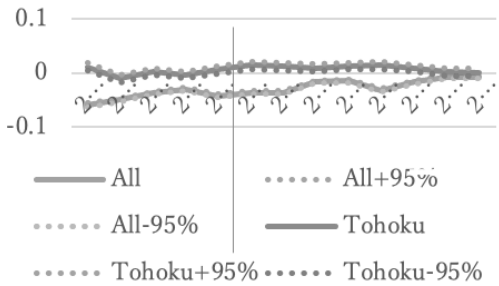


*Figure 3: Changes in the bid award rate*

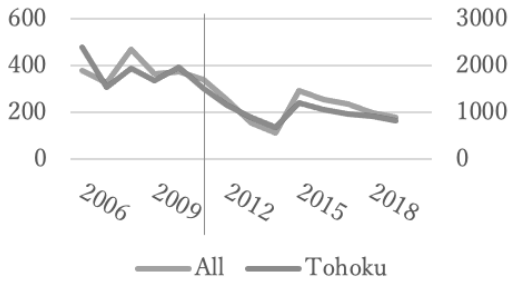


*Figure 4: Number of public procurements*

Fig 3 shows a regression in the winning bid rate with year dummies, controlling for the lower limit price (with the low-price survey standard price as a covariate), the coefficients of the year dummies and the upper and lower limits of 95% and -95%, respectively, on the same graph (based on 2019).

According to this result, the bid price in Tohoku is significantly higher from 2011 until 2015. Then, it has been decreasing, and since 2016, it has been almost the same as the base year (2019).

Fig 4 shows the change in quantity by year. These results show that the volume of public procurement in Tohoku has not increased significantly since FY 2011.

Under normal circumstances, both supply and demand could have been reduced due to a major shock, but both the price and the quantity were not significantly reduced, suggesting that there was appropriate demand management and supplier support. The reason why the prices were raised without increasing quantities is believed to be because the demand, which could have shrunk, increased investment ahead of time, thereby increasing the total amount of public procurement. This is seen in the change

in the total planned prices by year (the comparison is made using an index with FY2019 as 100). This total scheduled price is likely to be determined exogenously (by policy necessity and so on) rather than by factors determined by the market and can be considered a powerful method of demand control.

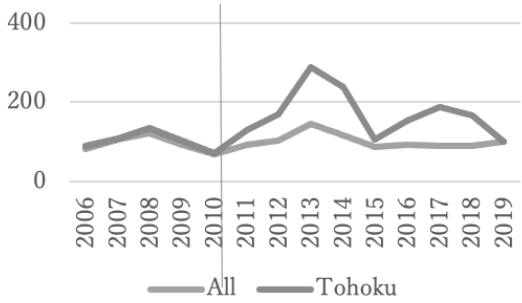


*Figure 5: Trends in the total planned public procurement prices*

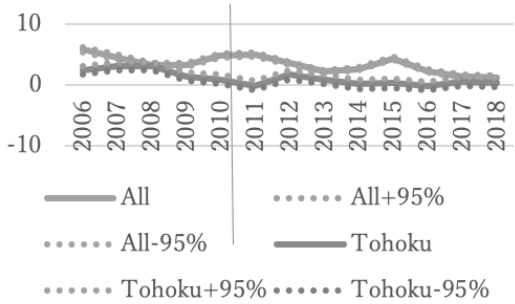


*Figure 6: Trends in the number of suppliers*

Since FY 2011, the Tohoku Regional Development Bureau has been paying more for total planned prices than the rest of Japan. In response to this, the situation regarding the supply (suppliers), which is usually considered to fall due to large damages, is as follows. Here, supply can be seen in terms of trends in the number of participants (based on 2019).

In 2011 (before the earthquake), the number of suppliers in Tohoku almost decreased, and the following year, they increased and then levelled off. In other words, when suppliers were about to be severely affected, a large increase in public procurement resulted in an increase in suppliers, which is believed to have led to a smooth recovery.

As shown below, this relationship is estimated by a simple regression Eqn. (1). In other words, the changes in the total estimated price, which is set by exogenous factors, before and after the earthquake is estimated by fixed effects for each local development bureau using the earthquake dummy.

$$PP_t = \alpha_1 + \sum \beta_{1,t} Region \times TED + \sum \beta_1 Region(fixedeffect) + +\varepsilon_1 \qquad (1)$$

where the subscript t denotes the month. PP is a variable that represents the total expected price for a given month, Region represents the regional development bureau, and TED is the Tohoku earthquake dummy (TED), which is a dummy variable that takes the value 0 for the months before the earthquake and 1 for the months after the earthquake. The coefficients to be obtained are α1, α2, α3, and α4. The coefficients to be calculated are α1, β1, r, β1, and rt; ε is the error term.

The data used here are the public procurement data from FY2006 to FY2019 for general civil engineering projects in the eight regional development bureaus of the Ministry of Land, Infrastructure, and Transport and Tourism (MLITT) (Kanto, Kinki, Kyushu, Shikoku, Chugoku, Chubu, Tohoku and Hokuriku). The results are shown in Table 1.

According to the results in Table 1, the Tohoku Regional Development Bureau, which was hit hard by the earthquake, has seen a clear increase in public procurement costs

since the disaster, showing its significant increased while other regions have been forced to reduce their public works.

| Dependent Variable: | Log(PP) | Method: Pooled Leas | | n=1,326 |
|---|---|---|---|---|
| | Coefficient | Std. Error | 95% upper | 95% lower |
| C | 22.192 | 0.052 | 22.293 | 22.091 |
| Kanto*TED | 0.181 | 0.179 | 0.532 | −0.170 |
| Kinki*TED | 0.499 | 0.179 | 0.850 | 0.149 |
| Kyushu*TED | −0.002 | 0.179 | 0.349 | −0.353 |
| Shikoku*TED | 0.232 | 0.185 | 0.594 | −0.131 |
| Chugoku*TED | −0.175 | 0.180 | 0.177 | −0.528 |
| Chubu*TED | 0.128 | 0.183 | 0.487 | −0.232 |
| Tohoku*TED | 0.820 | 0.180 | 1.173 | 0.466 |
| Hokuriku*TED | −0.214 | 0.180 | 0.138 | −0.566 |
| Fixed Effects | Yes | | | |
| R−squared | 0.124 | | | |
| Adjusted R−squared | 0.114 | | | |
| Durbin−Watson stat | 1.510 | | | |

*Table 1: Movement of total estimated prices by district since the earthquake*

| Dependent Variable: | ANoP | Method: Pooled Leas | | n=1,326 |
|---|---|---|---|---|
| | Coefficient | Std. Error | 95% upper | 95% lower |
| C | −0.288 | 1.319 | 2.298 | −2.874 |
| Log(PP) | 0.385 | 0.059 | 0.501 | 0.269 |
| Kanto*TED | 0.072 | 0.384 | 0.825 | −0.681 |
| Kinki*TED | 0.202 | 0.385 | 0.957 | −0.552 |
| Kyushu*TED | −1.307 | 0.384 | −0.555 | −2.060 |
| Shikoku*TED | −1.502 | 0.397 | −0.725 | −2.280 |
| Chugoku*TED | 0.164 | 0.385 | 0.919 | −0.591 |
| Chubu*TED | 0.107 | 0.394 | 0.879 | −0.664 |
| Tohoku*TED | −2.204 | 0.390 | −1.440 | −2.968 |
| Hokuriku*TED | −2.430 | 0.385 | −1.675 | −3.185 |
| Fixed Effects | Yes | | | |
| R−squared | 0.303 | | | |
| Adjusted R−squared | 0.294 | | | |
| Durbin−Watson stat | 1.167 | | | |

*Table 2: Movement of the average number of participants by district since the earthquake*

The following Eqn. (2) is used to estimate how this has changed the number of suppliers. To see how the average number of participants is affected, under the same formulation, changing the dependent variable to the average number of participants and including the total expected price as an exogenous variable, the equation becomes

$$ANoP_t = \alpha_2 + \beta_2 \log PP_t + \sum \beta_{2,t} Region \times TED + \sum \beta_{2f} Region\,(fixedeffect) + \varepsilon_2. \quad (2)$$

Here, the same subscripts are the same as in the previous Eqn. (1) ANoP (Average Number of Participants) is a variable that represents the average number of participants in a given month; PP is a variable that represents the Predetermined Price.

However, according to the results in Table 2, the number of participants in the Tohoku Regional Development Bureau after the earthquake has been trending negatively and is no longer significant. This is further broken down by year for further examination.

This is analysed in further detail by the total amount of public procurement in the Tohoku region by year. The same type of estimating Eqn. (3), with the independent variable being the total expected price (PP) for the Northeast region, is used to analyse year-to-year changes in policy.

$$\log PP\_Tohoku_t = \alpha_3 + \sum \beta_{3,t} Year + \beta_3 \log Others_t + \varepsilon_3. \quad (3)$$

Here, the variable PP_Tohoku is the total estimated price of the Tohoku Regional Development Bureau for the year, and the variable Others is the combined value (logarithmic value) of the other seven regional development bureaus outside Tohoku, which was included as a variable to control the trend of public investment in the whole country. The results of this estimation are as shown in Table 3.

According to this result, the total expected price was positive from FY2012 to FY2014, but it became insignificant in FY2015.

Now, let's examine the changes in suppliers in the Tohoku region.

In Eqn. (4), the same subscripts as in the previous equations stand for the same parameters. NoP_Tohoku (Number of Participants Tohoku) is a variable that indicates the average number of bidders for each project in that month of the year, and

Period is a dummy variable that indicates the year, taking the value 1 if it is a certain year and 0 otherwise. Period is a dummy variable indicating the fiscal year. The results are shown in Table 4.

$$NoP\_Tohoku_t = \alpha_4 + \sum \beta_{4,t} Period + \beta_{4,1,t} \log PP\_Tohoku_t + \sum \beta_{4,t} Regions + \varepsilon_1. \quad (4)$$

| Dependent Variable: | log(PP_Toh | Method: Pooled Leas | | n=155 |
|---|---|---|---|---|
| | Coefficient | Std. Error | 95% upper | 95% lower |
| C | −0.862 | 2.304 | 3.655 | −5.378 |
| 2006 | 0.121 | 0.350 | 0.808 | −0.566 |
| 2007 | 0.024 | 0.342 | 0.693 | −0.646 |
| 2008 | −0.029 | 0.342 | 0.641 | −0.698 |
| 2009 | −0.054 | 0.342 | 0.616 | −0.724 |
| 2010 | 0.209 | 0.351 | 0.897 | −0.479 |
| 2011 | 0.245 | 0.350 | 0.932 | −0.441 |
| 2012 | 0.672 | 0.342 | 1.341 | 0.002 |
| 2013 | 0.876 | 0.335 | 1.532 | 0.219 |
| 2014 | 1.032 | 0.334 | 1.687 | 0.378 |
| 2015 | 0.418 | 0.342 | 1.088 | −0.252 |
| 2016 | 0.850 | 0.335 | 1.507 | 0.194 |
| 2017 | 1.151 | 0.342 | 1.822 | 0.481 |
| 2018 | 0.818 | 0.342 | 1.488 | 0.148 |
| log(Others) | 0.951 | 0.093 | 1.134 | 0.769 |
| R-squared | 0.512 | | | |
| Adjusted R-squared | 0.464 | | | |
| Durbin-Watson stat | 1.799 | | | |

*Table 3: Yearly movement of total estimated prices since the earthquake*

| Dependent Variable: | Nop_Tohoku | Method: Least Squar | | n=155 |
|---|---|---|---|---|
| | Coefficient | Std. Error | 95% upper | 95% lower |
| C | −2.098 | 3.417 | 4.600 | −8.795 |
| 2006 | 3.340 | 1.060 | 5.417 | 1.262 |
| 2007 | 2.550 | 0.985 | 4.481 | 0.620 |
| 2008 | 2.166 | 0.892 | 3.914 | 0.418 |
| 2009 | 2.154 | 0.887 | 3.893 | 0.416 |
| 2010 | 1.436 | 1.079 | 3.551 | −0.680 |
| 2011 | 1.572 | 1.048 | 3.627 | −0.482 |
| 2012 | 3.342 | 0.989 | 5.280 | 1.404 |
| 2013 | 1.957 | 0.848 | 3.618 | 0.295 |
| 2014 | 1.181 | 0.886 | 2.918 | −0.555 |
| 2015 | 1.699 | 0.937 | 3.535 | −0.138 |
| 2016 | 0.326 | 0.823 | 1.939 | −1.287 |
| 2017 | 1.901 | 0.812 | 3.493 | 0.309 |
| 2018 | 0.697 | 0.805 | 2.275 | −0.881 |
| log(PP_Tohoku) | 0.121 | 0.146 | 0.408 | −0.165 |
| Other Regions NoP | Yes | | | |
| R-squared | 0.501 | | | |
| Adjusted R-squared | 0.422 | | | |
| Durbin-Watson stat | 1.807 | | | |

*Table 4: Yearly movement of suppliers since the earthquake*

According to the results, the number of bidders (suppliers) increased in FY2012 and FY2013, but the number of suppliers has not been significantly affected since FY2014.

Therefore, in response to the shock of the earthquake, the amount of total planned prices for public procurement is expected to have increased in FY 2012-2014 as a measure to stimulate demand. In the previous Figs. 1 and 2, this situation could have been represented by Fig 2 (Table 3). In contrast, the demand expansion measures shifted the D2 demand curve to D3, and the price realised did not fall below the original price. As a result, the situation where the number of suppliers could have fallen temporarily recovered in FY2012 and FY2013 (Table 4). However, demand stimulus measures alone would not be enough to maintain and secure the number of suppliers, and hence, they have been declining since FY2014.

In other words, to recover from the damage including that to the infrastructure, demand control measures are considered to be the primary necessary condition followed by supply control measures for more effective and efficient provision of construction services. As a preliminary conclusion from the analysis of demand and supply in public procurement, short-term demand-boosting measures have been quite successful. However, further efforts are required for medium- to long-term supply stimulus measures.

## CONCLUSIONS

This study analysed and examined the effects of demand control and supply stimulus in public procurement after the Great East Japan Earthquake. The bidding data of general civil engineering works of the Regional Development Bureau of the MLITT from FY2006 to FY2019 was used for the analysis. The results show that demand control measures are the first prerequisite to recover from extensive damage, including infrastructural damage, and this was implemented appropriately. In addition, it is

necessary to take measures to control supply to provide construction services effectively and efficiently, and further measures are desirable to stimulate supply from a medium- to long-term perspective.

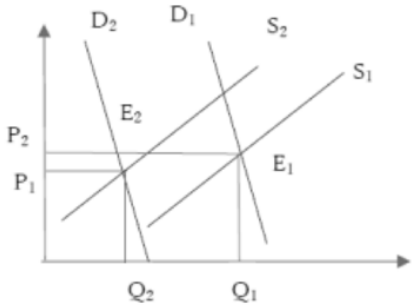


*Figure 2 (Reprint)*

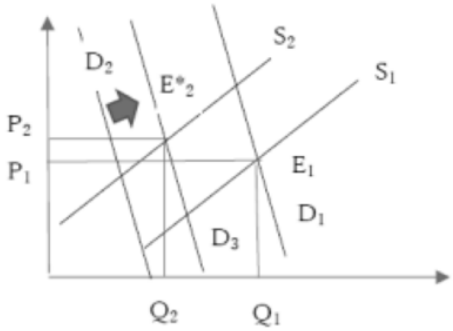


*Figure 7: Demand–supply curve extend shift*

For this purpose, i-Construction, which focuses on the use of ICT in national land transportation policy, has been systematically and actively implemented since FY2016. For details, refer to Arai and Morimoto (2020), who promote i-Construction based on the rapid development of satellite positioning technology and IoT. Their report summarises the perspectives for promoting i-Construction based on the rapid development of the IoT as “turning construction sites into state-of-the-art factories,” “introducing state-of-the-art supply chain management to construction sites,” “breaking down the existing old ways of thinking and old regulations at construction sites” and “"continuous kaizen.” For example, “full use of ICT (ICT earthwork),” “introduction of total optimisation (standardisation of concrete work standards, etc.),” and “equalisation of construction time” are set. As a mechanism to promote i-Construction, the government established a promotion system and a public-private consortium, used big data, and collaborated with other outdoor industries.

In Japan, these lessons have been applied to the COVID-19 crisis. According to the MLITT data from August 2020, the number of construction projects subject to ICT construction is expanded annually. The ratio of ICT construction to the number of public notices is increasing. The number of companies with multiple experiences has increased by about eight times from 107 at the end of FY 2016 to 873 at the end of FY 2019, accounting for approximately 60%.

The originality and novelty of this research is due to the fact that few studies have analysed of demand management and supply stimulation in the public procurement market of the construction industry after natural disasters from the perspective of construction management. The contribution of this study to construction management research is that it not only tracks supply and demand trends but also organises them from the standpoint of shifting equilibrium in the market and shifting demand and supply curves. In addition, statistical analysis and reduction based on data processing are considered to contribute to the advancement of construction management as a science. One of the limitations of this study is that it is a case study based in Japan. However, an analysis of the incentives of participants in public procurement in response to a major natural disaster that could shake the country has implications that go beyond a case study. In Japan, the experience of managing supply and demand in the aftermath of the earthquake is being utilized in response to COVID-19. This is where stable orders are being placed in the short term, and where the importance is given on improving productivity to support businesses in the medium to long term.

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# COMMUNITY ORIENTATED POST-DISASTER SUSTAINABLE HOUSING RECOVERY, REBUILDING AND COMMUNITY RENEWAL: SRI LANKA CASE STUDY

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Disasters, both natural and manmade, are increasing in frequency and have devastating effects on many communities, resulting in destruction of the built environment, displaced population, and poverty. The losses and damage as a result of disasters are often worse felt in least developed and middle-income countries, due at times to increased vulnerability and lack of preparedness. Disaster management and appropriate post disaster housing design approaches are demanding issues required for the successful long-term sustainable recovery of the affected communities. To be sustainable, communities need to be empowered and self-reliant, to enable them to cope with the adverse effects of past and possible future disaster events. The aim of this study is to explore the approach and strategy undertaken by an international non-governmental organisation (INGO) in the design and delivery of post disaster housing with a stated community participation orientated approach. A case study approach, utilising interviews with key INGO personnel, building studies and documentation evidence, of two post disaster housing projects in Sri Lanka is undertaken. The research uncovers the 5 key stages undertaken in the overall approach by the INGO. Each stage contains a subset of criteria considered by the organisation to enable meaningful community participation throughout the process. Participation approaches included design input, skills training in both labour and building product production and creation of enterprises. Non construction related aspects including the use of alternative simple household technologies and saving schemes were introduced by the organisation to further contribute to the community's long-term sustainability and resilience of the community.

Keywords: community empowerment; disaster management; resilience; sustainability

## INTRODUCTION

The provision of long-term sustainable housing in post disaster contexts creates additional challenges to an already difficult task of housing provision. The contexts are usually chaotic, have limited resources available, timescales are usually tight for implementation of the projects, and often many different projects are running simultaneously. Post disaster housing is often seen as an opportunity to build back

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better and create lower levels of vulnerability and higher levels of resilience in the affected community. The value added by community participation in the design and delivery of post -disaster housing is a widely accepted paradigm in the literature on the topic. However, the concept of community participation can take many forms in housing design and delivery and to be relevant and beneficial to the communities' it must be used in an appropriate manner, be meaningful and used at the relevant times for each individual project depending on the specifics of that project. The purpose of this research is to explore the levels and methods of community participation used by a community orientated INGO in both the design and delivery of sustainable housing in a post disaster context. The research used 2 individual case studies of post disaster housing development undertaken by the INGO. The research examined the projects holistically in terms of their design and delivery to identify the key decision-making process and various stages and considerations undertaken by the INGO and the levels of beneficial community participation as part of these processes. The study provides new information for academia and practice on the decision making and processes used by a leading INGO in the design and delivery of community orientated post disaster housing.

**Community Participation in Post Disaster Housing**

The literature highlights that in the past, approaches to post-disaster housing delivery often involved a top-down macro level approach (Andrew et. al 2013). The approaches often involve the requirements of those implementing rather than the communities being served (Shaw and Ahmed 2010). Many of these approaches have failed due to issues including displacement, lack of community capacity, cost recovery, corruption, gender issues, affordability, lack of NGO competence, government policies and practices (Muraya 2006, Sadiqi et. al 2016). Muraya (2006) outlines the change in approaches and policies for housing have evolved over decades, from one centred on top-down macro level government provided housing, to a more bottom-up micro level, adopting a self-help approach that would focus on enablement and the involvement of communities and community-based organisations (CBOs). Sadiqi (2016) states the idea of community participation is not a new one but the concept of community participation as it is known today is a relatively new one.

Davidson *et al.,* (2007) states that although the value of community participation as a paradigm approach to housing delivery is now widely accepted in contemporary literature and by academics and practitioners, it can exist in many forms in practice. Davidson *et al.,* (2007) argues that the difficulty with the application of a participation approach is that it is not defined in terms of a project environment and the concepts are so widely expressed under various headings, that it now lacks the essential clarity that is required for its implementation on projects. Arnstein (1969) provided a ladder of citizen participation and Choguill (1996) provided a ladder of community participation to outline the various elements and ranking of this process. Davidson *et al.,* (2007) provides a "ladder of participation" adapted from both these original ladders of participation, noting that approaches at the top of the ladder empower people and communities, offer collaboration, and give communities control over the project.

The lower end of the ladder offers beneficiaries a possible consultation or they are merely informed the shape their project is taking or possibly manipulated in to taking part in the project. Both Arnstein (1969) and Choguill (1996) argue that this cannot really be classed as actual participation, as users have little or no control over actual

decision making. Davidson *et al.,* (2007) outline that for participation to be meaningful for a project, communities have to be involved in the early stages of the project and have genuine control and influence over decision making to benefit their long-term wellbeing, with full responsibility for their own choices and projects, as opposed to being treated as passive victims receiving aid.

The research questions to be addressed include 1) what are the main stages a community orientated INGO goes through from inception to completion in the design and delivery of post disaster housing? 2) What are the main subsets and considerations under these stages? 3) What part does community participation play in the overall approach of the organisation and how meaningful is the participation?

## RESEARCH DESIGN

The research proposes to examine the INGOs processes for the design and delivery of sustainable post disaster housing projects from inception to completion of the project. Based on the research questions and aim, a case study qualitative approach was identified as appropriate for this study to enable thorough examination of the process and decision-making process. Baxter and Jacks (2008) state that a qualitative case study is a tool that enables researchers to study complex phenomena in their context and inform professional practice and evidence informed decision making. Two case studies were undertaken on the suburbs of Batticaola in Sri Lanka involving the design and delivery of 151 post disaster houses following the 2004 Indian Ocean tsunami. The overall objective of the INGO was to use a methodology that enabled the dwellings to be designed and constructed in partnership with the community. The INGOs aim is to enable the limited financial resources to be used to their maximum benefit while concurrently empowering the community to be self-sufficient in many different aspects of their life. The empowerment and self-sufficiency for the community was considered essential by the INGO to ensure long term sustainable survival with minimal displacement. The case studies were undertaken between 3-5 years after the completion of the dwellings. This extended period post completion was chosen to assess how successful the dwelling design and delivery approach and wider community development was over an extended period.

Multiple sources of information were collected and analysed to gain a thorough understanding of the both the organisation, wider context and post disaster housing. Data collection consisted of 4 sources; 1: Literature review of the subject area; 2: Documentation from the case study organisation; 3: semi structured interviews including the national director of the organisation and the regions senior architect. Both interviewees developed and implemented the overall INGOs process and community engagement strategy and were best placed to discuss it in detail for this INGO. Finally, 4. Observation and recording of the physical artefact. This involved the author visiting the communities and undertaking measure and draw and photographic surveys of the dwellings (artefact) and post occupancy evaluation studies.

A research protocol was agreed between all participating parties and ethical approval obtained from the research funding institution. Data analysis used number of approaches appropriate to the various data collection methods and aims of the research. These included the following;

1. Cognitive Mapping - Hurby (2006) defines cognitive mapping as a form of empirical research that uses a theoretical and methodological approach that contends

that cognitive maps represent manager's (designers and project managers) causal knowledge. Cognitive maps represent more than what was discussed in an interview. Banxia Decision Explorer software was used for the cognitive mapping process and analysis. Cognitive causal maps were constructed for individual transcribed interviews. A global organisation map was constructed from the individual interview maps for the overall organisation (Fig 4 below). Maps were formed with identified colour coded concepts/nodes that arose out of the interviews. Central and domain analysis was undertaken using Banxia Decision Explorer Software.

2. Logic Models - Logic models, also referred to as process Flow Charts (PFCs), are graphic depictions that trace actual events and processes in individual organisations over time tracing the sequential order of events while underlining causal links and patterns emerging for a process. They are useful in providing a clear and simple method of communication to the various stakeholders of how an individual or organisation approaches a process. Yin (2009) states that pattern matching logic is one of the most desirable analytic techniques for case study analysis stating a logic model stipulates a complex chain of events over a period of time with repeated cause and effect patterns where a dependent event at an earlier stage becomes a causal event for the next stage. Fig 5 (below) represents the logic model that emerged of the INGO for the selected case studies.

3. Physical artefacts - Groat and Wang (2002) argue that the study of contemporary environments can benefit from the analysis of physical artefacts. Yin (2009) notes that the use of artefacts as a source of evidence can provide insights into cultural features and technical operations. The physical artefact that this research relates to is the dwelling and community itself which is inhabited by the beneficiaries' this is the physical output of the design and delivery process which is being studied. The dwellings from the case studies are located in their natural settings and created the opportunity for direct observations and are another additional valuable source of evidence for the study. Direct observation from the field involved dwellings been analysed and recorded in the form of measured surveys, photographs, and condition surveys by the researcher.

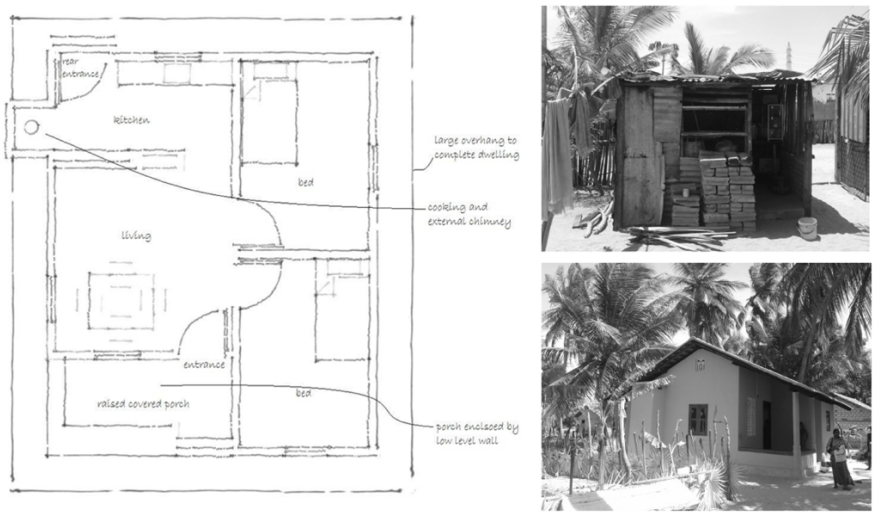


*Fig 1, 2 and 3: Example of case study data collection (Source author)*

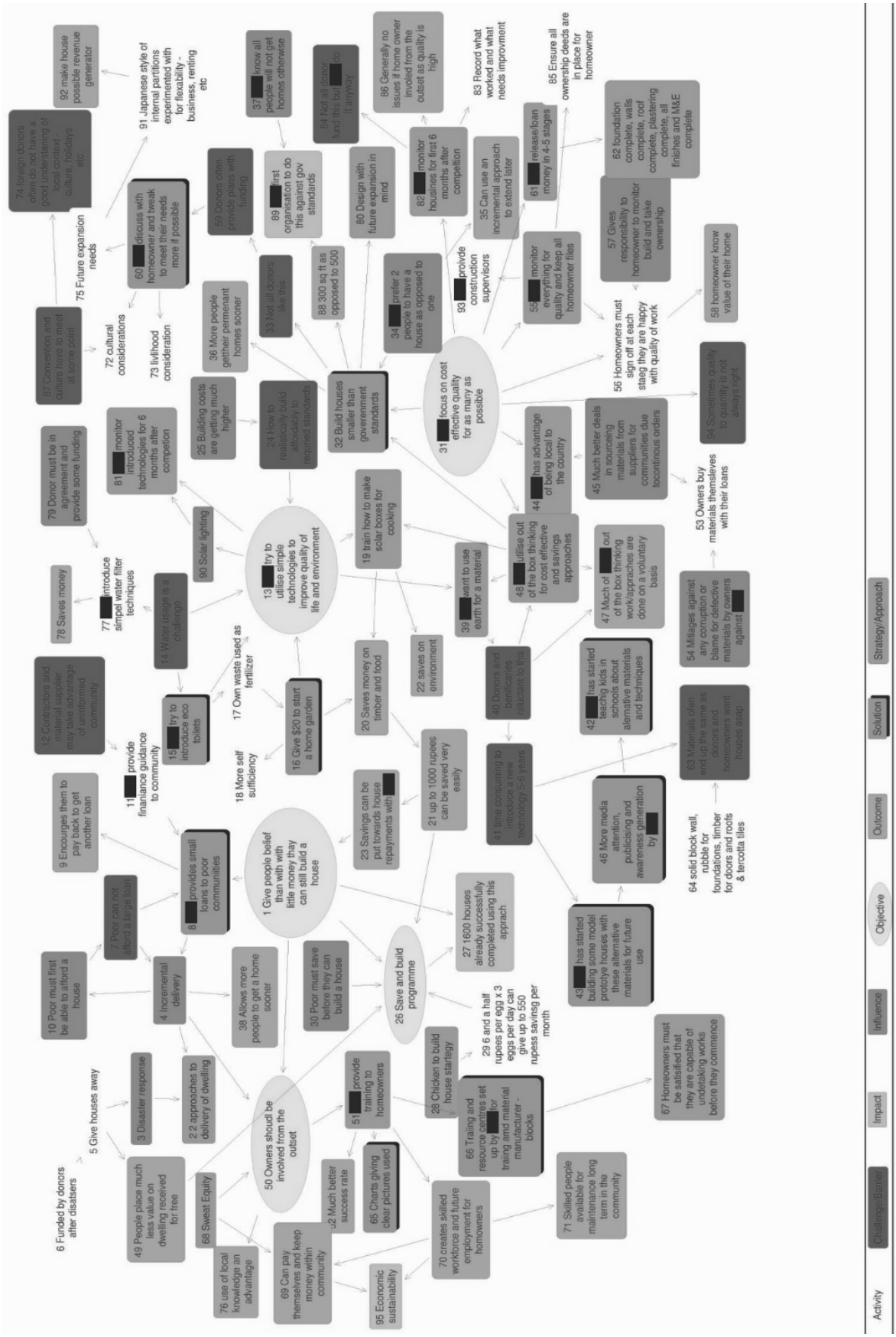


*Fig 4 Global map for organisation (Source: Author)*

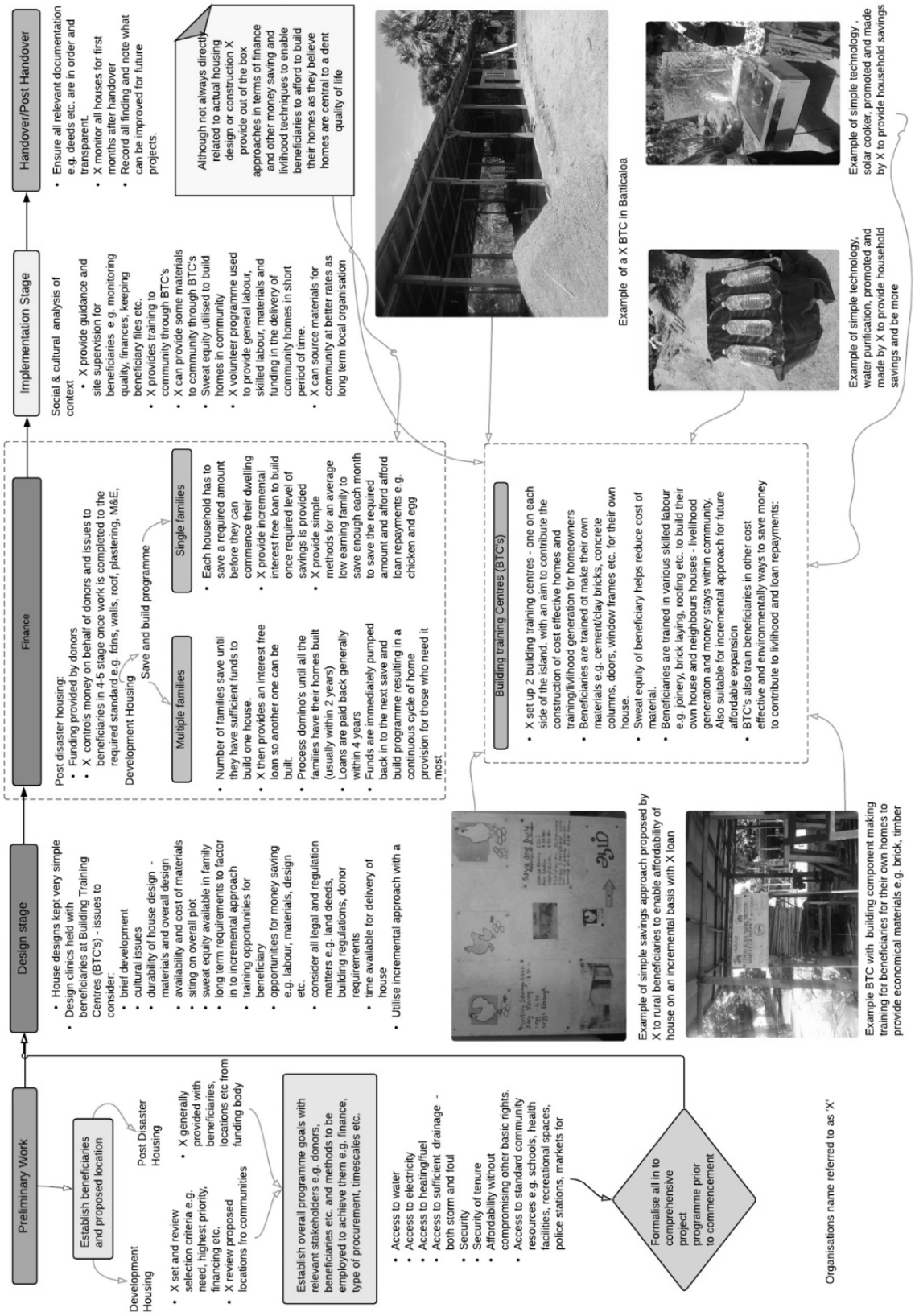


*Fig 5 Logic Model of Organisations Process and Key Stages (Source: Author)*

# FINDINGS

A total of 95 concepts were identified in the global map formed from the 2 individual interviews with each concept falling in to one of 9 identified colour coded themes as

outlined in the organisation map (Fig 4 above). Central and Domain analysis of the global map using Decision Explorer identified the 10 top featuring concepts under various identified category's (Table 1 below)

*Table 1: Top 10 Central and Domain Analysis from Interviews*

| Factor | Rank | Category |
|---|---|---|
| X try to use simple technologies to improve quality of life and environment | 1 | Objective |
| X focus on cost effective quality for as many as possible | 2 | Objective |
| Build houses smaller than government standards | 3 | Solution |
| Owners should be involved from the outset | 4 | Objective |
| X provides small loans to poor people | 5 | Strategy |
| Save and build programme | 6 | Objective |
| X provides training to homeowners | 7 | Objective |
| X utilises out of the box thinking for cost effectiveness and savings | 8 | Strategy |
| X monitor houses for first 6 months after completion | 9 | Strategy |
| Incremental delivery | 10 | Objective |

Key findings from the interview analysis outlined that the organisation was driven by specific objectives which included using simple technologies, cost effectiveness, owner involvement from the outset, saving to build concept, providing training to the community and the incremental delivery of housing. In terms of cost effectiveness, the organisation identified that the funds available for post disaster housing were not sufficient to achieve the dwelling area required by government standards. The area standard required resulted in poorer standard or incomplete houses. As a solution the organisation negotiated with government for a smaller area, 350 sq. foot as opposed to 500 sq. foot, dwelling and to build higher quality more resilient dwellings quicker using an incremental approach which could be extended and improved upon in the future. An incremental approach, factoring in the beneficiary's long-term requirements, was identified as a key objective of the organisation that enabled communities to start rebuilding quicker as many had been displaced and were living in temporary accommodation. This approach when first proposed was met with some resistance from both the government and funders. However, after the rational of an incremental approach was explained and demonstrated to work better long term for the beneficiaries it was accepted.

Consistent with the literature the organisation identified that for a community to be sustainable, it must have a meaningful input in to the overall process at the appropriate time from the outset to completion. The organisation formed a close working relationship with both communities from the outset as a key objective and considered that the genuine empowerment of the beneficiaries was essential, for both the buy in from the community and in relation to maximising their available project funds, and the communities long term sustainability. Effective financial management was identified as a core area that influenced a number of the themes, albeit the beneficiaries were empowered to spend it responsibly themselves with advice from the organisation. The organisation themselves funded many of their own projects and managed the funds on behalf of the donors on others. Funds were released in stages to the homeowner once certain milestones were met and demonstrated. The autonomy

of funding their own projects enabled some unique approaches that would not be possible on projects funded by others, for example, requesting households to save a certain sum themselves before commencing work, facilitating interest free loans for some households that could accommodate it. To assist households the organisation displayed divergent thinking to formulate savings schemes and efficient daily living approaches that enabled the community to maximise their funds. These included rural communities purchasing some animals to produce food with some of their available house funds to provide a better return for the household, more environment ways to light their dwellings and purify water without wasting fuel and simple technologies such as homemade solar cookers to enable food to be cooked without fuel and constant supervision. The latter example proved to be a very popular and simple technique among the beneficiaries in that it enabled the homeowner to focus on other tasks and earn money while food was cooking while simultaneously saving money on fuel. The organisation wished to instil in the communities that wise investment and financial management was key to their long-term security and that they had to take responsibility for this aspect of their lives themselves. In this respect the organisation was quite unique from others in terms of their consideration of the long-term wellbeing of the communities outside of merely building houses for them and invested time in the community in non-construction related elements of work to achieve this.

To facilitate community participation and empowerment from the outset Building Training Centres (BTCs) were established by the organisation on or close to the community site. The BTCs provided a number of functions in both the construction of the dwelling, but also the long-term sustainability of the communities. Training was provided in the making of various building components, for example, bricks, roof timber, doors and windows; thus' introducing new skills into the community, as well as saving money in the purchase of finished products. The BTCs also assisted the community in pooling their available funds to purchase the raw materials in bulk at better rates thus extending how far their funds would reach. Further training was provided for community members in skilled labour for example joinery, brick laying, roofing and plastering. The success of the BTCs was integral to the overall organisations approach and long-term sustainability of the community as they provided many in the community with new skills and means of livelihood generation for the long-term future. The ability of having the skills within the community also enabled the maintenance of their dwellings in the long term.

Observation studies of the dwellings identified that over 50% had already been extended or modified to meet the homeowner's needs, indicating the incremental housing approach was successful. The occupancy rate was 90+% which were high in comparison to some adjacent government funded schemes which displayed occupancy rates as low as 60%. The BTCs continue to serve the community and help generate income both in the production of building components and training in skilled labour years after the works completed. Community members are utilising the skills learned on their own homes and went on to work on adjacent housing schemes creating incomes for their families and community. Other smaller cottage industries were evident within the community at people's homes for example, food and building material sales.

The data analysis identified five key stages and a sequential approach by the organisation (Fig 2 above) in the two case studies albeit no formal approach or methodology was discussed or said to exist by the organisation. Stage one consisted of preliminary works involving an assessment of the beneficiaries and those with the

greatest needs. Other aspects of a practical nature were in relation to the proposed site location and legal tenure and its ability to be sustained as a community in relation to its adjacencies to services such as schools, health facilities and markets.

Stage two involved the overall design of individual dwellings and community master planning. House designs were kept relatively simple with set core house designs which could be revised within reason on consultation with the individual households, to reflect any particular aspect they may wish to change, be it for practical or cultural reasons. Construction methods were set as masonry construction and rendered walls with timber structure roof and timber joinery. This more contemporary method of construction was at odds with what some members of the community had lived in previously for example Cajun huts. However, this form of construction was deemed essential for the dwelling to be considered a house by government bodies. This stage was resource and time intensive for the organisation dealing with individual households, but it was considered essential as each household was assessed in terms of aspects including their demographic, available sweat equity and earning availability all of which informed how far each household could maximise the available funds.

Stage three was closely linked to and informed by stage two. The financial element of the overall process was considered key for the organisation as they endeavoured to instil financial empowerment and competency in the community. A save and build programme was also introduced and interest free loans were also made available where appropriate. All financial matters had to be agreed and finalised with individual households before work could commence on their dwellings.

Stage four involved the implementation and construction of the dwellings. The organisation provided mains services where required but took a more passive approach in terms of the dwelling construction as the majority of the labour was provided though sweat equity by the individual households. Guidance, training, and site supervision for quality control was maintained by the organisation throughout the builds with key milestones on each dwelling having to be signed off before the homeowner could proceed to the next stage and have funds released. The organisation did organise several volunteer programmes and where appropriate communities were assisted with these programmes in terms of manual and skilled labour.

Stage five involved the final sign off for the dwellings and ensured that all required documentation such as the house deeds were in place of the homeowner. The organisation monitored individual dwellings for 6 months after the handover to ensure they were performing to the required standards and that the beneficiaries were living in them. This was a basic form of post occupancy evaluation and any lessons learned were recorded for future projects.

## CONCLUSIONS

The research study involved an in-depth examination of the real-world approach and decision making of a community orientated INGO in the delivery of post disaster housing. Through interviews, observation studies, documentation research and analysis involving cognitive mapping and logic modelling, key individual sequential stages were identified in the overall approach. Within each of the identified stages, further key tasks were identified that informed the organisations overall decision making, design and delivery approach. The study demonstrated that meaningful community participation, if implemented correctly, had a positive impact on the overall project outcome and as such is consistent with the literature. The

organisations approach and level of community participation can be considered to be at the upper end of the ladder of participation proposed in the literature as it demonstrated genuine efforts to empower the community for their long-term resilience and sustainability. In doing this, the organisation went beyond the mere physical artefact of the building/dwelling and identified the aspects of providing skills for livelihood generation, financial management, and other simple technologies that benefited the community in the long term. The study provides new information on the decision making and aspects involved in the design and delivery of post disaster housing with a community participation and empowerment agenda central to the overall approach. The findings add to the current research and literature on the subject and will prove useful in practice for similar organisations and other relevant stakeholders for example donors, communities and funders in the design and delivery of post disaster houses and the long-term resilience and sustainability of communities.

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# DEVELOPMENT OF A CAUSAL LOOP DIAGRAM FOR BRIDGE RESILIENCE

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In recent years, the resilience assessment for bridges has drawn ample attention in the engineering and management community. It has been attempted to evaluate bridge resilience by developing a resilience matrix or single-measure index. However, existing studies overlooked the prevailing interdependency among various physical and social infrastructures. Moreover, the technical, organizational, social, and economic aspects of these infrastructures are of dynamic nature. Therefore, this study develops a causal loop diagram (CLD) of bridge resilience to explore and understand how other infrastructures and their dynamism influence bridge resilience. Total 21 bridge resilience factors are identified based on the literature review. Out of these, 14 bridge resilience factors are shortlisted by using the Delphi method. Along with these 14 shortlisted factors, four properties of resilience (robustness, rapidity, resourcefulness, redundancy) and four infrastructures (bridge, transportation network, other utility infrastructures, and governance system) are considered to develop CLD. Thus, eight causal loops are developed, validated, and presented for improving bridge resilience. Further, the proposed study can help to implement effective policies for improving urban resilience and developing a smart city digital twin (SCDT) system.

Keywords: bridge; resilience; causal loop diagram; Delphi method

## INTRODUCTION

A bridge is one of the essential components of the ground transportation system. Recorded past literature indicates that comprehensive studies in the vision for bridge engineering and management cover several concepts such as sustainability, adaptability, safety, risk, transformation, etc. Further, these concepts implicit as main guidelines for action in improving bridge engineering and management domain. But still, the understanding of these concepts is not generalized and often uncertain as bridges all across the globe are vulnerable to various natural disasters, such as earthquakes, floods, tsunami, cyclones, etc. Bridge failures that occurred due to various disasters in the USA, Colombia, and China are reported and studied (Harik *et al.,* 1990, Wardhana and Hadipriono 2003, Diaz *et al.,* 2009, and Fu *et al.,* 2013). In India, a total of 3709 incidents of bridge damage and failure are reported due to natural disasters from 2001 to 2018 years. The above studies reveal that the bridge engineering and management domains are concerned with the effective response to natural disasters. Therefore, bridge owners should implement pre-disaster

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maintenance work to make bridges more robust and plan for post-disaster rapid recovery work.

Nowadays, the concept of resilience has been increasingly addressed in academic studies of bridge engineering and management domain (Banerjee *et al.,* 2019). Bridge resilience is defined as a "bridge's ability to maintain its functionality, social, and economic value against the disaster; and to plan the recovery activities to regain its original functionality, social and economic values within the shortest time" (Patel *et al.,* 2020). Banerjee *et al.,* (2019) presented a systematic and comprehensive literature review of bridge resilience assessment for single and multiple disasters. Ikpong and Bagchi (2015), Domaneschi and Martinelli (2016), Andrić and Lu (2017), Minaie and Moon (2017), and Patel *et al.,* (2020) used a qualitative approach to develop a simplified subjective procedure that can quickly estimate the resilience of multiple bridges. Thus, all these studies reveal that researchers have tried to develop a relevant resilience matrix or single-measure index for the bridge. Moreover, the previously mentioned studies also explore that they lack in considering the interdependency of bridge resilience on other infrastructures such as transportation networks, other utility infrastructures, and governance systems. Moreover, this interdependency can also involve several factors that can have dynamic behaviour. Therefore, this study seeks an opportunity to understand complex bridge resilience problems along with the interconnected infrastructures (transportation network, other utility infrastructures, and governance system).

In this connection, the current study sets the objectives: (1) to identify the factors that influence the bridge's resilience along with transportation network, other utility infrastructures, and governance network, and (2) to develop a causal loop diagram (CLD) for the bridge resilience. To achieve these objectives, the paper proceeds with the following sections. The paper first summarizes the CLD for its better understanding. Then, sections include the research methodology, data collection and analysis, and conclusions.

## Causal Loop Diagram (CLD)

The causal loop (also called feedback loop) is defined as the closed sequence of causes and effects or a closed path of transmission and return of information of a system (Richardson and Pugh 1981). Further, Richardson and Pugh (1981) stated that the purpose of the causal loop diagram (CLD) is to understand the pattern behaviour of system model and to discuss management policies for the same. An example of a simple causal loop diagram is shown in Fig 1, where A, B, C, and D represent the variables of any system, arrows describe the links between the variables. The signs (+ or −) along with arrows annotate the movement of variables in the same or opposite direction. To briefly understand Fig 1, one can say that variable-A is linked positively (+) to variable-B. This link indicates that the increase in variable-A makes the same amount of increment to variable-B, or the decrease in variable-A makes the same amount of variable-B reduction. Similarly, variable-B is linked positively with variable-C, and variable-D is also linked positively with variable-A. But, variable-C is linked negatively (−) with variable-D (Fig 1), which indicates that an increase in variable-C reduces variable-D or a decrease in variable-C makes an increment in variable-D.

Further, the negative sign annotated with a bracket in the middle of Fig 1 describes the type of causal or feedback loop. Generally, there are two types of causal loop diagrams: (1) a positive causal loop, also called a reinforcing loop, and (2) a negative

causal loop, also called a balancing loop. The reinforcing loop is indicated with (+) sign in the bracket if there are an even number of negative causal links or if all the causal links are positive. The balancing loop is indicated with the (−) sign in the bracket if there are an odd number of negative causal links. The example shown in Fig 1 is a negative causal loop because it has only one negative causal link. One can refer to the procedure and guidelines presented by Richardson and Pugh (1981) and Kirkwood (1998) to create the causal or feedback loop diagram.

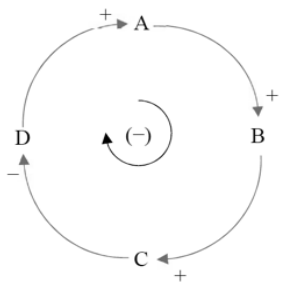


*Fig 1: Illustration of the causal loop diagram (CLD)*

## METHOD

In light of the previous sections, the ensuing research methodology is implemented in two phases, and they are illustrated as follows.

In phase-1, dynamic factors that represent bridge resilience are identified and shortlisted using the Delphi technique. Delphi technique is a structured and interactive research technique used to obtain the judgment of a panel of independent experts on a specific topic (Hallowell and Gambatese 2010). Further, Hallowell and Gambatese (2010) stated that Delphi is more accurate than other conventional simple survey methods. Because it allows researchers to maintain significant control over bias responses obtained from qualified experts. Based on this, controlled responses obtained during multiple rounds can easily help to achieve consensus among the experts. Therefore, the Delphi technique generally consists of two or more rounds of questionnaire surveys. In the first round, experts respond to questions developed from the literature review and personal judgment, while each additional round depends on previous rounds' responses. Thus, the process is concluded after the acceptable result is reached (Hallowell and Gambatese 2010). Further, the guidelines to certified respondents as experts in a panel and performing the Delphi technique are predefined before the survey process begins (Hallowell and Gambatese 2010). Hallowell and Gambatese (2010) also recommended that one can modify these guidelines as per the requirement of their study. Therefore, to implement the Delphi technique, this study's guidelines are modified and described in Table 1. These modifications in criteria are as per the requirement of Indian bridge engineering and management. Thus, at the end of phase-1, the study identifies the dynamic bridge resilience factors.

Subsequently, in phase-2, the CLD is developed to understand the dynamic bridge resilience behaviour. For determining CLD, Sterman (2000) suggested to acquired existing knowledge about real-world systems through literature review and experts' judgments. A questionnaire survey is performed in this study to have the expert's knowledge in developing the CLD. Finally, the CLD is validated using the face validation technique, in which the structure of the CLD is empirically verified using expert judgment (Lucko and Rojas 2010).

## DATA COLLECTION AND ANALYSIS

Data collection and analysis in both the phases of the research methodology are illustrated as follows.

*Table 1: Guidelines for Delphi method*

| Characteristics | Minimum requirement adopted in this study |
|---|---|
| Identifying potential experts | Experts must satisfy at least one of the following criteria: |
| | 1. Membership of IRC or IBC. |
| | 2. Known participation in similar expert-based studies. |
| | 3. Delegation and expert list of conferences, seminars, training, and other events. |
| Qualifying panellists as experts | Experts must satisfy at least three of the following criteria: |
| | 1. Invited to present at a conference, training program. |
| | 2. Member or chair of a nationally recognized committee, society, or council |
| | 3. At least five years of professional experience in designing, managing, and constructing bridges. |
| | 4. Advanced degree in civil engineering, structural engineering, CEM, or other related fields (minimum B.E./B. Tech.) |
| | 5. Professional registration such as Registered Engineer or Licensed Engineer |
| | 6. A primary or secondary writer of at least three peer-reviewed journal articles. |
| Number of panellists | 10 |
| Number of rounds | 3 |
| Feedback for each round | Round 1: Data from existing literature, personal judgment, interview with experts, or archived data (if available). |
| | Round 2: Median response from Round 1. |
| | Round 3: Median response from Round 2 and reasons for outlier responses. |
| Measuring consensus | Absolute deviation (median) (AD), coefficient of variance (CV), range of data |

Note: B.E./B.Tech. = bachelor of civil engineering; CEM = construction engineering and management; IRC = Indian Road Congress; IBC = Indian Building Congress.

### Phase-I

In the first phase of the study, first, factors essential for the bridge's resilience are identified through the literature review. These identified bridge resilience factors must fulfill the requirements of four properties of resilience (robustness, rapidity, resourcefulness, and redundancy). Then, a questionnaire survey is framed, and its evaluation is carry-out using the Delphi technique to shortlist these identified factors. Concerning the COVID-19 pandemic situation, google form and google meet tools are used to carry out the questionnaire survey in all Delphi technique rounds. Further, as mentioned in the research methodology section, this study modifies the selection criteria for selecting panellists (Table 1). Based on these criteria, a total of 10 experts are selected: four experts are from Surat Municipal Corporation (local government), three experts from Road and Building Department (state government), one expert is from Central Public Works Department (central government), and two experts are from the construction companies. Further, to emphasize on-field experience, at least

five years of professional experience in the bridge's construction and maintenance is fixed as one criterion for selecting experts. The average work experience of these ten experts is found approximately 17 years.

In the first round of the Delphi method, based on the literature review and interviews with ten selected experts, 21 dynamic bridge resilience factors are identified and listed in Table 2. Further, out of these 21 factors, 20 are identified from the following previous studies: Freckleton *et al.,* (2012), Decò *et al.,* (2013), Dong and Frangopol (2016), Andrić and Lu (2017), Minaie and Moon (2017), Karamlou and Bocchini (2017), Vishwanath and Banerjee (2019), and Patel *et al.,* (2020). While one factor, namely 'Political Condition,' is recommended by the four experts. The political dispute may change the structure/staff of governance/ management/organizations. Further, these changes may delay the bridge's restoration/ maintenance work.

*Table 2: List of bridge resilience factors*

| Resilience properties | Factors |
|---|---|
| Robustness | (F1) Bridge age, (F2) Bridge vulnerability, (F3) Severity of disaster, (F4) Average daily traffic, (F5) Load-carrying capacity of bridge, (F6) Deterioration rate of bridge, (F7) Bridge maintenance cost. |
| Rapidity | (F8) Area and region affected, (F9) Restoration time, (F10) Disaster preparedness, (F11) Type of bridge, (F12) Duration of procuring and tendering, (F13) Political condition. |
| Resourcefulness | (F14) Inspection techniques, (F15) Arrangement of funds, (F16) Automated planning and scheduling, (F17) Resources for network management, (F18) Access to fuel and energy. |
| Redundancy | (F19) Availability of backup contractor, (F20) Accessible material and equipment, (F21) Availability of funds. |

In the second round of the survey, the outcome from the first round is presented to the experts. Subsequently, experts are asked to quantify the importance of the dynamic bridge resilience factors on a six-point Likert scale, where extremely unimportant = 1, unimportant = 2, somewhat-unimportant = 3, somewhat-important = 4, important = 5, and extremely important = 6. In this study, 'Neutral' is not considered for having convenient scores without cognitive efforts. Further, to judge whether experts have reached consensus to a certain extent, all required statical parameters such as absolute deviation (AD)-median, coefficient of variation (CV), and range of data are computed. The cut-off values for these statical parameters (AD, CV, and range of data) are based on study requirements (Patel and Jha 2017). Therefore, in this study, AD-median, CV, and the range of the data should be less than 1.00, 0.25, and 3, respectively. The opinions obtained in the second round of the Delphi method are then analysed, and the statical parameters outcomes are shown in Table 3. It shows that seven factors (highlighted with star sign) exceed the fixed limit of statical parameters. Therefore, these seven factors are eliminated from the final list. After that, Cronbach's alpha of the remaining 14 factors is computed to check the reliability and internal consistency. Hair *et al.,* (2014) advocated that Cronbach's alpha value should be greater than 0.7 to have better reliability and internal consistency among the factors. In the current study, Cronbach's alpha value is estimated to 0.82, which indicates that the remaining 14 factors have better reliability and internal consistency. Thus, at the end of the second round of the Delphi method, 14 bridge resilience factors are shortlisted.

In the third and final round of the Delphi method, experts are asked to look at the results and analysis the final list of bridge resilience dynamic factors. Further, experts are also asked to rate the statements accordingly again. Moreover, if a particular expert rating differs from the panellist, the expert is asked to explain. However, there

is consensus among all the experts regarding the final list of bridge resilience factors. In brief, at the end of the first phase of the study, a list of 14 bridge resilience dynamic factors is finalized to develop a CLD.

*Table 3: Results of statical parameters*

| Factor's code | AD (Median) | CV | Range of data | Factor's code | AD (Median) | CV | Range of data |
|---|---|---|---|---|---|---|---|
| F1 | 0.71 | 0.12 | 2.00 | F12* | 1.17 | 0.49 | 3.00 |
| F2 | 0.67 | 0.13 | 2.00 | F13 | 0.52 | 0.11 | 0.00 |
| F3 | 0.82 | 0.16 | 2.00 | F14 | 0.70 | 0.21 | 2.00 |
| F4 | 0.74 | 0.23 | 2.00 | F15 | 0.67 | 0.13 | 2.00 |
| F5* | 1.03 | 0.32 | 3.00 | F16* | 1.25 | 0.54 | 3.00 |
| F6* | 1.05 | 0.26 | 3.00 | F17* | 1.33 | 0.33 | 4.00 |
| F7* | 0.79 | 0.36 | 2.00 | F18 | 0.32 | 0.06 | 1.00 |
| F8 | 0.74 | 0.14 | 2.00 | F19 | 0.74 | 0.15 | 2.00 |
| F9 | 0.82 | 0.16 | 2.00 | F20 | 0.42 | 0.07 | 1.00 |
| F10 | 0.67 | 0.13 | 2.00 | F21 | 0.52 | 0.09 | 1.00 |
| F11* | 0.95 | 0.41 | 3.00 | | | | |

Note: * indicated that factors are eliminated from the study.

Name of F1, F2, F3, …., F21 are available in Table 2

**Phase-II**

In the second phase of the study, the CLD is first created based on the procedure and guidelines presented by Richardson and Pugh (1981) and Kirkwood (1998). For this, Vensim (PLE version) software is used. Then, a face validation technique is utilized to verify the CLD. For this, a questionnaire with a two-point scale of 0-1, in which 1=satisfied and 0=unsatisfied, is designed. The same ten bridge experts from the first phase of the study are selected for verification. Moreover, google form and google meet tools have been used to carry out the questionnaire survey. Thus, all ten experts responded 1, which means they are all satisfied with the structure of the CLD. Therefore, no modification is required, and CLD is considered reliable. The finalized CLD is shown in Fig 2. Subsequently, the finalized CLD is discussed with experts to understand the dynamic behaviour of the bridge resilience along with the transportation network, other utility infrastructures, and governance system. Thus, the bridge owners can use the Delphi technique to select the qualified experts of their region/area. Based on those selected experts, the bridge owners can modify/upgrade CLD and understand the resilience of any bridges located anywhere in the globe.

## DISCUSSION

In the finalized CLD (Fig 2), eight causal loops are formed, and all are reinforcing loops as there are no negative links involved in them. These all loops are discussed as follow:

- Loop-1: Bridge resilience → Transportation network → Average daily traffic → Robustness

Loop-1 indicates the interconnection between the bridges and the transportation network, considering the average daily traffic. Decò *et al.,* (2013) have signified average daily traffic as the level of service (LOS) of the bridge. Further, Minaie and Moon (2017) have described the LOS of the transportation network or bridge as robustness. For illustration, flooding events can affect the road network functionality, which can also affect the bridge LOS or visa-versa. This situation can compromise

the region's connectivity, accessibility to essential services, economic productivity, and logistics (Cartes *et al.,* 2020). Therefore, if the operation of the transportation network is affected, then the nature of the bridge resilience also changes.

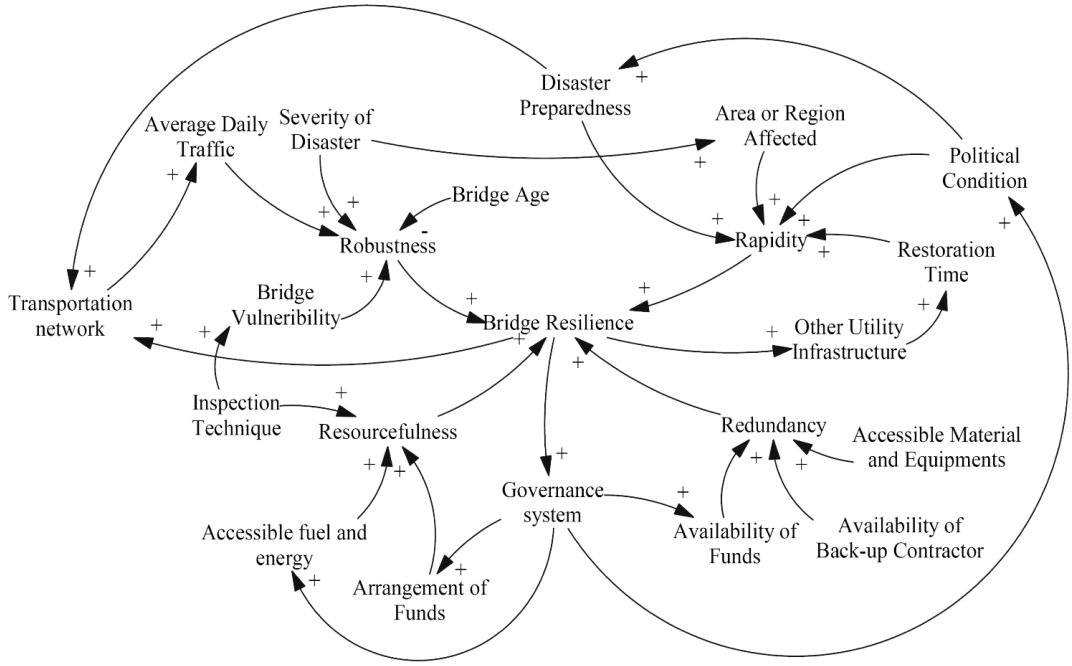


*Fig 2: Causal loop diagram of bridge resilience*

- Loop-2: Bridge resilience → Other utility infrastructure → Restoration time → Rapidity

Loop-2 indicates the interconnection between the bridge resilience and the other utility infrastructures such as liquefied petroleum gas line, water pipeline, communication cable line, etc. Thus, the loop represents the effect on the restoration time of the bridge due to the other utilities' infrastructure restoration time or vice versa. In this regard, Minaie and Moon (2017) advocated that the utility infrastructures and bridge owners should stay interconnected to have early restoration time after the disaster.

- Loop-3: Bridge resilience → Governance system → Political condition → Rapidity

Loop-3 represents the interconnection between the bridge resilience and governance system, considering the political condition. During the Delphi, procedure experts recommended that the political situation significantly impact the recovery phase of the bridge. As changes in the structure/staff of governance, management, or organizations due to the political condition may delay the restoration/maintenance work of the bridge. Moreover, the dispute in the political situation would also interrupt the recovery process of the bridge and road network. Thus, the political condition represents the dynamic nature as it is hard and uncertain to describe the political situation during and after the disaster.

- Loop-4: Bridge resilience → Governance system → Accessible fuel and energy → Resourcefulness

Loop-4 describes the interconnection and dynamic nature between the bridge resilience and governance system, considering fuel and energy resources. Freckleton *et al.,* (2012) stated that limited access to fuel and energy would deteriorate the ability

of the road network and the bridge. Moreover, it would increase the impact of the destabilizing event on the resilience of the bridge. Thus, access to fuel and energy has a dynamic nature as it is based on governance policies, which can affect bridge resilience.

- Loop-5: Bridge resilience → Governance system → Arrangement of funds → Resourcefulness

Loop-5 is similar to loop-4 as it describes the interconnection and dynamic nature between the bridge resilience and governance system considering the arrangement of funds. Patel *et al.,* (2020) described arrangements of funds under resourcefulness because the adjustment in the financial budget by bridge owner is required if there is a strain in the available budget. Thus, these factors describe the dynamic nature of resourcefulness of the bridge resilience. The arrangement of the financial budget might change every year, and it depends on the requirement of the restoration/ maintenance of bridges.

- Loop-6: Bridge resilience → Governance system → Availability of funds → Redundancy

Loop-6 indicates the interdependency of the bridge resilience and governance system, considering the availability of funds. Patel *et al.,* (2020) describe the availability of funds factor as the redundancy to bridge resilience as it limits the options for repair and reconstruction work. Thus, the factors have a dynamic nature to the redundancy of the bridge resilience as the availability of the fund for maintenance might vary every year.

- Loop-7: Bridge resilience → Governance system → Political condition → Disaster preparedness → Rapidity

Loop-7 is the extension of loop 3, as the disaster preparedness factor is added to loop-3. Minaie and Moon (2017), Andrić and Lu (2017), and Patel *et al.,* (2020) stated that bridge owners conduct educational programs, schedule tests, and drill programs for the preparedness faster recovery from disaster. Further, this disaster preparedness program is interdependent on the political situation and governance policies. Therefore, a dispute in the political condition or delay due to the governance system would affect the disaster preparedness program by the bridge owner and eventually impact the recovery of the bridge.

- Loop-8: Bridge resilience → Governance system → Political condition → Disaster preparedness → Transportation network → Average daily traffic → Robustness

Loop-8 represents the interconnection between the bridge, ground transportation network, and governance system considering political conditions, disaster preparedness, and average daily traffic factors. This loop indicates the behaviour of the governance system to plan, manage, and maintain the physical condition of bridges along with the transportation network. Further, the loop also indicates the functionality of commerce and services for a particular region or highway. Thus, this loop is vital as it represents the dynamic relationships of three different infrastructures consider in this study.

Thus, the proposed CLD includes a sufficient number of factors and their relationships to present the reality of bridge resilience interdependency with the other infrastructures. Based on the discussion of all the eight loops, it is clear that they represent a dynamic nature of bridge resilience. Further, this dynamic nature can provide some implications for bridge owners to improve or create a resilience policy

scenario. However, improving or creating a bridge resilience policy is a complicated and uncertain process. To overcome it, bridge owners must use system dynamic approach (SDA) as its simulation process can provide twice the result with half the effort to improve or create policy scenarios. Thus, based on SDA, more implications can be provided to bridge owners about building comprehensive bridge resilience.

## CONCLUSIONS

This study develops and presents a causal loop diagram (CLD) to represent the dynamic nature of bridge resilience considering the interdependence of transportation networks, other utility infrastructures, and governance systems. To do so, the Delphi technique is utilized to identify and shortlist the dynamic factors of bridge resilience. In the first round of the Delphi technique, 21 factors are identified from the literature review and expert knowledge. Then, in the second round, absolute deviation (AD)-median, coefficient of variation (CV), and range of data are computed. The limit for AD-median, CV, and range of data should be less than 1.00, 0.25, and 3, respectively. Based on these statistical parameter limits, seven factors are eliminated from this study. Then, the Cronbach's alpha of the remaining 14 factors is estimated to 0.82, and it indicated that the remaining factors have better reliability and internal consistency. Finally, in the third round, the experts agree to the second round's results, so 14 dynamic bridge resilience factors are shortlisted and finalized.

Along with these14 shortlisted factors, four properties of resilience (robustness, rapidity, resourcefulness, and redundancy) and four infrastructures (bridge, transportation network, utility infrastructures, and governance system) are considered to develop a CLD. Eight loops are identified from the finalized CLD, and they all represent the dynamic nature of bridge resilience. Moreover, the CLD also indicates the importance of considering transportation networks, utility infrastructures, and governance systems while computing bridge resilience.

The study is only limited to the factors related to bridge resilience. Further study can use the simulation tools to study this dynamic nature of bridge resilience. As it can be helpful to predict and determines the changes in bridge resilience over time. Moreover, studies could use this CLD to propose a measure or methodology of governance policies for bridge resilience. The current research is a part of developing the smart city digital twin (SCDT) system.

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# BUILDING RESILIENT SUPPLY CHAINS FOR CONSTRUCTION SMALL AND MEDIUM SIZED ENTERPRISES

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Along with global economic growth and the prevalence of global trade, uncertain and turbulent markets can lead to construction supply chain vulnerabilities and disruptions. Within this environment, small and medium enterprises (SMEs) in the construction industry are booming, despite being considered one of the most vulnerable sectors in the economy. Therefore, construction SMEs need to implement fundamental changes and adopt agile methods of coping with supply chain uncertainties to withstand the effects of unpredicted events, such as the COVID-19 crisis. In Australia, SMEs account for more than 99% of all Australian enterprises and deliver up to 60% of the total value of the construction industry. This research aims to identify resilience factors to optimize the supply chains of the SMEs in construction industry. Through a systematic review of literature, this research firstly identifies the resilience factors under the general supply chain environment. Subsequently, it systematically identifies the resilience factors for construction supply chains and SMEs supply chains with an objective to characterise the similarities and difference in these factors. Finally, this research demonstrates and applied these resilience factors in a small Australian building company. This research will contribute to the body of literature of resilient supply chains and to qualitative and quantitative research into building of resilient supply chains in the construction sector SMEs.

Keywords: supply chain; globalization; resilience factors; resilient supply chain; SME

## INTRODUCTION

External risks or disruptions in local branches may not be considered as a severe impact for a large global organization. However, these risks can be significant if they strike small and medium sized enterprises (SMEs). Since SMEs only have less than 250 employees and account for 70% of the global production, supply chain disruptions can severely affect the sustainability of SMEs (Bak *et al.,* 2020). According to Wedawatta (2010a), the construction SMEs were the least prepared business sector compared to manufacturing, retail, transportation, or business and financial services. After conducting an extensive literature review on the supply chain resilience, Bhamara *et al.,* (2011) called for researchers to conduct empirical studies specifically for SMEs.

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The aim of this study is to identify supply chain resilience factors for construction SMEs to enable these companies to manage potential risks. This will be accomplished by identifying resilience factors in the supply chain literature and comparing these to the factors that apply to the construction supply chain given that construction is often characterised as 'project-based' and not dependent on enduring supply relationships. The next step was to examine how these resilience factors apply differently to construction SMEs. Examples of these resilience factors from an Australian home builder's perspective are listed.

## LITERATURE REVIEW

Along with the disruptive events happening around the world, researchers have focused on improving supply chain resilience (SCR) to reduce and prevent the potential supply chain risks (Christopher and Peck 2004). This study will adopt the definition for SCR proposed by Christopher and Peck (2004) and Ponomarov and Holcomb (2009): "capability of a supply chain to develop required level of readiness, response and recovery capability to manage disruptions risks, get back to the original state or even a better state after disruptions."

*Supply chain resilience*

In an extensive review of supply chain management literature, Chowdhury and Quaddus (2016) identified the antecedent factors for SCR through structural equation modelling and analysis. Following on their 2016 study, Chowdhury and Quaddus (2017) affirmed that SCR is a multidimensional and hierarchical model, which consists of three primary dimensions, including proactive and reactive capabilities, and supply chain design quality. They further established that SCR to incorporate factors of operational vulnerabilities (OV) and supply chain performance (SCP). Moreover, Chowdhury *et al.,* (2019) developed the SCR model by considering external context variables, supply chain relational practices (SCRP) and network complexities (NC) and proved the link between SCRE and supply chain performance was strengthened through the interaction effect of SCRP and NC. Therefore, the supply chain network complexities were conceptualized based on Chowdhury and Quaddus (2017).

The most comprehensive supply chain resilience conceptualised network was developed by Chowdhury and Quaddus (2017) is structured with four major classifications of factors as shown in Table 1.

*Table 1: Supply chain resilience factor model (Adapted from: Chowdhury and Quaddus 2017:196)*

| Proactive Factors | Reactive Factors | Design Factors | Operational Vulnerability Factors |
|---|---|---|---|
| (i) Disaster readiness | (i) Response | (i) Node density | (i) Skilled workers |
| (ii) Flexibility | (ii) Recovery | (ii) Complexity | (ii) Production/inventory management |
| (iii) Reserve capacity | | (iii) Criticality | (iii) Utility supply |
| (iv) Information integration | | | (iv) Product quality |
| (v) Efficiency | | | (v) Worker supervision |
| (vi) Market strength | | | |
| (vii) Financial strength | | | |

*Construction supply chains*

Although construction supply chain management (SCM) is closely related to the general SCM methodology, Vrijhoef and Koskela (2000) identified four distinctive roles in construction including focusing on the interface between supply chain and construction site, focusing on supply chain, focusing on transferring activities from construction site to supply chain, and focusing on the integrated management of supply chain and construction site. Due to the external risks and construction project complexity, the construction SCM is a unique and problematic issue in the construction industry (Wang *et al.,* 2017). Efficient construction supply chain management can improve the project performance and reduce the potential material waste. Construction supply chains have complex networks which require a comprehensive project management plan, strict budgetary controls, and effective monitoring of the construction schedule. These additional complexities increase the SCM risks and difficulties (O'Brien *et al.,* 2008).

A systematic literature review was conducted using the Scopus search engine for construction supply chain resilience (SCR) using the following search string:

"<TITLE-ABS-KEY ( construction AND supply AND chain AND resilience ) AND ( EXCLUDE ( SUBJAREA , "MATE" ) OR EXCLUDE ( SUBJAREA , "MATH" ) OR EXCLUDE ( SUBJAREA , "AGRI" ) OR EXCLUDE ( SUBJAREA , "CENG" ) OR EXCLUDE ( SUBJAREA , "CHEM" ) OR EXCLUDE ( SUBJAREA , "MEDI" ) OR EXCLUDE ( SUBJAREA , "PHAR" ) OR EXCLUDE ( SUBJAREA , "PHYS" ) OR EXCLUDE ( SUBJAREA , "PSYC" ) ) AND ( EXCLUDE ( DOCTYPE , "ch" ) ) AND ( LIMIT-TO ( PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) >".

A total of 35 articles were obtained and after filtering through all these articles for relevance, accessibility, duplication, and completeness, only 17 articles were selected. These articles are marked as [CONS] in the list of references.

*SME supply chains*

While SMEs are essential for economic growth and innovation, a supply chain disruption can have disproportionate repercussions for SMEs compared to larger firms. SMEs face two main challenges: their susceptibility to disruptions and their ability to recover from disruptions. In comparison with large firms, SMEs often lack sufficient resources, technological systems, financial abilities, and enterprise management systems, and are therefore viewed as more vulnerable (Sullivan-Taylor and Branicki 2011). Also, SMEs must adopt new innovative capabilities to cope with the challenges brought on by globalization. Hence, it is important for SMEs to constantly update and modify their management strategies to fulfil their customers' needs and to stop them leaving for their competitors.

Based on the literature review carried out by Arthur-Aidoo *et al.,* (2015), the Bolton Committee first formulated both "economic" and "statistical" definitions for small firms in 1971. From the "economic" perspective, there are three criteria. Firstly, they have a relatively small share of their marketplace. Secondly, they are managed by owners or part owners in a personalized way instead of a formalized management structure. Thirdly, they are independent and not recognised as a large enterprise branch. As for the "statistical" definition, the three criteria include the revenues of the firm, contribution to value add, and the number of employees. The Bolton Committee's definition for small firms in manufacturing, construction and mining industries was based on the number of employees, namely 200 or fewer employees while the European Union defined SMEs as firms that employ less than 250 persons and have annual turnovers not exceeding EUR 50 million.

According to the Australian Bureau of Statistics (ABS), there were more than 2.3 million SMEs in Australia in 2017-18. SMEs account for 99.8% of all enterprises in Australia. According to Gilfillan (2018), small businesses have 71.1% of the total employment in the construction industry and contributed 59% of the construction Industry Value Added (IVA). Based on Australian Taxation Office (ATO) guidelines, a business with an aggregated annual turnover of less than AUD 10 million from 1st July 2016 is identified as a small business. The ABS adopts a different definition for SMEs based on the number of persons employed (Gilfillan 2015): (i) 0-4 persons belong to a micro business; (ii) 5-19 persons belong to a small business; (iii) 20-199 persons belong to a medium business; (iv) 200 or more persons belong to a large business.

The next search for SMEs was carried out using this search string:

"<TITLE-ABS-KEY ( supply AND chain AND resilience AND for AND smes ) AND ( EXCLUDE ( SUBJAREA , "MATH" ) OR EXCLUDE ( SUBJAREA , "AGRI" ) OR EXCLUDE ( SUBJAREA , "ECON" ) OR EXCLUDE ( SUBJAREA , "PHYS" ) OR EXCLUDE ( SUBJAREA , "BIOC" ) OR EXCLUDE ( SUBJAREA , "CENG" ) OR EXCLUDE ( SUBJAREA , "EART" ) OR EXCLUDE ( SUBJAREA , "ENER" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) OR LIMIT-TO ( DOCTYPE , "re" ) )>".

A total of 18 articles were obtained and after a similar filtering process, only 9 articles were selected and marked as [SME] in the list of references. Only two articles, Wedawatta *et al.,* (2010a) and Wedawatta *et al.,* (2010b) were associated with SMEs in construction industry and were concerned with the impact of extreme weather events.

# RESULTS

A compilation of general supply chain resilience factors from Chowdhury and Quaddus (2017) is presented in the first column of Table 2. These factors are further elaborated for applications to the construction industry in the second column, and additionally for SME firms in the third column. The literature clearly shows that several additional factors were evident for the construction sector and for SMEs compared to the general SCR. These include reduced financial capacity and resources, unclear organisational structure, tendency to overlook industry norms and regulations, and a lack of risks management tools.

# DISCUSSION

Resilience factors in the construction sector and those specifically pertaining to construction SMEs were mapped and compared to the general supply chain resilience factors. While the construction and SME sectors have factors that are analogous to the general supply chain resilience, they also exhibit several additional factors that were exclusive to either construction or SMEs.

*Construction supply chain resilience*

In contrast with general supply chain resilience, construction companies are exposed to different disruptive events during various project phases together with potential changes in regulations, policies, material standards during the project's life cycle. Project sites are exposed to poor weather conditions, site hazards, and other environmental hazards with site resilience being defined as "anticipation" by Vrijhoef and Koskela (2000). Construction supply chain needs additional "adaptability" features to ensure project can be finished within the anticipated time, and "capacity" factors for alternative suppliers, backup equipment and repair agreements. In addition, the construction enterprises should build up reflective business models to

keep upgrading the business operations to comply with the business goals. Information integration shall apply to the entirety of construction project stages to minimise the potential risks caused by misunderstanding. In construction "efficiency" denotes managing the construction process and avoiding variations. Additionally, the construction sector must manage different transportation nodes, and project stakeholders need to build a strong network and maintain a positive relationship.

As for the "reactive" factors, construction companies should have knowledgeable leaders to manage the whole project team and develop protocols and procedures to comply with the construction legislations. Considerations about quality, cost and time when selecting suppliers and subcontractors, prepare risk mitigation strategies, and improving project team communication are additional factors for the construction sector. In contrast to the general supply chains, construction supply chains have numerous stakeholders (including users, client, designer, contractor, subcontractors, and suppliers) to be considered in the whole supply chain design process. From an "operational vulnerability" perspective, construction supply chains are susceptible to skills shortages or turnover since it takes a long time for a skilled or professional worker to attain competency in the industry. The industry also needs to maintain a high level of safety for works at the construction site.

*Table 2: Supply chain resilience factors from construction and SME perspectives*

| Column 1<br>Supply chain resilience factors | Column 2<br>Application to construction industry | Column 3<br>Application to SMEs | Column 4<br>Examples from an Australian SME |
|---|---|---|---|
| Proactive Factors<br>(i) supply chain disaster readiness: readiness training, research, warning signals, forecasting, security | Involve contractors in pre-disaster planning: immediate relief, long term recovery.<br>Disaster management: developing and implementing disaster planning; preparedness strategies.<br>Additional:<br>Anticipate extreme weather events: forecasting possible delays, employ experienced professionals to plan and forecast, regular maintenance, adequate safety training, manage custom clearance process, quality control, hire skilled labour.<br>Time dependence: disruptive events have a dissimilar impact at various times after the initial event.<br>Situational awareness: the enterprise has comprehensive understanding of project risks, such as construction site hazards, environmental/natural hazards, failure of lifelines etc.<br>Political or regulatory changes: Building code update and material standard update. | Supply chain disaster readiness: improving resilience to EWEs.<br>Additional:<br>Logistic resilience: production plan, warehouse information, documented procedures, Insurance for transportation<br>Personnel training<br>Risk taking<br>External situation monitoring and reporting.<br>A safety management system | List all relevant information before the project starts.<br>Consider unpredictable events before project started.<br>Prepare project schedule.<br>Purchase shipping insurance for materials from overseas.<br>Assign tasks to relevant personnel.<br>Develop site safety management plan.<br>Consider about extreme weather events during project planning stage.<br>Keep update the latest regulations and standard. |
| (ii) Flexibility: ability to produce a wide variety of product based on customer requirements, flexibility in contract with supply chain partners, flexibility of sourcing, distribution | Flexibility: alternative transportation routes, alternative supply sources, vertical integration, flexible supply agreements.<br>Additional:<br>Adaptability: early orders, adequate buffer time in between supply chain and onsite, well planned site layout, well planning material loading/unloading, enhanced site supervision, frequent maintenance. | Flexibility: offer products more often and more innovatively.<br>Have a faster response in the process. | Predict the potential risks based on experience.<br>Update the management methods/communication methods based on the current situation.<br>Plan project schedule as early as possible to avoid material shortage and project delay. |
| (iii) Reserve capacity: backup machinery, equipment, logistical options, and energy source | Capacity: have alternative transportation backups, supplier backups, alternative machine/equipment backups, emergency repair agreements, machinery instead of labour, specialised sub-contractor.<br>Additional:<br>Reflective business model: Companies regular self-evaluation and assessment to update the business operations in terms of their goals. | Capacity: offer a broader range of products, ability to adjust demand capacity,<br>Delivery and inventory, capability and capacity of internal resources. | Prepare for contingency plans or have alternative suppliers.<br>Establish material order lead-times, material delivery period and subcontractor booking period.<br>Build up business model to conduct self-assessment and improve business operation efficiency. |

| | | | |
|---|---|---|---|
| (iv) SC information integration | Visibility: advanced IT systems, RFID tags to track prefab units | Information integration: purchasing Information technologies | Updated records of material purchase information/project progress and share information to other project stakeholders |
| (v) Efficiency: waste reduction, quality control, productive employees | Efficiency: automated manufacturing, avoiding variation.<br>Additional:<br>Transportation nodes | Efficiency: demand forecast in the logistic area | Ensure that materials can be delivered on time by contacting the suppliers/subcontractors a few months earlier before the project starts. |
| (vi) Market strength: buyer/supplier satisfaction, supplier product differentiation | Market position: have healthy, long-term relationship with client; market pressure; sensitive to market; robustness of network | Market strength: customer service, social network relationships, higher customer-oriented performance<br>Additional:<br>Improvements: improvements to quality | Update the clients/owners with the latest information and obtain feedback.<br>Provide professional advice to the client.<br>Communicate with the client and solve problems positively. |
| (vii) Financial strength: diversified business portfolio, fund availability | Financial strength: adequate contingencies, insurance coverage, healthy cash flow | Financial strength: sufficient cash flow | Ensure sufficient funding is available based on the contract.<br>Conduct precise estimating before sign the contract to make sure company has sufficient cash flow. |
| Reactive factors<br>(i) Response: quick response, adequate response team | Additional:<br>Leadership and management: the company has experienced leaders with a wise vision of its objects.<br>Aligned business practice: the organisation implements protocols and procedures that are compliant with legislation.<br>Primary performance: product quality, commodity price and cost, delivery and service | Response: Internal situation monitoring and reporting, emergency response.<br>Additional<br>Indicators to measure performance.<br>Innovativeness. | Communicate immediately to seek solutions.<br>Post-completion review and list improvements for future projects. |
| (ii) Recovery: quick recovery, reduction of impact and reduction of recovery cost | Recovery: have professional team deal with vulnerabilities, consequence mitigation strategies, improve project team effective communication | | Record the past project problems and make project risks mitigation plan. |
| Supply Chain Design Factors<br>(i) Node density: concentrated market vs diversified market | Additional:<br>Supplier/subcontractor: competitive supplier selection; procurement process | Additional:<br>Production plan. | Build a database of suppliers.<br>More than two subcontractors/suppliers each type of work. |
| (ii) Complexity: more tiers, multiple buyers | Contractor: collaboration; dispersion - empower site staff control the process quality | | Actively communicate with project stakeholders. |
| (iii) Criticality: alternatives for critical supply/item | Designer/Owner: sustainability for design and environment; eco-design; energy resilience | | Fully review the working drawing before construction to collaborate with architects. |
| Operational vulnerability factors<br>(i) Skilled workers | Efficiency: improve labour productivity.<br>Additional:<br>Difficulty in finding the right people | Difficulty in finding the right people | Retain good employees. |
| (ii) Production/inventory management | Material inventory management | Inventory policies | Conduct construction management plan to sufficient manage materials on site or on stock. |
| (iii) Utility supply disruption | Utility supply disruption | Utility supply disruption | Install temporary utilities and facilities before work starts |
| (iv) Product quality | Quality management<br>Additional:<br>Sensor technology | Quality management | Experienced site manager |
| (v) Worker supervision | Security: onsite safety | Onsite safety management | Experienced safety manager |

*Construction SMEs' supply chain resilience and future research opportunities*

Construction SMEs are particularly concerned with extreme weather events since the supply chain and project sites can be adversely affected. SMEs need to focus on logistic resilience, personnel training, and using risk control method to continuously

monitor the external situation and update their database to prevent potential risks. Despite their limited size, SME contractors are obliged to develop a safety management system.

As for the "flexibility" factor, construction SMEs are more likely to be client oriented, therefore, they need to update their product or services in an innovative way and response to the project stakeholders efficiently. The project management team needs to collaborate with the clients, and to manage project schedule in an efficient way to avoid material shortage issue and project delays.

Regarding "capacity", "information integration" and "efficiency" factors, SMEs are more related to construction relationship network and management process. Construction SMEs must ensure that they have sufficient capacity to cope with supply chain disruptions. The whole SME supply chain network needs to collaboratively build up business resilience to maximize the use of resources and suppliers based on different construction SMEs' organizational goals, therefore, improve the supply chain efficiency (Sahebjamnia *et al.,* 2015). Further research also needs to consider how to build up information integration system for construction SMEs as these SMEs do not adopt advanced technologies such as BIM (Hosseini *et al.,* 2016).

In the "market and financial strength" dimension, SMEs should continuously improve their construction or product finish quality to satisfy the clients' requirements. They also need to maintain a positive communication system with clients. The SMEs always require sufficient funds to ensure the company can run smoothly. While SMEs contributed 60% to the Australian economy, SMEs are consistently facing financial constraints. Therefore, policy makers should enact policy initiatives to strengthen SMEs' financial position and their contribution to the economy (Banerjee 2014).

As for "reactive" factors, construction SMEs should develop their own indicators to evaluate their project performance after the project is completed, and apply lessons learned to improve their future project quality. In addition, SMEs should also innovate their construction scheduling and management system to keep up with the current practices.

For the "supply chain design" and "operational vulnerability" factors, construction SMEs need to positively build up their own project stakeholder database. In addition, since there is no clear organizational structure, employees normally handle multiple tasks in construction SMEs, therefore, it is hard for SMEs to find a right person to replace the original staff.

This review has revealed several gaps in construction SMEs' resilience factors that can be addressed in future research projects. These include developing qualitative methods to identify additional risks in construction together with quantitative methods such as structural equation modelling to prioritise these risks (Wang *et al.,* 2014). Other research areas include evaluating innovative organisational structures for construction SMEs (Davis *et al.,* 2016), the investigation into level of collaboration with SMEs' key project stakeholders (Bak *et al.,* 2020), identifying the response (internal and external) and recovery strategies, improving leadership roles to maintain a positive relationship of all the project stakeholders and maintain good employees and managers (Gallego-Roquelaure 2020).

## CONCLUSION

This systematic literature review on the resilience factors for both construction and SMEs supply chains aims to improve supply chain resilience by compiling, adopting,

and linking all applicable supply chain resilience factors. The review has clearly identified factors that are common between supply chains in general, construction supply chains, SMEs, and construction SMEs. More importantly, the review has identified factors that specifically pertain to construction and construction SMEs that will be the subject of future research into construction SCR. The review has also confirmed the limited research into the resilience of construction SMEs in the light of recent disruptions. This will adopt either in-depth interviews, quantitative data analysis or case studies on construction SMEs to expose and elucidate further resilience features.

This review contributes to the body of knowledge concerning construction supply chain resilience, also demonstrates the supply chain resilience factors for construction industry and particularly focused on construction SMEs. This research is expected to form the basis for further qualitative and quantitative research in supply chain resilience for construction SMEs in the light of increasingly challenging global trade tensions and supply disruptions as the result of the pandemic.

Some limitations of this paper include the review of only the Scopus database and the application of SMEs supply chain resilience factors solely from an Australian perspective. Future research may be extended to examine resilience from other project stakeholders' perspective.

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# THE ROLE OF CONSTRUCTION CORRUPTION IN WORSENING THE HUMAN IMPACT OF NATURAL DISASTERS: A SYSTEMATIC LITERATURE REVIEW

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This paper presents a review of international peer-reviewed academic research into the question of how corruption in the construction industry can exacerbate the human impact of naturally-triggered disasters. A systematic review of peer-reviewed academic papers from the fields of corruption, construction and disaster management over the past thirty years reveals a dearth of empirical research in this area. Results indicate that existing research tends to focus on the quality of governance and the drivers of corruption and is fragmented, limited and narrow in scope. Despite these limitations, evidence is found to support the proposition that corruption in the construction industry can significantly worsen the economic, social and environmental impacts of naturally-triggered disasters. This appears to be especially the case where corruption, disaster, and poverty intersect. Acknowledging the methodological challenges of undertaking research in this area, it is concluded that more research is needed to test this proposition which intersects the related fields of corruption, natural disasters and the construction industry.

Keywords: corruption; disasters; social impact; community

## INTRODUCTION

The Centre for Research on the Epidemiology of Disasters (CRED) (2019) Emergency Events Database (EM-DAT) defines a disaster as "a situation or event that overwhelms local capacity, necessitating a request at the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering". In 2019 alone, CRED recorded 396 disasters, impacting 95 million people, causing 11,755 deaths and costing US$103 billion in economic losses globally.

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Disasters such as these are triggered by natural hazards such as earthquakes, tsunamis and windstorms (cyclones, hurricanes and typhoons). The natural hazard however is only half the story. A hazard needs to strike a vulnerable location to become a disaster. A tsunami striking a deserted coastline may have very little immediate impact on a population; a tsunami striking a dense, low-lying coastal city is a different matter. Poorly designed, constructed and managed buildings built in high-risk areas and urban densification in many parts of the world is increasing community vulnerability to natural disasters (Sanderson and Sharma 2018). For example, Smith (2006) shows that in every phase of a disaster (Mitigation, Preparedness, Response, and Recovery), human decisions play a critical role in determining the impacts of disasters for communities. Using Hurricane Katrina as an example, Smith (2006) shows how these impacts follow social stratifications, with wealthier people typically living in less vulnerable areas, being more informed, more able to escape and having better insurance policies for rebuilding. Smith (2006) provides anecdotal evidence that corruption in the construction industry exacerbates the negative impacts of natural disasters. More recently, the COVID-19 pandemic has increased the risk of corruption occurring. As the OECD head of bribery and corruption recently warned, governmental relaxing of procurement regulations and speeding up of processes and building and infrastructure projects in the wake of the COVID-19 disaster was creating, across the globe, a 'paradise for corruption' which could reduce future resilience to future disasters and potentially make them worse (OECD 2020).

And it is for these reasons that in this paper we do not refer to 'natural disasters', but rather, naturally-triggered disasters. Many natural disasters are not as natural as they may first seem.

The United Nations Development Programme defines corruption as the misuse of entrusted power, office or authority for private benefit and estimates that USD$1,000 billion are paid in bribes every year, costing countries up to 17 percent of its GDP (United Nations Development Program 2020). The construction and infrastructure industry has been repeatedly labelled the most corruption-prone industry in the world by Transparency International and World Bank (WEF, 2016). The Global Infrastructure Anti-Corruption Centre (2020) provides many examples of corruption in infrastructure projects around the world including bribery, rigged tendering, extortion, fraud, cartels, abuse of power, embezzlement, and money laundering. There is significant evidence that large amounts of public funding injected into infrastructure and construction projects are syphoned off into private hands (up to 40% in some countries) acting to further increase the vulnerability of communities to future disasters (Kenny 2006, Hostetler 2011). Indeed, Transparency International (2006) describes a world built on bribes and reports that the human impact of corruption is especially threatening for fast-growing cities in low and middle-income countries.

There has been a considerable amount of research into corruption in the construction industry (Bowen *et al.,* 2012, Le *et al.,* 2014, Brown and Loosemore 2015, Chan and Owusu 2017). However, the question of how corruption in the construction industry exacerbates the impact of naturally-triggered disasters has received surprisingly little research attention. The aim of this paper is to investigate this gap in knowledge through a systematic literature review (SLM) of extant research in the fields of corruption, built environment and hazard related disasters was undertaken. This is important in building a conceptual foundation for both research and practice in advancing this important but neglected field of knowledge.

## METHOD

The study employed a SLM methodology informed by Tranfield *et al. (*2003) and Thorpe *et al.,* (2005) given its demonstrated value in understanding the state of knowledge in a field. The authors adopted an SLM approach because as Tranfield *et al. (*2003) notes, in comparison to traditional narrative reviews it is based on a replicable, scientific and transparent process/method which minimises potential bias through exhaustive literature searches of empirical research in respected peer-reviewed sources.

A systematic search of databases (PubMed, JSTOR, and ProQuest) of extant research in the fields of corruption, built environment (design, construction, planning) and hazard related disasters was undertaken. The reputable databases of PubMed, JSTOR, and ProQuest were used, as these databases constantly index scientific journals with the vast majority of peer reviewed literature at the convergence of these three topics. To adequately represent the current state of the literature and of this field, the literature search was limited to publications from the years 1990 to 2020, encompassing the last 30 years of scholarship.

Inclusion criteria were: Written in English; Original peer-reviewed research; Implicit discussion of corruption, built environment (design, construction, planning) and/or disaster. Additionally, the references of the selected studies and requested references were searched from various experts in the field to find any other papers that may have been missed by the search strategy. After duplicate publications were removed, a final count of 59 papers qualified for full content extraction and analysis. The majority of papers published in the years 2005 (6), 2017 (6), 2015 (7) and 2019 (7). All papers were published post 1990. These papers were then analysed by extracting and summarizing from each paper: descriptive metrics of each study; key findings; recommendations; and authors' narrative perspective, if given. All of the authors independently performed a critical review of the extracted summary findings generated by this data extraction process using methods described by Grant and Booth (2009). A process of cross-checking allowed high inter-rate agreement and provided confidence in the validity of the results reported below.

## RESULTS AND DISCUSSION

*Evidence of correlation between disasters, construction and corruption*

The review highlighted evidence of correlation between disasters, construction, and corruption. For example, Linthicum (2018) reported that building collapses killed 228 people during an earthquake in Mexico City due to poorly constructed buildings signed-off by private building inspectors hired and paid by developers. Ambraseys and Bilham (2011) drew a direct correlation between corruption and disaster, when they calculated 83% of all deaths from building collapse in earthquakes over the past 30 years occurred in countries that are anomalously corrupt. As the authors note, earthquake-resistant construction depends on responsible governance, its implementation undermined by corruption through the use of substandard materials and assembly methods, or through the inappropriate siting of buildings.

*A focus on earthquakes*

Among the various disaster types, earthquakes were discussed the most in relation to corruption (34% of papers). Corruption was exposed in the compromises to earthquake preparedness in buildings due to lax, deficient, or absent building codes and laws in low- and middle-income countries which amplified poor standard of

building construction (Crowley and Elliott, 2012). In Turkey, several papers discuss how constructed buildings were unsafe prior to the earthquakes (Green, 2005; Gunduz and Önder, 2013; Kenny, 2012; Özerdem and Barakat, 2000). For example, Özerdem and Barakat (2000) found that bribes and political favours were common practice in Turkey to obtain building permissions. These papers about earthquakes in Turkey converge on the idea on how fraud and lack of regulation were institutional failures within the government system.

In earthquake-related studies, papers were found to suggest that public and private sector corruption was connected to additional lives lost to disaster impact which could have been avoidable (Ambraseys and Bilham, 2011; Anbarci, Escaleras, and Register, 2005; Escaleras, Anbarci, and Register, 2007). For example, Ambraseys and Bilham (2011) found that poor construction was exposed during earthquakes, citing examples from Haiti, China, India, Japan, Indonesia, Iran, and New Zealand, which led to a catastrophic scale of lives lost and costs. Escaleras *et al.,* (2007) analysed 344 earthquakes occurring between 1975 and 2003 and found that public sector corruption was found to be positively related to earthquake deaths. Highlighting the nuances that level of governance is embedded into the institutional failures and built environments within local communities.

*Types and causes of corruption*

Most papers were not specific about the type of corruption, although bribery and mismanagement of public funds were the most frequently discussed when relating to disasters. Unsurprisingly, almost every publication discussed the quality of governance in relation to corruption and disasters. Issues included limited government oversight, incompetence, weak controls, low capacity, limited budgets and weak, if any, preparedness planning, or after disaster, competency in recovery efforts (Ambraseys and Bilham, 2011; Rumi, 2010; Schultz and Søreide, 2008). Where governance is stronger, disasters are fewer. Persson and Povitkina (2017) carried out a study using time-series and cross-sectional data from CRED. The authors found that in countries where democratic institutions are strongly developed, there was a higher quality of government associated with substantively lower numbers of people affected by naturally-triggered disasters (Persson and Povitkina, 2017). In an examination of risk financing and disaster mitigation of tsunamis affecting Southeast Asian countries, Loh (2005) found that good governance is the key element for reducing corruption in post-reconstruction countries for the long term.

*Focus on developing countries*

China and Indonesia were the two countries which were discussed most frequently (88% of the papers). Apart from Smith (2006) there were few papers that considered the interaction between disasters, corruption and construction in developed countries. The papers in developing countries discussed the failures within political context, local institutions and established built environment in communities (Bamidele, Olaniyan, and Ayodele, 2015; Calgaro and Lloyd, 2008; Kharas *et al.,* 2009; Konadu-Agyemang and Shabaya, 2005; Porteria, 2015; Rodolfo and Siringan, 2006; Smith, 2007). Poverty related to corruption in relation to high unemployment levels, human rights violations, and opportunities for local officials to supplement low-paying salaries (Alamgir *et al.,* 2017; Brown and Brown-Murray, 2010; Gros, 2011; Özerdem, 2006; Özerdem and Barakat, 2000; Schultz and Søreide, 2008; Smith, 2007; Weinstein, Fletcher, and Stover, 2007). Lewis (2012) examined the long-term vulnerability and risk of disasters in several countries including Indonesia, and India and found that impoverishment was as active threat to communities, especially with

the changing culture, denial of access of resources, and siphoning of public money. In a follow up paper, Lewis (2017) found that almost half of all deaths due to disasters that occurred in low-income countries from 1996 to 2015 were tied to a country's apparent poverty. The authors suggested that this apparent poverty was closely connected to commercial mismanagement and corrupt politicians.

Examining data from 1990 to 2010 on the occurrence of disasters and its effects on corruption in the public sector, Yamamura (2014) found in high-income countries ongoing incentives to live with disaster risk exist due to future compensation payments. These payments connect economic motivations to the determinants of corruption. Shabbir and Anwar (2007) and Seyf (2001) suggest that corruption negatively impacts the economy of countries, especially low-income countries. These economic ramifications were also explored by Ambraseys and Bilham (2011) who found a correlation between poverty and corruption by examining the relationship between countries perceived to be those most corrupt (using Transparency International's Corruption Perception Index) and Gross National Income per capita.

The publications reviewed suggested that three key drivers that lead to opportunities for corruption are economic development, inequality and poverty. Mochizuki, Mechler, Hochrainer-Stigler, Keating, and Williges (2014) looked at past methodologies, modelling, understandings of economic risk, vulnerability, resilience, adaptive capacity and development as it relates to disasters. The authors found causal relationship between levels of economic development, quality of institutions (including corruption levels), and disaster impacts.

Examining the power structures, injustices, corruption and inequalities which remained from Hurricane Katrina in the United States, Belkhir and Charlemaine (2007) found that Hurricane Katrina heightened the existing social crisis within communities. This social crisis was seen in the race, gender and class inequalities which manifested in disaster management decisions to initially protect property and wealthier regions over lower income areas where the hurricane's impact was most severely felt. Voigt and Thornton (2015) reviewed 10 years of media, court cases and public documents related to post-Katrina and disaster-related human rights violations and corruption. The authors found that corrupt practices by government officials in public services in the recovery efforts from Hurricane Katrina included bribery, dishonest services, wire fraud, money laundering and tax violations.

## CONCLUSION

Within the context of the increasing risks of naturally-triggered disasters and increasing urbanisation in many countries, the aim of this paper was to review the existing scholarship found in leading databases to address a gap in knowledge about the relationship between corruption in the construction industry and the impact of disasters. This review found that this critically important area of research is largely unexplored. This review found a lack of empirical research on disasters and corruption to provide the basis for informed evidence-based policy and practice development and raises many new questions and key avenues for further research. The limited research that does draw the link between disasters, construction and corruption focusses mainly on earthquakes and do not reflect the increasing risks of extreme weather events facing many countries. The literature is also limited to developing countries and fails to draw definitive links between causes and consequences.

These findings indicate a clear need for cross-disciplinary research to explore the potential impact of corruption in construction with disaster outcomes over the life cycle of construction projects, in every phase of a disaster (causes, vulnerability, preparedness, results and response, and reconstruction) and, given references to the importance of governance, in a wider sample of countries. In particular, there is a need to broaden out the types of disaster types researched, and the range of countries impacted - beyond earthquakes, China, and Indonesia - to a variety of high-, medium-, and low-income countries, all of which are prone to corruption.

Our findings indicate that linking the currently disconnected fields of corruption, construction and disaster management could contribute significant new insights into reducing the human impacts of future naturally-triggered disasters. Standard global indexes of corruption appear to be of limited value in indicating what this relationship may be and where it may be most strong.

There is also an important social justice dimension to future research in this area. For example, it would be useful to explore how different types of construction corruption actions impact the vulnerability, preparedness, response, and reconstruction of different elements of communities in terms of their socio-economic status, education and geographic location.

Acknowledging the complex and sensitive issues and challenges and even risks in undertaking such research, it is likely that construction researchers will need to explore new innovative methodologies and methods of data collection and analysis to move this new area of research forward. The current dependence on anecdotal examples and case studies points to the need for more empirical research. There is a rich untapped body of information, that is publicly available, rigorous, and evidence-based from which the links to a disaster occurring can be found. While interesting ethical challenges in gathering primary data from respondents in the field, sources of secondary data such as published criminal court case findings can also be explored using newly available and powerful textual analysis software and can release researchers from the burden of ethical challenges to undertake the research, since the findings are already public domain information. This approach is already underway in criminal studies but has not yet sufficiently found its way into the construction literature.

The authors recognise the limitations to the methods used in this study. Our study strictly covers scientific non-invited peer-reviewed journal articles that make explicit mention of the above search terms and that we do not cover other related concepts. We recognise the limitations of using only peer-reviewed literature for this paper, which does not cover works published in books, magazines, reports, working papers, grey literature, and other non-refereed sources. Finally, the focus of this paper is on the level of pre-disaster corruption that plays a large role in determining how damaging a disaster may be. The significance and scale of post-disaster corruption in relief and recovery activities should be the subject of future research.

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# Equality and Diversity

# DESIGNING THEORETICALLY AND EVIDENCE-BASED SOCIAL PROCUREMENT PROGRAMMES IN CONSTRUCTION: A CAPABILITY EMPOWERMENT APPROACH

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Social procurement policies require companies to develop and implement initiatives to create social value, yet many programmes created in response to these emerging policies lack a reliable empirical and theoretical foundation. Addressing this problem and brining a new theoretically informed evidence-based approach to social procurement research in construction, this paper presents a theoretically informed and methodologically robust social return on investment (SROI) analysis of a construction training programme developed to reduce the risk of youth homelessness. Mobilising Sen and Nussbaum's Capability Empowerment Approach, the paper provides robust, testable and transparent evidence of the social impact of the programme on the lives of the homeless people who went through it. Robust theoretically informed social procurement initiatives are critically important in ensuring that social procurement policies have their intended social outcomes.

Keywords: social procurement; theory of change; SROI; employment; youth

## INTRODUCTION

Recent research into the growing use of social procurement in construction has argued that there needs to be further empirical exploration of social procurement as it is under theorised and conceptualised (Troje and Andersson 2020). As these policies continue to evolve in countries such as the UK, Sweden, Australia, Canada and South Africa, there have also been calls for more research into the measurement of social procurement policy outcomes (Watts *et al.,* 2019). However, social value measurement methodologies remain contested and theoretically unsound (Raiden *et al.,* 2019). One potentially valuable theory, which could be employed to conceptualise the social value created by social procurement initiatives, is Nussbaum's (2000) capabilities empowerment approach. This is founded on the idea that there is a threshold level of capability across a number of dimensions, which need to be achieved to enable people to meet their full potential as members of society. Notably, Nussbaum (2000) also explains that the capability empowerment approach could be used with cost benefit analysis (CBA) as long as it is acknowledged that one capability is not prioritised over the next. The increasingly popular social return on

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investment (SROI) approach is based on the principles of CBA and works by assigning monetary values to social and economic returns (Rotheroe and Richards, 2007). The aim of this paper is to address the lack of theory and rigorous measurement in the context of social procurement by examining whether the capabilities empowerment approach can be used as a theoretical basis to underpin the measurement of the social value. Using a case study of an intermediate employment programme created to help young people at risk of homelessness to find work in construction, this paper contributes to the advancement of research into social procurement practice and social value measurement in the field of construction management.

*Measuring social value using a capabilities empowerment approach*

In measuring the impact of social procurement initiatives, SROI is increasingly used (Watts *et al.,* 2019). SROI is a framework for measuring and reporting on the social, economic and environmental value created by a policy, programme or intervention (Nicholls *et al.,* 2012). Based on traditional economic evaluation including CBA and accounting the SROI methodology provides a holistic framework to include wider social impact based on strong engagement with stakeholders (Gosselin *et al.,* 2020, Rotheroe and Richards, 2007). SROI is a metric used to quantify the impact an organisation generates per unit of currency (£1) invested. In order to determine the SROI, organisations assign a monetary value to economic, social and environmental outcomes produced over a specified period. A ratio of 1: 2 would indicate for every £1 invested in a programme there was £2 of wider social value creation. There have been examples of the SROI methodology being used in construction. For example, Watson *et al. (*2016) used SROI to capture the social value of buildings created for end users. Watson and Whitley (2016) suggest SROI is a well-developed method with significant potential to gather feedback from the end users of buildings and a way of communicating this value in an effective way.

Criticism of the approach tends to focus on the technical and instrumental challenges of SROI and its weak theoretical basis (Krlev *et al.,* 2013, Raiden *et al.,* 2019). Fujiwara (2015) also argues that in contrast to more established cost benefit analysis methodologies which have a strong foundation in ethics, the guidance on SROI does not provide a principled normative account of 'the good' (Fujiwara, 2015). Fujiwara (2015) suggests without a moral account of 'the good' valuation methods can be ad-hoc with the weights and values applied being subjective and haphazard with the outcome of SROI having little value. However, as Watson and Whitley (2016) note, SROI is not just about a single financial ratio it is a framework that gathers qualitative data with the potential to communicate value in an effective way.

The implementation of SROI methodologies in research is relatively rare because SROI methodologies have emerged from practice, and as such there is limited peer-reviewed literature on the subject and a lack of theoretical underpinning (Krlev *et al.,* 2013). While the SROI methodology does emphasise the importance of a 'theory of change' to represent all the steps needed for a programme to reach its intended outcomes (Nicholls *et al.,* 2012), SROI practitioners are not required to justify the theoretical foundations of the inherent causal mechanisms in the 'theory of change' that lead to the desired outcome. Therefore, while a theory of change is seen as crucial for an effective social impact assessment, they are in reality rarely theoretically informed. Arvidson *et al. (*2010) and Raiden *et al. (*2019) recognised that this is a fundamental weakness of the SROI approach and that more research is needed in order to understand how SROI can be used to understand change in order to improve

the rigour, robustness and reliability of claims about the social value of social programme interventions. Without a sound theoretical foundation, claims about the social impact of programmes implemented in response to social procurement policies in construction cannot be made with any legitimacy because the causal links between inputs, outputs and outcomes cannot be empirically supported.

In addressing this problem, the capabilities empowerment approach is a potentially valuable conceptual framework because it conceptualises the types of social problems targeted by social procurement policies (such as homelessness) as a form of 'capability-deprivation' (Kimhur, 2020). Kimhur (2020) suggests Nussbaum's list provides a good philosophical grounded framework that keeps open a flexible space for defining specific contextual central capabilities. The capabilities approach argues that these capability deprivations are often the result of relative deficiencies in opportunities and resources available to people who suffer them, rather than any innate fault of their own. It is an especially useful framework because it presents a codified list of central capabilities which people need to develop in order to mitigate the risks of these types of problems These include: Life (living a life of a normal length and having a life that is worth living); Bodily health (having good health, adequate nourishment and adequate shelter); Bodily integrity (freedom of movement and autonomy over bodily boundaries); Senses, imagination and thought (being able to think, imagine and reason); Emotions (being able to have attachments to things and people). Practical reason (participating in the planning and managing of one's own life); Affiliation (the development of self-esteem and dignity through relationships); Other species (having concern for nature); Play (the ability to laugh, play and enjoy recreational activities); and Control over one's environment (having the right to seek employment on an equal basis to others and having the freedom to control one's life (Nussbaum, 2000).

## METHOD

Data was collected within a single exploratory case study of an intermediary construction programme which had been set up to provide disadvantaged youth who were at risk of homelessness, access to work in the construction industry. Following Yin (2017), we adopted a single case study approach because as far as we are aware, the case study described below is the only example internationally of such an initiative. The programme was called Symud Ymlaen/ Moving Forward (SYMF) it provided individualised and tailored support and training alongside on-going mentoring and culminated in a 26-week paid construction work placement. Fitzpatrick *et al. (*2021) proposed a five-part homelessness prevention typology to explain the particular types of interventions needed at specific times to prevent homelessness: Universal - preventing or minimising homelessness risks across the whole population; Targeted - early-stage, focused prevention aimed at groups at a higher risk of experiencing homelessness; Crisis - the prevention of homelessness likely to occur within a foreseeable time period; Emergency - support for those at immediate risk of homelessness, especially those young people sleeping rough. Recovery - the prevention of repeat homelessness (Fitzpatrick *et al.,* 2021). Fitzpatrick *et al. (*2021) argues that if we are to end homelessness, we need to move resources upstream towards the universal prevention and targeted prevention components of the typology. The SYMF programme is an example of targeted homelessness prevention as it is aimed at young people who are at risk of experiencing homelessness (Schwan *et al.,* 2018).

To provide a theoretically informed empirical evidence-base around the social impact of this programme, an evaluative SROI was undertaken based on Nussbaum's (2000) capabilities empowerment approach and on evidence from semi-structured interviews with ten young people who were purposefully sampled on the basis of completing the programme. The SROI methodology was based on Nicholls *et al. (*2012) and involved the following steps: Step 1. Establish scope and consult key stakeholders - Once scope was established semi-structured interviews were conducted with SYMF participants to explore the impact of the programme against each capability variable, data was supplemented by programme evaluation forms distributed during the programme; Step 2. Mapping outcomes - A theory of change for the SYMF programme was developed showing the relationship between inputs, outputs and outcomes; Step 3. Evidencing and valuing outcomes - The semi-structured interview data was analysed to identify programme outcomes for participants using inductive and deductive thematic analysis (Guest *et al.,* 2012) based on a coding framework using Nussbaum's (2000) capability categories, followed by desk-top research to find and apply the most appropriate financial proxy for each outcome; Step 4. Establishing impact - Desk based research was conducted to establish deadweight (what would have happened anyway); Displacement (what activities were displaced); Attribution (who else contributed to the change) and drop-off (does the outcome drop off in future years); Step 5. Calculating the SROI - The outcomes were divided (once impact had been established) by inputs into the SYMF programme. The sensitivity analysis was undertaken in order to understand the difference different decisions would have made e.g., using higher or lower financial proxies. Following these stages, the results are presented below.

## RESULTS

An evaluative theory of change was constructed, at the end of the SYMF programme with data from interviews with participants and desk-based research (See Table 1). The theory of change shows all the building blocks that were needed for the SYMF programme to reach its intended outcomes. A theory of change is a representation of all the steps needed for a programme to reach its intended outcomes and enables programme designers to be clear on long-term goals, identify measurable indicators of success and formulate actions to achieve these goals (Nicholls *et al.,* 2012).

In calculating programme inputs, the cost per participant was £13,477 which included pre-employability support and a paid 26-week work placement paid at minimum wage. An employer's time supporting, training and supervising a SYMF placement. Hogarth *et al. (*2012) calculated the costs of staff time for the first year of an apprenticeship was £6,584. As SYMF placements lasted for six months, we claimed for £3,292 for construction industry time. The inputs of the SYMF programme are listed in table 2. Data was analysed from the semi-structured interviews and the monitoring and evaluation forms distributed during the programme to determine the outcomes of the programme (see Table 3).

Desktop research was then undertaken to find the most appropriate financial proxies to value these outcomes (see Table 3). It can be challenging to value intangible outcomes (Arvidson *et al.,* 2010) and for this reason social value portals have begun to emerge to provide comparative and stable proxies for SROI practitioners to use. These are sometimes restricted to specific sectors. For example, the HACT (2018) value bank uses national surveys to isolate factors such as increased confidence or a person's wellbeing meaning it has been possible to calculate the amount of money

needed to improve a person's wellbeing (Gosselin *et al.,* 2020). However, as Raiden *et al. (*2018) note there are no universal value banks, data sets or frameworks for assessing social value within the built environment. A summary of how each component of the capabilities approach was valued is detailed below.

*Table 1: The Capabilities Approach: Theory of Change*

| Inputs | Activities | Outputs | Outcomes: The Capabilities Approach | Impact |
|---|---|---|---|---|
| Cost per participant<br>Mentors time<br>Employer time | Assessment<br>Mentoring support<br>Occupational area identified<br>Training courses<br>26-week work placement | Construction specific accreditations<br>Accreditations gained including literacy and numeracy<br>Completion of personal development plan<br>Completion of a work placement | Life - Homelessness prevented (rough sleeping and staying in unsafe places)<br>Bodily integrity - Practical knowledge of Health and Safety on a construction site<br>Health - Improved mental health, physical health and reduced harmful substance use.<br>Senses, Imagination and Thought - Contextualised learning of literacy and numeracy skills on a construction site.<br>Emotions - Young people improve their relationships with their families.<br>Practical reason - young people reflect and plan for the future<br>Affiliation - Young people are better at talking to colleagues and strangers.<br>Other species - young people develop a concern for nature.<br>Play - Young people take part in recreational activities<br>Control over one's environment - Desistance from offending and young people progress into construction employment, apprenticeships, and vocational training | Homelessness and repeat homelessness prevented |

*Table 2: The Inputs of the SYMF Programme*

| Input | Description | Value |
|---|---|---|
| Cost per participant | Full costs of programme (£13,477 per participant) x 10. | £134,770 |
| Mentors time | £11.85 an hour a week over 26-weeks (£308.10 per participant) x 10. | £3,081 |
| Time of construction industry placement provider | Employer time supporting an apprentice for 6 months (£3,292 per participant) | £32,920 |
| | Total inputs per ten participants | £170,771 |

The life component concerns being able to live to the end of a human life of normal length; and not having one's life reduced so it is not worth living (Nussbaum, 2000). An SROI of the Nightstop service where volunteer hosts in the community open their

homes to young people to prevent them sleeping rough or in an unsafe place valued preventing youth homelessness at £26,000 this is the financial proxy that was used to value the life component (McCoy and Kempton, 2016).

Homelessness makes it difficult for people to maintain their bodily integrity (McNaughton Nicholls, 2010). However, it was decided to value the training and experience of working on a live construction site which helped young people maintain their bodily integrity. The experience of following safe practices on a construction site in order to preserve bodily integrity has been valued at £2,507 for general work-related training to help find a new job (HACT, 2018).

Improved physical health will have a significant impact on a young person's life and is valuable. SYMF participants were aged 16-18 and improvements in physical health would be unlikely to result in significant cost savings until they are older. The HACT (2018) database values 'frequent mild exercise' at £2,130. New Economy Manchester (2019) has a value of £32 for a GP prescription costs per consultation this is the value that was used. For improved mental health a financial proxy was used from an SROI project that was a partnership between NHS Wales and charity Change Step a value of £9,926 (Lloyd, 2018). A financial proxy was used of £4,215 to value decreased substance misuse based on reductions in drug-related offences and effective treatment programmes taken from an SROI study on the value of youth work (Murphy, 2020).

The senses, imagination and thought component covers the cognitive capability to perceive, imagine and think informed by an adequate education including but not limited to literacy, numeracy, and scientific training (Nussbaum, 1993). Participants indicated they valued the opportunity to improve their literacy and numeracy skills while working on a construction site. Ideally, a financial proxy would have been used that valued contextualized learning to explain the value of learning on a construction site rather than a classroom. The HACT (2018) value of £484 for employment training was used to value this change.

For the emotion component participants indicated that they had improved how they managed their emotions while participating in the SYMF programme. An SROI of a parenting programme in Wales used a financial proxy of £600 the cost of six family therapy sessions this was used to value this change (Barnardo's Cymru, 2018).

The practical reason component concerns people participating in the planning and management of their own lives (Nussbaum, 1993). An analysis of participant's personal development plans showed that they had engaged in planning for the future, and critical reflection. To value this change a financial proxy of £1,316 was used the market value of a career development course (Leathem Bradly, 2014).

The affiliation component describes the sense of affiliation and concern for other people and the value these recognitions and affiliations add to the quality of our lives (Nussbaum, 1993). An SROI report of a parenting group used 40% of the HACT (2018) value totalling £740 to value being a member of a social group (Barnardo's Cymru, 2018). This financial proxy was used to value the affiliation component.

Other species is an important component of the empowerment capabilities framework. Bagnall *et al. (*2019) used a financial proxy of gardening as a hobby to value nature relatedness in an SROI of the Wildlife Trust of £847 per person.

The play component is about being able to laugh, play and enjoy recreational activities (Nussbaum, 1993). Two participants told us they were more likely to participate in

recreational activities following participating in the SYMF programme. The HACT (2018) value of attending a youth club at £2,464 was used to value this change.

Part of the control over one's life component is having the right to seek employment on an equal basis to others and having the freedom to control one's life (Nussbaum, 2000). New Economy Manchester (2019) reports the average cost per prisoner is £37,543 per year this was used to value the reduced strain on the prison system. Another SROI analysis of an employment programme valued reduced reliance on state benefits, increased tax take and national insurance payments and minimum wage to value increased income as a result of going into employment (Every, 2012). The same approach was updated and used consisting of Universal Credit, local housing allowance and minimum wage this totalled £15,325.64 (Gov.UK, 2021a, Welsh Government, 2021, Gov.UK 2021b). For young people who secured a construction apprenticeship the HACT (2018) proxy of £1,756 seemed low to value this change. Instead, the same methodology as progression into employment was used to value progressing into an apprenticeship (Every, 2012). The minimum wage rate for an apprentice, totals £7,605 a year with no income tax or NI (Gov.UK, 2021b). The HACT (2018) proxy of £1,019 was used to value young people going into training.

*Table 3: Valuing the Capabilities Approach*

| CA Domain | Outcome | Proxy | Deadweight | Quantity |
|---|---|---|---|---|
| Life | Homelessness prevented | £26,000 | 15% | 3 |
| Bodily integrity | Health and safety knowledge | £2,507 | 15% | 9 |
| Health | Improved physical health | £32 | 27% | 7 |
| Health | Improved mental health | £9,926 | 27% | 4 |
| Health | Reduction in harmful substance use | £4,215 | 27% | 6 |
| Senses, imagination and thought | Contextualised learning of literacy and numeracy skills | £484 | 15% | 9 |
| Emotions | Improved relationships | £600 | 19% | 3 |
| Practical reason | Planning for the future | £1,316 | 27% | 10 |
| Affiliation | Better at talking to colleagues/strangers | £740 | 40% | 3 |
| Other species | Concern for nature | £2,258 | 19% | 0 |
| Play | Recreational activities | £2,464 | 19% | 2 |
| Control over one's environment | Reduced offending | £37,543 | 62.1% | 4 |
| Control over one's environment | Secured employment | £15,325.64 | 15% | 4 |
| Control over one's environment | Secured apprenticeship | £14,447.54 | 15% | 3 |
| Control over one's environment | Vocational training | £1,019 | 15% | 2 |

Once evidence of change was collected and the most appropriate financial proxies were selected, counterfactuals (adjustments to reflect the impact of the programme) and negative impacts needed to be accounted for to establish social impact (Nicholls *et al.,* 2012). The most important of these is deadweight (Fujiwara, 2015) which refers to how much change would have happened anyway. Pathak and Dattani (2014) suggests, as it is unlikely that the perfect counterfactual is available and measuring deadweight will more than likely have to be an estimate. For example, HACT (2018) estimate that 15% of young people would get a job anyway without an employment intervention. Nicholls *et al. (*2012) proposes using data from the Office of National Statistics (ONS), government departments or sector groups that represent the interest

of stakeholders. However, Pathak and Dattani (2014) use the examples of welfare to work programmes for young people explaining the typical counterfactual to use would be the regional government statistics although in some cases the counterfactual might need to be adjusted. For example, if young people are the hardest to reach because of harmful substance use or being known to the criminal justice system, then deadweight might be overestimated leading to the SROI being understated.

In calculating the SROI ratio, the impact was divided by the inputs of the SYMF programme. A sensitivity analysis was completed in order to establish the difference different decisions would have made e.g., using higher or lower financial proxies. This resulted in a SROI ratio of £3.08 this means for every £1 invested in the programme there was wider social value creation of £3.08.

## CONCLUSIONS

Using the capabilities approach to underpin an evaluative SROI of an intermediate labour market programme set up for young people at risk of homelessness in Wales UK, this paper has provided some important missing theoretical and empirical insights into the potential impact of social procurement policies in construction (Troje and Andersson, 2020, Raiden *et al.,* 2018). Acknowledging the limitations of SROI as a methodology, this paper provides a rigorous basis for the theoretically sound design and evaluation of similar programmes in the future as social procurement policies are increasingly used by governments around the world to leverage their construction spending to create social value in the communities they represent. The findings show that the Capability Empowerment framework provides a potentially valuable framework to design and evaluate other types of social procurement programmes. However, we would note that this should rest on evidence that this framework has been demonstrated in a priori research to be of value in these other contexts. It is likely that other theories will be found which could form more reliable foundations for the design and evaluation of social procurement programmes in other disadvantaged cohort contexts.

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# WOMEN OWNER-MANAGERS OF SMALL CONSTRUCTION FIRMS: A COMPLEMENTARY PERSPECTIVE

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Studies on women in construction tend to focus on women in professional roles and building trades. Current literature has a bias towards the assumption that barriers affecting women hinder the efforts to address the gender imbalance in the industry. These barriers have been linked to the vertical and horizontal segregation that the industry exhibits. Although there is a growing number of small construction firms that are owned-managed by women, there is a scarcity of research on the experience of these owner-managers. Thus, exploring women's experience in senior management positions within their organisations offers a complementary perspective to the ongoing discussion of the gender balance in construction. This paper aims to examine how the experience of women in construction has been reviewed to date and to present the need to gain a more situated understanding of the experience of women owner-managers, especially those within small construction firms, which comprise 98% of UK construction businesses. This paper will contribute to a contextualised understanding of why the study of women's individual experience in small construction firms continues to be relevant in construction gender research.

Keywords: gender; small firms; social constructionism; women owner-managers

## INTRODUCTION

Construction remains a male-dominated industry in terms of representation, with women accounting for 15.6% of the workforce as of December 2020 (ONS 2020). Attracting and retaining more women in the construction sector is suggested as a key priority for the UK construction sector as it faces skill and labour shortages (Aboagye-Nimo *et al.,* 2019). In contrast, Norberg and Johansson (2021) advocate for the balanced view of supporting the improvement of equal opportunities for women and addressing labour shortages. To understand this ongoing challenge, a significant body of research has focused on analysing the experience of women in the industry (Galea *et al.,* 2015; Navarro-Astor *et al.,* 2017). According to these studies there are barriers faced by women working in the sector (Regis *et al.,* 2019). Some of the identified barriers, such as differentiated pay levels, inadequate career progression, prejudice by employers and discriminatory selection process during recruitment, are closely linked to the argued vertical and horizontal segregation that the industry exhibits (Bridges *et al.,* 2020; Navarro-Astor *et al.,* 2017). Vertical segregation is thought to be the distribution of men and women in the same occupation but with one sex more likely to

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be at a higher grade or level, and horizontal segregation refers to the distribution of men and women across occupations (Gurjao 2006). The proposition is that in the case of vertical segregation means that at senior levels, women in the construction professions are not proportionately represented (Fernando *et al.,* 2014), while in the case of the horizontal segregation, women that are officially employed are mainly engaged in clerical/secretarial/administrative roles (e.g., Briscoe 2005, Fielden *et al.,* 2000). Vertical and horizontal segregation, and the challenges that women face to join and remain in the industry, have been a concern for a number of scholars for many years (Norberg and Johansson 2021). Despite all these obstacles, a small but growing number of women choose to be part of the industry as business owners. Whilst certain barriers are often outside women's control when they are in employee positions, Kalnins and Williams (2014, p. 824) suggest that women owner-managers have more autonomy than do employees and that they "have already overcome some hurdles to attaining status and power by gaining access to the prototypically male role of business owner". Hence, exploring the experience of women owner-managers offers a much-needed complementary perspective and thus merits further attention. In order to gain a general understanding of the understudied phenomenon of women owner-managers in construction, this paper proposes the need to explore their roles, experiences and responsibilities within their firms. Roles are understood as the duties or functions that women have in technical, professional and managerial occupations in the construction industry (e.g., Sommerville *et al.,* 1993), the experiences as "the consciousness that emerges from personal participation in events" (Foss and Foss 1994, p. 39); and the responsibilities as the domains that women owner-managers themselves choose to consider most important in their positions (Azam Roomi *et al.,* 2009). Furthermore, although around 99.8% of UK construction firms are small enterprises with 0 to 49 employees (BEIS 2019) and are largely family owned (BEIS 2020a, 2020b), most studies on women in construction tend to focus on the settings of large firms. Within this context, through a critical literature review, the aim of the paper is to examine how the experience of women in construction has been reviewed to date and to present the need to gain a more situated understanding of the lived experience of women owner-managers in small firms in the construction industry.

## LITERATURE REVIEW

### Women in Construction

A large part of the literature on women in construction focuses on identifying barriers preventing women from entering and remaining in the construction industry (Bridges *et al.,* 2020). This follows a previous trend in mainstream management exploring gender equality. However, as noted by Francis (2017) the dominance of career barrier investigations suggests that construction management research into gender is lagging behind mainstream management. Nonetheless, the existing literature supports the case for gender studies that focus on the construction industry. The male-dominated nature of the industry has been cited as one of the barriers that explain the under-representation of women (Dresden *et al.,* 2018) and the difficulties in that women face in progressing their careers (Clarke *et al.,* 2017). Contesting this perception is significantly important to make the industry more attractive for both women and men. To that aim, a lot of effort has been put into creating strategies or external approaches that, unfortunately, have not delivered the anticipated results (Clarke *et al.,* 2017). Nevertheless, the focus on the exploration of women's individual experience by previous studies has highlighted women's perceptions which have provided insights into the reasons behind their under-representation in the industry (Aboagye-Nimo *et*

*al.,* 2019). Other studies instead have focused on the external perceptions towards women in construction. For instance, a recent study by Norberg and Johansson (2021) presented an analysis of how women in construction are represented in publicly available texts by mapping and analysing qualities and abilities connected with women. Their study indicates that although there is a central message in the material examined proposing that the industry offers many opportunities for women, a close examination indicates that women in the industry encounter gender-biased attitudes, discrimination and unrealistic demands (Norberg and Johansson 2021).

Naoum *et al. (*2020) report that whilst often men experience a consistent upward trajectory in their career progression, women tend to experience a 'zig-zag' career progression. Perrenoud *et al. (*2020) report that opportunities for women are improving with social attitudes and organisations becoming more accepting of women. However, sociological and cultural barriers remain; as explained by Clarke *et al. (*2017) structural barriers to equality and diversity are especially entrenched in segregated contexts, such as construction. Indeed, French and Strachan (2015) point out that the construction industry is "not engaging with equal employment issues and the numbers of women working in the industry and/or management are based on individual decision rather than an institutional commitment to equality in diversity". This resonates with Lu and Sexton (2010) study exploring the career journeys and turning points of senior female managers in small construction firms, which suggested that the choices of women senior manager appear not to be tangibly affected by any externally driven agendas. Francis (2017) further found that individual factors such as work experience, number of organisations worked for since starting work, relocations, tenure, work hrs/week, developmental opportunities, training for job, rather than interpersonal and organisational factors have the greatest influence on women's career progression. Hence, understanding women's individual experience in the industry arguably proposes a consistent source to gain an in-depth understanding of the issues faced by female construction professionals (Aboagye-Nimo *et al.,* 2019). Moreover, this approach offers the opportunity to propose recommendations for improving the working conditions of women, which are in alignment with their personal lived experience (Regis *et al.,* 2019). For these reasons, the study of the individual experience of women in construction continues to be relevant not only to identify the barriers affecting the attraction and retention of women in the industry (Navarro-Astor *et al.,* 2017), but also to identify the success factors behind the progress of some women in the industry (Francis 2017).

The discussion of women in construction has been explored by analysing women's position in multiple roles and occupations. Examples of research into exploration of women's roles in the industry include senior female managers in small construction firms (Lu and Sexton 2010); women in managerial and employee levels in construction organisations (Watts 2012); women in construction education (Richard *et al.,* 2018); women apprentices in construction (Struthers and Strachan 2019); women in construction occupations studies including engineering (Cadaret *et al.,* 2017), women in electrical construction roles (Perrenoud *et al.,* 2020); women quantity surveyors (Greed 1991); women in architecture (Matthewson 2015); and women in the construction trades (Ness 2012; Regis *et al.,* 2019). This approach to exploring the experience of women has mostly focused on their position as employees in the construction industry and in the challenges that these women face in these roles. In contrast, senior female managers who are also owner-managers have received little attention (e.g. Lu and Sexton 2010). Exploring women's advancement and success as

leaders in their roles as owner-managers rather than the focus on the external barriers hindering their career development presents a timely research opportunity. This paper argues that in order to understand the persistence of the low participation of women in the construction industry, it is important to continue exploring the experience of women in all the roles they perform within the industry.

**Women Owner-Managers in Construction**

Research into women owner-managers has often been carried out in the context of multiple industries. Although the results from this body of work have provided useful insights, scholars assert that it has limited in the development of theory in specific industries (Amit *et al. (*1993). For example, it has been identified that female-run businesses (and corresponding research) are concentrated in traditional areas of employment for women, such as retail, education, health, and distribution / domestic services sectors (Carter and Shaw 2006). Women owner-managers remain under-represented in traditionally male-dominated sectors such as manufacturing, construction and transport (Carter and Shaw 2006). Kalnins and Williams (2014) argue that to capture the diverse range of different opportunities and constraints for women owner-managers, research needs to consider a broader range of industrial contexts. The issue of gender in these 'non-traditional' industries often have different connotations. Calabrò *et al. (*2020) reports that, in traditionally male-dominated industries, women are encouraged to go into traditional 'women's jobs', and their ability to be leaders of businesses in those industries may not be well recognised by members of their own industries. For instance, in the construction industry where gender segregation is present, senior female managers are underrepresented (Gurjao 2006). In addition, the difficulties that women experience, either in trade or in professional roles, have been linked to the industry's culture with its prevailing masculine attitudes and discriminatory work practices (Dainty *et al.,* 2000). How these construction-specific connotations affect the experience of women owner-managers in the industry is unclear.

A further reason that calls for a focus on the particularities of the construction industry rather than studies that cover women business ownership in the context of multiple industries, is that the construction industry is largely composed of small and medium enterprises (SMEs)[1] with over 98% of UK construction firms being SMEs (BEIS 2019). It has been identified that women in construction are increasingly likely to work in smaller firms or as self-employed professionals (Greed 2000). In addition, construction has one the highest number of family firms in the UK, where 83% of SME firms with employees are family owned (BEIS 2020b). This might present opportunities for women interested in forming part of the family enterprise as Salganicoff (1990, p. 121) indicates "the career that women can pursue in family businesses are often better than those available in the corporate world." Nevertheless, construction, like other male-dominated industries, presents unique challenges for women seeking to succeed as owner-managers. Women owner-managers might experience difficulties that have not yet been explored in the women in the construction research field, such as limited funding, overall negative attitudes towards them as 'female' business owners, cash flow problems, high business rate and overheads, lack of business networking and support groups (Carter and Shaw 2006; Fielden *et al.,* 2003; Marlow *et al.,* 2009).

Apart from forming part of a small family business, in some cases, business ownership is pursued by women working in senior roles within the industry switching

to owner-managers roles in order to obtain a greater autonomy over their working life (Marlow 2002). Flexibility and the glass ceiling are the top reasons cited by women who had left their previous employment to start their own businesses ( Mattis 2004). The path to business ownership is not always a prearranged career plan. In construction, for instance, some women business owners, who already in the industry, have expressed they did not consciously choose a career in the sector (Lu and Sexton 2010). Lu and Sexton (2010, p. 125) further argue that "the career decisions of senior female managers in small construction companies are a product of serendipitous circumstances and choices". In Lu and Sexton (2010) study, some of the women participants were joint owners of small construction firms with their spouses, and their roles which demonstrate leadership capabilities, were mainly focused on 'organisation and management' instead of the 'project delivery' their spouses perform. Although these women's participation in the industry is relevant, it is often overlooked with limited research dedicated to understanding more about their involvement in the construction industry and the particularities of their roles. Nonetheless, it could be argued that the split of business responsibilities reported in Lu and Sexton (2010) between husband-and-wife joint owners uphold socially constructed gender roles. Marlow (2002) suggests that women's subordination within wider society is brought with them into self-employment; essentially, business ownership does not separate an individual from the prevailing rules of an androcentric society. Whether this assertion applies to the construction industry remains to be explored. This identified research gap prompts the need to initially explore how women owner-managers of small firms experience business ownership in the UK construction industry. This seemly broad research goal offers a flexible and dynamic entry point into this understudied phenomenon, which might allow to contribute towards more general themes such as the role and responsibilities of these women within their organisations.

There is a small body of literature that is concerned with women-owned small firms in the UK (Azam Roomi *et al.,* 2009; Fielden *et al.,* 2003). Although the literature addressing women ownership of small firms in the construction industry is still limited, where exceptions were found, these studies tend to focus on countries other than the UK, such as the United States and South Africa (Jonas *et al.,* 2014; Mattis 2004). Most of these explorations on women-owned small construction firms have used quantitative methods such as surveys as their main research method. Research exploring women business ownership in other sectors has demonstrated that women business owners are not a heterogeneous group (Carter and Shaw 2006); they differ in the importance that they attribute to professional achievement, level of motivation in the scope of enterprise growth, managerial style and even the administrative participation in their organisations (Plawgo 2013). Hill *et al. (*2010) argue that it is essential that research is designed to capture their heterogeneity. In line with this assertion, exploring the lived experience of women business owner-managers in the UK construction industry is of interest.

The recent 2019 'Labour Force Survey', an annual survey of small businesses, carried out by the Department for Business, Energy and Industrial Strategy (BEIS), offering the most robust source of data in the UK which provides gender-disaggregated for business ownership, reveals that 43% SMEs' with employees' have women owner-managers within their organisations; 21% SMEs 'with no employees' reported having women owner-managers (BEIS 2020a, 2020b). The 'businesses with no employees' category include sole proprietorships, self-employed or partnerships. Considering that nearly a fifth (around 1 million) of all SMEs in the UK operate in the construction

industry (BEIS 2019) the percentage of women owner-managers of small firms is noteworthy. Thus, exploring women owner-managers' experience in small construction firms could present invaluable insights.

**Theoretical Positioning - Social Constructionism**

The approach taken to explore the literature presenting the experience of 'women in construction' and 'women business owners' is based on the understanding of gender as a social construction, which refers to the social roles that men and women play and the power relations as self-perceived between them (Foss and Foss 1994). Lorber and Farrell (1991) argue that gender is continuously created and re-created out of human interaction. Thus, we argue, gendered behaviour is learned, unlearned and relearned across social ripples of structure and time. Mikkola (2019) claims that it is possible to create more equal societies by 'unlearning' social roles. A social constructionist perspective is adopted as it allows the study of the conditions and practices that produce gender rather than focusing on the differences between women and men. In the case of studies related to gender, a common approach using a social constructionism is the focus on human experience (Friedman 2006). Experience is extracted through "women's personal narratives about the events of their lives, their feeling about those events, and their interpretations of them" (Foss and Foss 1994, p. 39). Malmström (2011) notes that paying attention to 'lived experience' prompts inquiry into the role of agency in the construction of gender and further calls for exploring 'gendering practices' as 'lived experience' rather than as fixed subjective positions. Most social constructionist studies apply specific social constructs that delineate the positioning of their exploration. The exploration of the experience of women in construction is often based on the understanding that women's socialisation is different, and due to this, they have different experiences that deserve to be analysed separately (Francis 2017; Gurjao 2006; Ness 2012). The three concepts considered to be of particular importance in this research are career, leadership and women's enterprises. The three identified social constructs offer the possibility to categorise some aspects of women's experience between structurally determined or socially constructed. This differentiation allows for a critical exploration of their experience from a social constructionism perspective which seeks to reveal the social world's operations and the political distribution of power to challenge social injustice and replace them with something fairer (Friedman 2006). The following will explain and justify the chosen reason for each of the three constructs.

(1) Career: Research exploring women in construction have often analysed women's career development and their experience in the industry and hence incorporated this concept into this analysis (Dainty *et al.,* 2000; Francis 2017; Lu and Sexton 2010). Past studies discussing the career development of women in construction has demonstrated that women progress more slowly (Naoum *et al.,* 2020), this could arguably contribute to the understanding that traditional gendered views of career might be acting as a constraint for women in the industry. This is supported by a growing body of research that links the role that individuals' social contexts have in shaping career decisions (Hodkinson and Sparkes 1997). The study of career as a social construction explores the culturally and socially rooted nature of career and the influence of social processes in understanding career (Young and Collin 2004). This perspective enables studies to explore the association between social settings and career.

(2) Leadership: The concept of leadership is presented in a growing body of research proposing to identify specific challenges faced by women in leadership roles within a male-dominated sector such as construction (Thayaparan *et al.,* 2014; Watts 2012). Leadership as a social construction proposes that leadership is a product of the observer's perception (Billsberry 2009). This socially constructed approach to leadership contests the dimensions that are central to most theories of leadership: Quality of leaders (e.g., trait theory), a response to environments (e.g. situational theory), or a combination of both (e.g. contingency theory) (Billsberry 2009); instead, it proposes that there are no fixed characteristics that can be attributed to a person to designate them as a 'leader'. Studies focusing on women in leadership roles argue that women in these positions continuously negotiate their roles as they face the competing demands of their roles as women and as leaders (Watts 2012). However, this review of the literature found that other understandings of leadership seem to be more prominent in the research of women in construction (Thayaparan *et al.,* 2014).

(3) Women's enterprises: This concept of women's enterprises has been identified based on research focusing on the experience of women business owners, which argues the need to understand the gender factors that influence business ownership (Azam Roomi *et al.,* 2009; Haupt and Ndimande 2019). A recurrent theme in the literature is placed on women's enterprises, presenting not just the gendering factors affecting the individual experience of these women but also the influence of gender interfering in the growth of these businesses (Fielden *et al.,* 2003). The view of women's enterprise as a social construct recognises that notwithstanding the progress in women's participation in multiple aspects of economic and social life, their participation is affected by cultural values and social structures governing gender roles (Carter and Shaw 2006). Carter and Shaw (2006) further argue that the social construction of women's enterprise emphasises that gender is not a characteristic of individuals, but a fundamental process of understanding women experiences of business ownership. This review encountered limited research specifically exploring how/whether gender affects the experience of women owner-managers in the construction industry and hence, this paper poses the need to further explore this understudied phenomenon.

## CONCLUSIONS

There is much literature exploring women's experiences in employee positions within the construction industry which offers important and crucial insights into the external barriers hindering women's career development. This paper, however, proposes the need to study women owner-managers' experience, which allows the exploration of women's advancement and success as leaders in construction. Most studies on female owner-management tend to encapsulate firms in multiple sectors and fail to capture the gendered reality of male-dominated industries such as construction. Moreover, these studies tend to use quantitative methods such as surveys which could be argued to not effectively capture the nuances of the experience of these women. To address this gap, this paper proposes to use women's first-person accounts of their lived experience as owner-managers of small construction firms rather than explaining generalisation about women owner-managers or comparing their experience to that of male owner-managers; and, in doing so, contribute to a richer and contextualised understanding of the experiences of women in small construction firms.

### NOTE

[1] According to (BEIS 2019), small firms are enterprises with 0 to 49 employees; and small and medium enterprises (SMEs) are businesses with 0-249.

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# TAKING A BROADER APPROACH TO WOMEN'S RETENTION IN CONSTRUCTION: INCORPORATING THE UNIVERSITY DOMAIN

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Arguably, young professional women commence their transition into the construction industry upon commencement of their university studies. It is possible that women may be exposed to gendered barriers to success both directly and indirectly while at university, which may impact on their intentions of pursuing a career in construction. Construction can be considered as an ecosystem consisting of various interrelated components. This paper aims to extend the 'leaky pipeline' narrative by identifying key actors in the university domain who can influence the retention of young professional women in construction. Faculty can support women in construction through learning and teaching and research activities. A critical reflective approach is used to explore the characteristics of the university learning and teaching environment and the peer-review research process. It is recommended that the university be acknowledged as an integral component of the construction ecosystem. Future research should consider how the university influences and shapes decisions around the retention of women in construction. Without substantial and sustained change across the construction ecosystem, women will remain underrepresented in the construction industry and futile calls for increased participation will continue.

Keywords: faculty; ecosystem; gender; university; women

## INTRODUCTION

Women are acknowledged as an underrepresented group in the construction industry. The proportion of women working in construction is low internationally, and little has changed in the past decades (French and Strachan, 2017). The Workplace Gender Equality Agency (2019) reports that in Australia between 1998 and 2018, there was a slight decline in female representation in the construction industry from 13.8% to 12%. The underrepresentation of women in construction has received considerable attention in the literature (e.g., Gale, 1994; Dainty *et al.,* 2004; Rosa *et al.,* 2017) and it has been well established that the barriers faced by women working in construction are the major reasons for consistently low participation rates (Amaratunga *et al.,* 2006). In a review of the literature, Amaratunga *et al.,* (2006) identified the key barriers for women as: The negative image of the industry, lack of career knowledge, hostile and discriminatory culture and working environment, work-family conflict,

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male dominated training courses, and recruitment practices. To respond to the underrepresentation of professional women in construction, formal strategies and policies have been developed by governments and organisations to improve gender diversity, equity and equality in construction (Galea *et al.,* 2015; Lu and Sexton, 2010). Despite these initiatives however, women remain an underrepresented group in construction and continue to face gendered barriers in the workplace.

The experience of women during the early stages of their professional pathway has a critical influence on their subsequent career intentions. Evetts (1996) found that young women's first experience of industrial work clarifies and confirms the career path they subsequently follow, including leaving the industry. Dainty *et al.,* (2000) reported that female professional entrants tend to become disillusioned with their career choices more rapidly than their male counterparts and leave the construction industry early in their careers. The early exit of female professionals from the construction industry has remained unchanged in the past two decades (Morello *et al.,* 2018). Among construction professional women, women in the age group of 18-24 are significantly more likely than those in other age groups to express a desire to leave their construction careers (Morello *et al.,* 2018).

In Australia, women account for 16.2% of professional and management roles in the construction industry (Australian Bureau of Statistics, 2019). Despite the increasing number of females studying built environment courses in higher education, the percentage of female professionals in construction has not had a noticeable increase in the past decade (Naoum *et al.,* 2020). It is important to understand what happens to women once they are exposed to the industry so that the barriers to retention can be removed. In this paper, the 'leaky pipeline' phenomenon refers to the notion that many women in construction are filtered out along the career pipeline, leaving only a few to arrive at the other end (Blickenstaff, 2005). Much of the research on the leaky pipeline in construction has focused on women in full time professional work. However, in construction management university programs in Australia it is common for students to commence their professional roles while concurrently undertaking their university studies (Lingard, 2007; Mills *et al.,* 2012). Furthermore, throughout their program of study, students are exposed to the construction industry through presentations by construction professionals, site visits, as well as undertaking analysis of industry case studies. It is also common that faculty have prior experience of working in the construction industry which can inform their pedagogy and interaction with students. Consequently, rather than only focusing on the factors which shape retention once women enter the industry on a full-time basis, there is merit in extending the focus to include the factors which can shape the experiences of women from the time they enter university. Research, however, has yet to comprehensively explore the university domain and how it may impact on the retention intentions of professional women in construction.

This paper aims to contribute to the literature on women's participation in construction by extending the focus of the 'leaky pipeline' phenomenon. By taking a broader approach to the 'leaky pipeline', this paper considers how the university domain can influence and shape the retention of young professional women in construction. At university, faculty typically undertake both teaching and research activities, therefore two research questions are proposed:

1. How does the university learning and teaching environment impact on the retention of women in construction?

2. How does the research process impact on our understanding of women's retention in construction?

The first research question critically reflects on the conditions of the learning and teaching environment and considers the role that faculty may play in introducing and reinforcing conditions which subtly or overtly disfavour females. The second research question critically reflects on research and peer review and considers how faculty may hinder or support the progress and understanding of women's retention.

# METHODOLOGY

A critical reflective approach was used to explore the two research questions. Critical reflection as a research methodology focuses on "how assumptions about the connection between oneself and social context/structure can function in powerful ways, so that awareness of these assumptions can provide a platform for transformative action" (Fook, 2015, p.441). Critical reflection can be used as a method for challenging and changing structurally produced power relations and redressing power inequities (Brookfield, 2016; Fook and Gardner, 2007; Morley, 2008). The construction industry operates according to a strong male-based power structure (Galea *et al.,* 2015). In this structure, women experience conscious and unconscious bias and discrimination (Petersen, 2006; Walker, 2019), therefore critical reflection is considered as a suitable lens from which to consider the topic. We draw on the extant literature as well as our own experience as educators and researchers in construction management. We start by reflecting on the experience of women undertaking construction management studies in Australia. We then reflect on a recent publishing experience. We use these two areas to illustrate why the focus of the 'leaky pipeline' should be expanded to include the university domain and the critical role of faculty.

# FINDINGS

## University and the Learning Environment

Women's participation in construction management programs
One way of increasing women's participation in the construction workforce is to increase the number of women graduating from university. In Australia, university students undertake a three or four-year full-time Construction Management program of study. While there have been calls to increase the number of women undertaking science, technology, engineering and mathematics (STEM) related disciplines in tertiary education, rates remain consistently low (Australian Government, 2019). Girls and women face multiple barriers to STEM participation and as a result, must overcome more challenges than their male counterparts. Factors such as bias and stereotyping, career insecurity, a lack of flexible work arrangements, and lack of female role models have been shown to influence girls and women's decisions to enter and remain in STEM education and careers (Dee and Gershenson, 2017; Professionals Australia, 2018).

The proportion of women entering and graduating from construction management university programs in Australia appears to be reflective of broader graduation rates in STEM-related professions. Oo and Widjaja (2018) report that the percentage of female construction management enrolments at three Australian universities between 2006 and 2015 ranged from 5% to 20%, and these percentages are consistent with global trends (Oo *et al.,* 2018). The authors of this paper used their academic networks to obtain information on the number and percentage of female graduating

students from universities across Australia from 2016-2019, and the information is summarised in Table 1. While the information does not purport to be representative of the Australian context, it provides a snapshot from two large urban universities and one rural university. In 2019, University 1 had the largest graduating female cohort across the three universities during the four-year period (28.3%), and University 2 had the lowest graduating female cohort (2.4%). Across the three universities, female students can be considered as a minority group. This can have detrimental impacts on women, as women in male-dominated programs of study can experience intimidatory behaviour and gender stereotypes as barriers preventing full participation in the classroom (Thurtle *et al.,* 1998). Furthermore, gender minority status over time can have a cumulative, dose-effect, impact on health (Ng *et al.,* 2019).

*Table 1: Percentage of women graduating from Australian construction management university degrees*

| | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|
| University 1 | 10.1 (n=9) | 21.1 (n=23) | 20.0 (n=21) | 28.3 (n=41) |
| University 2 | 3.2 (n=5) | 3.7 (n=6) | 2.4 (n=5) | 6.6 (n=15) |
| University 3 | 9.0 (n=11) | 12.8 (n=14) | 11.1 (n=11) | 9.1 (n=8) |

In further considering the intersecting domains of university and work, women commence university as a gender minority, and this status continues for the duration of their professional life in construction. With the recent low rates of enrolled and graduating females, together with the leaky pipeline phenomenon, it is difficult to see how the number of females in professional and management roles in the construction industry is likely to significantly increase in the foreseeable future. Until then, women will continue to belong to a gender minority and be exposed to conditions impacting on their health as well as their career.

Challenges in the learning environment

It has been suggested that both male and female faculty members behave in ways that subtly favour males in STEM disciplines. For example, faculty members are more likely to spend time mentoring males (Moss-Racusin *et al.,* 2012), responding to emails from males (Milkman *et al.,* 2015), and calling on males in class (Eddy *et al.,* 2014). Bevan and Gatrell (2017) argue that in science, men are positioned as dominant, and women are positioned as ‘different’ and do not fit into the masculine ideal. Consistent with this view of being 'different', females undertaking STEM degrees can experience gender bias and feelings of marginalisation, and report being subjected to a chilly climate for learning (Ceci *et al.,* 2014). Learning occurs when students take risks or step outside of their comfort zone. If the learning environment is unsafe, students learning is compromised (Anderson and Carta-Falsa, 2002). Female students undertaking STEM programs also report experiencing growing environmental barriers and lessening self-confidence as they progress through each successive year of their degree (Brainard and Carlin, 1998). Scott-Young *et al.,* (2020) contend that the construction classroom may be privileging male students and operating as a microcosm of the cultural environment faced by women in the construction industry, with its macho culture filtering back into the learning environment at university. Scott-Young *et al.,* (2020) suggest that this may be due to several factors: Students undertaking professional roles in the construction industry

bring the male-dominated industry culture back into the classroom; faculty impart their past work experience in the construction industry to the classroom; and the numerical dominance of male faculty and the relative lack of female academic role models.

Emerging from the literature, it appears that women undertaking studies in construction management begin their socialisation into the culture of the construction industry in the early years of their undergraduate studies. It is possible that the various gender-related challenges experienced by young female students while at university may inadvertently contribute to their decision to exit the industry. It is therefore imperative that future research examining the leaky pipeline considers the impact of the university learning environment on women's construction career intentions.

## Supporting Young Women Through Research

### Importance of research in supporting women in construction

Research plays an integral role in supporting the retention of women in construction. Research can help to understand the barriers and supportive factors which contribute to the retention of women at all stages of their career. Research findings can be used to guide policy and practice to bring about positive change. Along with their role in learning and teaching, faculty also play an important role as researchers in construction management. Critically reflecting on faculty's role in the research process is important in the context of impartiality (Helmer *et al.,* 2018).

### Reflecting on the peer-review process

The peer review process is described as the expert assessment of materials submitted for publication in scientific and technical journals. Peer review is intended to serve two primary purposes: Assist the board of editors to accept or reject a paper and help to improve submitted manuscripts by eliminating major flaws and gaps. As reviewers play an important role in publication decisions, they are described as the gatekeepers of science (Hojat *et al.,* 2003; Haffar *et al.,* 2019). Peer review outcomes "influence the very nature and direction of future scientific research" (Hojat *et al.,* 2003, p.76), and the peer review process can affect society when a social policy implication is suggested or inferred from the published manuscript. While a critical review of the peer-review process is beyond the scope of this paper, it has been acknowledged to be imperfect (e.g., Hojat *et al.,* 2003; Haffar *et al.,* 2019).

In the context of progressing our understanding and support of young women in construction, a recent publishing experience by the authors is explored. As way of background, the authors submitted a manuscript on early career women in construction to an Architecture/Engineering/Construction journal and received feedback from three reviewers through a double-blind review process. Several issues were raised by the reviewers which prompted reflection and constructive discussion by the research team and their wider academic network. Reflections about the content of the manuscript and the reviewers' comments merit wider consideration and exploration in relation to women in construction. Of note was the emergence of neurosexism and the use of gender-based solutions to address a deeply entrenched cultural problem. To highlight the key issues raised through the review process as they relate to young women undertaking studies in construction, we have used illustrative quotes to provide the context. Importantly, we make no claims that the issues raised in this section represent common practice. We believe however, the issues warrant critical reflection by researchers in the field of engineering and

construction management, as conscious and unconscious bias can inadvertently impact on the experience of young professional women in construction.

Neurosexism

Neurosexism refers to "the practice of claiming that there are fixed differences between female and male brains, which can explain women's inferiority or unsuitability for certain roles" (Rippon, 2016). According to Fine (2010), neurosexism reflects and reinforces cultural beliefs about gender, and it may do so in a particularly powerful way. Fine (2010, p.xxviii) further contends that neurosexism is damaging, as "dubious 'brain facts' about the sexes become part of the cultural lore". In support of Rippon (2016) and Fine (2010) for example, Else-Quest *et al.,* (2013) found that male and female adolescents earned similar end-of-year grades in math and science. Neurosexism can perpetuate gender-based stereotypes which specify what is considered "men's" and "women's" work. This belief functions to repress the opportunity of women to enter industries or professions considered as the realm of males. Similarly, it represses the opportunity for men to enter industries or professions considered as the realm of females.

It appears that neurosexism emerged in the peer-review of our manuscript. Reviewer [X] provided the following feedback: "What is considered underrepresentation in construction? What is the ideal percentage? By thinking that the distribution should be 50-50 (men-women) or any other percentage, one would be undermining or ignoring that the brain by gender could be wired differently? That given the option, women would still not choose engineering. Is there research that presents what this percentage would be / should be?". In response to Reviewer [X], the authors raised the issue of neurosexism to rebut the view that "the brain by gender could be wired differently".

The paper went through a second revision, and Reviewer [Y] commented on the remarks made by Reviewer [X]: "I commend the authors' response to Reviewer [X's] comment related to neurosexism. To slightly expand, while women have a choice to pursue engineering, many do not because of the barriers uncovered by the research. Just last week, we had a student leave our A/E/C [Architecture / Engineering / Construction] major because of sexual harassment during an internship. She left the major because of how she was treated on-site, not because her brain was "wired" in such a way that she wasn't able to do the work or that the work didn't appeal to her. Through publication, your work will help us to better understand these kinds of barriers specifically for early career professionals so that anyone with passion, interest and aptitude for A/E/C work will be unhindered in pursuit of their career goals". While Reviewers [Y] and [Z] were satisfied with the revision, the editor rejected the manuscript, and the paper was not published. It is possible that gender bias around women's place in construction informed the decision on publication. Subsequent discussions by the authors and their academic network reflected on the importance of impartiality in the peer-review process, reflecting on possible blind spots, and for calling out bias.

Gender-based solution to a context-based problem

The barriers facing women in construction are known to be contextual and arise due to the male-dominated norms of the industry (e.g., Gale, 1994; Dainty et al.,2004; Rosa *et al.,* 2017) and this was categorically reflected in the literature of the submitted manuscript. Contrary to this, Reviewer [X] suggested a gender-based solution rather than a context-based solution to the problem of women's participation in construction:

"I would like to suggest the authors to look into psychological type, as defined by the MBTI [Myer-Briggs Type Indicator] test and how it also relates to the choice of career…..the MBTI type is relevant to how to teach engineering students, as it affects the learning preferences / model. I think that would also apply to the way young professionals are guided through the early parts of professional learning. Is it men-women with different needs for guidance and mentoring to progress, is it confidence, or personality / way to see and react to the world around us?". As discussed in the previous section, women undertaking STEM programs at university and women in full time professional roles must contend with gendered challenges (e.g., Thurtle *et al.,* 1998; Amaratunga *et al.,* 2006; Scott-Young *et al.,* 2020). Rather than focusing on brains wired differently or gender-based capabilities, the narrative must focus on removing the barriers and challenges for success which emerge from the university and work environments. The peer-review process should play a critical role in supporting research which focuses on changing the context for women in construction rather than individualising the problem.

## CONCLUSION

The leaky pipeline concept focuses on the factors which contribute to the exit of women in various stages of their construction career. By considering construction as an ecosystem, this paper recommends the expansion of the leaky pipeline to include the university domain. Faculty play an integral role in creating a learning and teaching environment which supports all students, irrespective of gender. Furthermore, faculty play an integral role in conducting and peer-reviewing research which seeks to better understand the barriers and supportive factors which can impact on women's retention. It is recommended that faculty be aware of neurosexism, conscious and unconscious gender bias and critically reflect on their own practice as educators, researchers and peer reviewers. It is also recommended that faculty reflect on the way in which the learning environment operates to introduce and socialise students into the culture of the construction industry. This is important, as it's likely that current practice is perpetuating the male-based power structure which disfavours females. Research could usefully explore how the university learning environment influences and shapes decisions around the retention of women in construction. In doing so, consideration must be given to the small number of women undertaking studies in construction management and how this may impact on research design and sample size. Finally, impartiality in the peer-review process continues to be critical in progressing this important field of research. Journal editors and advisory boards play an important role in putting processes in place which seek to counter bias and subjectivity and promote impartiality in peer-review.

It is acknowledged that critical reflection is an examination of our own practice in relation to a specific context, therefore the content of this paper does not purport to be representative of the Australian context or the wider construction management academic community. Notwithstanding these limitations, the paper outlines some important considerations for progressing the retention of women in construction.

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# Health, Safety and Well-Being

# IDENTIFYING AND RANKING THE OCCUPATIONAL STRESSORS AND DEVELOPING A TOPSIS FRAMEWORK FOR PROJECT MANAGERS IN IRAN TO COPE WITH OCCUPATIONAL STRESS

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Occupational stress (OS) is the result of the accumulation of stressors and the interaction between working conditions and individual needs and personality. Owing to the nature of the construction industry, the levels of technical and social complexities are high in projects, and this causes tensions and stress specifically for employees who take management positions. Moreover, as construction is widely affected by political and economic instability and external environmental factors, project management often needs to overcome an extra amount of stress that endangers their mental and physical health. The devastating impacts of excessive stress can be observed in the project manager's personal life, projects progress and consequently on the performance of construction organisations. This research has refined and prioritised the stressors by interviewing project managers and administering a survey using the RII technique. Moreover, stress coping strategies have been proposed and ranked by therapists using the Delphi technique that includes two iterations of interviews and one iteration of weighting the coping strategies for each stressor by implementing the TOPSIS method. The outcome is presented in a framework that can improve the understanding of project managers in Iran on occupational stress and strategies to overcome excessive stress in construction projects.

Keywords: Iran; mental health; occupational stress; stressors; stress coping strategies

## INTRODUCTION

Occupational stress (OS) has become widely recognised as a major mental health (MH) issue that negatively affects the performance of human assets in organisations. OS is a global dilemma that arises at different levels in all types of jobs. The World Health Organization (WHO) has predicted that by 2030 MH issues, such as stress, will be the main cause of mortality and morbidity in the world (Funk 2011). OS is a result of an imbalance between demands in association with work and available resources to

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respond them (Lazarus 1990). Although a moderate level of stress helps people to carry out their duties, excessive amounts of stress for a prolonged period can be detrimental to their productivity (Ree-Evans 2020).

Loosemore *et al.,* (2010) pointed out construction as a stressful, challenging, and risky job. Also, Lingard and Turner (2017) stated that people working in construction projects have constantly experienced a variety of MH problems, such as anxiety, stress and depression. According to Gerrard 2018, 82% of people working in construction were stressed at least some of the time during a typical week.

Limited-term contracts, long hours, remote working, tight deadlines and budget, late payments, and uncertainties are unique factors to the construction industry, which can cause a high level of stress in project professionals (Ree-Evans 2020). Specifically, Project managers (PMs) should carry out a diverse range of activities that are highly stressful because they are directly responsible for the success or failure of the project while in many cases, they find themselves out of control as multiple internal and external forces hinder them to achieve their targets. Excessive stress deteriorates PMs capabilities for managing projects effectively (Amankwah *et al.,* 2015) and causes behavioural and health disorders. The Health and Safety Executive (HSE) stated that 11 million working days are approximately lost in the UK annually because of OS (HSE 2019).

While avoiding OS is not an option in the construction project environment, how PMs respond to it is critical. In many cases PMs are not truly aware of the negative consequences of excessive stress on their personal life and project outcomes as they accept OS as an integral part of their job. This can be seen in the CIOB report (Ree-Evans 2020) that claimed 39% of participants in a survey stated that they often felt stressed while 45% felt stressed sometimes. Despite this, only 45% of respondents know who they can talk to if they are experiencing excessive stress (Ree-Evans 2020).

In the male-dominated working environment of construction projects, seeking MH support is not a norm and people are not willing to talk about their problems (Roche *et al.,* 2016). This is owing to the stigma the industry has towards MH issues. Furthermore, the macho-culture in construction which determines what a 'real man' should act like (Malsen 2014), leads to hasty acceptance of excessive OS that will put individuals at high risk of chronic mental and physical health issues.

It should be noted that the situation might be worse in developing countries like Iran where mental help supports available in the UK such as helplines, MH first aiders, and training courses do not exist. Additionally, a lack of legislation and organisations policy in Iran for MH could lead to tragic results. In such a condition, awareness raising is a solution that can help PMs to manage OS and promote their wellbeing. This research aims to develop a framework to enhance awareness of PMs on frequent sources of stress in construction projects and familiarise them with coping strategies that are effective for each type of stressor.

**Construction Industry in Iran**

Iran's population has grown by 30% in 20 years (Amar 2020) which has led to a huge demand for built assets. To fulfil this need, many facilities have been constructed or are under construction in different sectors. The contribution of construction to Iran's Gross Domestic Product (GDP) is 19.4% and the building sector alone constitutes 4% of GDP (TCCIMA 2019). Therefore, construction plays an important role in the country's economy, employment, income generation, and social welfare.

However, the existing conditions in Iran with poor economic performance owing to political sanctions cause instabilities in managing construction projects. Lack of relationship with the international community hinders new knowledge, technology and information exchange leads to poor productivity in construction projects because of using traditional methods and machinery. Besides, the high inflation rate, corruption, low project management knowledge, and constantly changing rules and regulations impose more challenges to construction projects that consequently elevate the OS level of PMs.

## LITERATURE REVIEW

This research is based on the transactional theory of "stress and coping" developed by Lazarus and Folkman (1984) that is the most frequently used theory for exploring these subjects in different disciplines (Liu *et al.,* 2020). According to this theory, when stress exceeds an individual's capacity, coping is needed to moderate the stressful situation. Liu *et al.,* (2020) discussed that two coping approaches include (i) problem-focused coping that tries to resolve the individual-situation relationship involved with stress and (ii) emotion-focused coping that attempts to manage the negative emotions of an individual and keep moderate levels of arousal. This research is emotion-focused and aims to enhance awareness of PMs involved in the construction industry in Iran on how to cope with OS.

OS has attracted the attention of researchers globally in different disciplines. In Iran, Lotfizadeh *et al.,* (2011) examined OS among Esfahan Steel Company employees where 53% of employees had experienced excessive OS. Using a sample of 400 employees, they confirmed that OS rises when there is a large gap between job requirements and individuals' abilities, capabilities and expectations. In this study, while the correlation between age, marital status, work experience, literacy and working shifts with the level of stress was not significant, the level of stress in employees who had family issues, tough working conditions, a second job and a low salary was significantly higher than average. Although it is focused only on one organisation, this research illustrates the necessity of attention to employee's MH, but the results cannot be properly applied to construction owing to its unique attributes.

Langdon and Sawang (2018) explored OS in construction and concluded that time, personal finances and the nature of duties are the main stressors. They, also, highlighted the coping mechanisms adopted by construction workers that lead to increased feelings of psychological distress such as acceptance, self-blame, and disengagement. Although Langdon and Sawang's work provides insight into stressors relevant to the construction industry, they were only focus on workers and not project professionals such as PMs.

De Silva *et al.,* (2017) identified 11 stressors that professionals have experienced in construction such as time pressure, work overload, lack of control over the pacing of work, long hours of work and different views from supervisors. They also discussed three primary stress prevention strategies that can be used by construction organisations to improve the MH of different professionals.

Although a questionnaire survey that is adopted in this study and many other studies (Enshassi and Al-Swaity 2015; Leung *et al.,* 2010) is useful to generate statistical data, it may ignore contextual factors that are associated with economy, politics and culture that are highly influential specifically in developing countries. The three preventive strategies that are suggested are valuable on an organisational level but do

not promote the personal awareness of professionals on how to deal with OS personally.

Enshassi *et al.,* (2018) investigated coping strategies among construction professionals in Palestine by dividing them into problem-focused and emotion-focused coping behaviours. Problem-focused involves actions to do the task and emotion-focused involves actions to feel better (Enshassi *et al.,* 2018). Although this research shed light on the ways professionals deal with stress in construction projects, the majority of the participants in their samples include engineers and architects. So, their sample consisted of only 18.6 per cent of PMs that does not represent PMs viewpoints while the stress level of PMs is often higher as they hold more responsibilities. Furthermore, this research mainly reflects the way construction professionals respond to stress instinctively and it does not provide a professional perspective of stress management therapists. It should be noted that the coping strategies implemented by professionals may not be appropriate to reduce distress.

Although literature focusing on OS is rich in construction, proposing one-size-fits-all solutions is not possible (Rebar and Taylor 2017) because MH interventions should be exclusive to variable cultures, race and age (Nwaogu *et al.,* 2019). Thus, cross-cultural studies are required to generate new context-dependent insight and facilitate the development of cultural-specific MH intervention (Liu *et al.,* 2020). While exploratory inquiry for identifying and prioritising stressors in Iran is limited, there is no research that raises awareness of PMs on how to cope with OS in the construction industry. Hence, this paper attempts to fill the gap in the knowledge by developing a specific, refined and ordered list of OS in Iran and develop a prioritised list of strategies that help to deal with each specific stressor.

## RESEARCH METHODOLOGY

A mixed method approach including both qualitative and quantitative methodologies is adopted owing to the nature of the research questions. The qualitative part helps to explore OS and coping strategies deeply. The quantitative method is used to prioritise stressors that occur more frequently in construction projects in Iran.

A long list of stressors that were extracted from literature is refined through 36 semi-structured interviews with PMs who have at least 15 years of experience in Iran. Interviewees, who were selected using a snowball sampling method, were asked to provide feedback and reflect on the long list of stressors to highlight those that they have been exposed to during their professional life.

Moreover, interviewees add stressors associated with the context of Iran that they believed were missed in the long list. The interview transcripts were coded using thematic analysis to identify new stressors and merge similar stressors. Based on the results of the literature review thematic analysis, 92 stressors were identified that are specific to socio-economic dimensions of the construction industry in Iran.

To facilitate the TOPSIS stage, 92 stressors should be reduced because a large number of factors in this method deviates expert judgment and misleads the outcome of this stage (Soltani *et al.,* 2019). A Likert-scale questionnaire was distributed among 120 PMs in Iran and 100 completed questionnaires were returned (83% response rate). To make the shortlist, stressors were ranked using the Relative Importance Index (RII) in which a higher RII would indicate a higher frequency of the stressors. Finally, 15 stressors with an RII score of over 0.8 were selected for further study.

To recognise the most effective coping strategies, five accredited therapists were interviewed using the Delphi technique with three iterations. The unique attributes of the construction industry were explained to the therapists and they were asked to comment on 40 strategies that were identified in the literature. After two iterations, the coping strategies were refined into ten categories based on therapists' judgment.

In the third iteration, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to prioritise the coping strategies over the stressors. TOPSIS is a method developed by Hwang and Yoon (1981) that is used for extracting the best rank of a set of criteria through using five steps as follows (Soltani *et al.,* 2019):

1. Constructing the normalized decision matrix
2. Determining the positive ideal and negative ideal solutions
3. Computing the separation measures of each alternative from the positive ideal solution and the negative ideal solution using the Euclidean distances
4. Calculating the relative closeness to the ideal solution
5. Ranking the results in descending order.

This stage aims to find out which strategy works the best for each stressor. The TOPSIS questionnaire was created and distributed among five therapists. In this way, therapists provided professional recommendations for PMs on how to minimise the detrimental impacts of excessive OS on their health according to each cause of stress.

## DATA ANALYSIS

According to the RII ranking (Table 1), 'Unrespectful and/or inappropriate behaviour of stakeholders', 'Inflation and economic conditions' and 'Delay in payment of salaries are the top three factors that put much stress on PMs. Unrespectful and inappropriate behaviour of stakeholders refers to unrealistic expectations imposed by the clients or consultants. Respondents also stated about the top-down view, impolite conversation, double standards and unreasonable request from clients and consultants as main stressors within this category. The high rate of inflation caused by political sanction has made construction a stressful job. With prices changing regularly owing to national exchange rate fluctuation, PMs can hardly keep the projects on budgets.

As shown in Table 1, eight stressors among 15 are about communication issues (rank 1, 5, 9, 10, 11, 13, 14 and 15). This emphasises the importance of the social side of construction projects and the necessity of establishing effective relationships among all parties involved to minimise OS. This has not been adequately addressed in the work of De Silva *et al.,* (2017) as only one stressor (Different views from superiors) regarding communication issues is pointed out.

However, Enshassi and Al-Swaity (2015) discussed relationships with others at work deeply and highlighted it as the second important factor in their study. Three out of fifteen stressors relate to financial and economic consideration (rank 2, 3, and 12) that have not been recognised in Enshassi and Al-Swaity (2015) and De Silva *et al.,* (2017) that sound challenging in Iran owing to sanctions and traditional allocation system of public budget to construction projects. There are also two stressors related to the personal stressors of PMs (rank 6 and 8) and two associates to managerial considerations (rank 4 and 7). These stressors have attracted more attention in previous literature (Enshassi and Al. Swaity 2015; De Silva *et al.,* 2017) and are confirmed as critical in this research too.

Surprisingly, time overrun, lack of job satisfaction and heavy workload are not among high ranked stressors while literature identified these stressors as influential (Enshassi and Al-Swaity 2015; De Silva *et al.,* 2017; Ree-Evans 2020). One reason might be the fact that delay is a recurring problem in many projects in Iran and PMs use to exceed the predetermined time. In terms of job satisfaction, often construction professionals work hard to get a project management position and it is an achievement to them. Thus, they expect the heavy workload associated with this position and macho culture prevents them from talking about these issues.

*Table 1: Prioritised list of stressors and stress coping strategies*

| Rank | Stressor Description | RII | Coping Strategies recommended by Therapists | TOPSIS Weight |
|---|---|---|---|---|
| 1 | Unrespectful/ Inappropriate behaviour of stakeholders | 0.856 | Reframing the issue | 0.220 |
| | | | Learning about coping strategies | 0.168 |
| | | | Setting work-life boundaries | 0.145 |
| 2 | Inflation and economic conditions | 0.846 | Relaxation and meditation | 0.197 |
| | | | Seeking employer and family support | 0.197 |
| | | | Clarifying duties, responsibilities & authorities | 0.197 |
| 3 | Delay in payment of salaries | 0.844 | Reframing the issue | 0.266 |
| | | | Talking to the superior | 0.156 |
| | | | Setting work-life boundaries | 0.156 |
| 4 | Poor management of superiors | 0.830 | Learning about coping strategies | 0.220 |
| | | | Healthy responses | 0.166 |
| | | | Taking time to recharge | 0.162 |
| 5 | Discrimination/ unfair exchange in the organisation | 0.826 | Relaxation and meditation | 0.225 |
| | | | Healthy responses | 0.144 |
| | | | Taking time to recharge | 0.144 |
| 6 | Job security | 0.826 | Setting work-life boundaries | 0.162 |
| | | | Healthy responses | 0.162 |
| | | | Clarifying duties, responsibilities & authorities | 0.162 |
| 7 | Complex decisions making | 0.816 | Relaxation and meditation | 0.199 |
| | | | Clarifying duties, responsibilities & authorities | 0.179 |
| | | | Taking time to recharge | 0.174 |
| 8 | Lack of work-life balance | 0.814 | Reframe the issue | 0.258 |
| | | | Setting work-life boundaries | 0.178 |
| | | | Learning about coping strategies | 0.178 |
| 9 | Stakeholders' interference | 0.814 | Talking to the superior | 0.269 |
| | | | Learning about coping strategies | 0.235 |
| | | | Healthy responses | 0.169 |
| 10 | Unrespectful/ Inappropriate behaviour of superiors | 0.810 | Relaxation and meditation | 0.377 |
| | | | Talking to the superior | 0.194 |
| | | | Reframe the issue | 0.183 |
| 11 | Lack of superiors' support (within the organisation) | 0.808 | Talking to the superior | 0.264 |
| | | | Tracking stressors | 0.152 |
| | | | Setting work-life boundaries | 0.136 |
| 12 | Lack of project finance sources | 0.806 | Clarifying duties, responsibilities & authorities | 0.228 |
| | | | Seeking employer and family support | 0.195 |
| | | | Reframing the issue | 0.141 |

| | | | | |
|---|---|---|---|---|
| 13 | Lack of trust between superiors and the PM | 0.804 | Relaxation and meditation | 0.255 |
| | | | Talking to the superior | 0.204 |
| | | | Taking time to recharge | 0.124 |
| 14 | Irresponsibility of subordinates | 0.800 | Seeking employer and family support | 0.323 |
| | | | Clarifying duties, responsibilities & authorities | 0.323 |
| | | | Tracking stressors | 0.077 |
| 15 | Tensions in workplace relationships | 0.800 | Clarifying duties, responsibilities & authorities | 0.253 |
| | | | Tracking stressors | 0.231 |
| | | | Healthy responses | 0.231 |

Coping Strategies

Enshassi *et al.,* (2018) defined stress coping strategies as individuals' ability to deal with stress for diminishing its damaging effects through better control and management instead of taking medication. Besides the lack of legislation around treating poor MH in construction projects in Iran, companies have no clear strategy or policy to help tackle the issue - including access to helplines, awareness talks, training, and support systems. This section describes ten coping strategies that are agreed by the therapist that may help PMs to manage moderate day-to-day OS in projects (Table 2).

*Table 2: The description of stress coping strategies (adopted from Dhaliwal 2016)*

| No | Stress Coping strategy | Description |
|---|---|---|
| 1 | Reframing the issue | A technique that helps individuals to see the situation from a different perspective. It can turn a stressful event into more manageable circumstances. |
| 2 | Learning about coping strategies | Form/informal education to cope with stress by taking courses or reading books. |
| 3 | Setting work-life boundaries | The extent to which individuals blend their work and home life e.g., setting some rules such as not checking email in the evening or not taking calls during dinner. |
| 4 | Relaxation and meditation | Meditation followed by relaxation to eliminate the stream of a stressed mind. |
| 5 | Seeking employer & family support | The ability to overcome fear and concern of being stigmatised. |
| 6 | Clarifying duties, responsibilities & authorities | The ability to say 'No' and to negotiate/clarify duties and responsibilities when people are overloaded. |
| 7 | Talking to the superior | Forming a good relationship with the superior to communicate concerns. |
| 8 | Healthy responses | Exercising, healthy sleep habits, yoga, favourite activities, playing games and doing hobbies are some health responses to stress. |
| 9 | Taking time to recharge | The necessity to have times without involvement in work-related tasks or thoughts. |
| 10 | Tracking stressors | Recording thoughts, feeling and information on OS, including the people and circumstances involved, the physical setting and how to react. |

In the TOPSIS stage of the research, therapists were asked to prioritise coping strategies for each stressor by weighting them according to their effectiveness for each stressor. This is illustrated in Table 1 (TOPSIS Weigh column) where for each stressor a list of three highly effective strategies is suggested by therapists. For instance, for the rank one stressor, the most effective stress management strategies are "Reframe the issue", "Learning about coping strategies" and "Setting work-life boundaries".

The most frequent stress management strategies selected by therapists are "Clarifying duties, responsibilities and authorities" (frequency of six), "Healthy responses", "Reframe the issue", "Relaxation and meditation", "Setting work-life boundaries" and "Talking to your superior" (all frequency of five). Hence, forming a good relationship with the superior and the opportunity to talk about responsibilities and authorities help PMs to cope with OS. This highlights the importance of having the quality of conversations among parties involved in the project. The other four strategies are about the inner state of PMs and their perception of stressors. PMs by making healthy choices when their stress rises can tolerate those situations. Exercising, healthy sleep habits, yoga, favourite activities, playing games and doing hobbies are some health responses to stress. The effectiveness of meditation that is followed by relaxation is emphasized by the therapists to eliminate the stream of a stressed mind.

## DISCUSSION

As explained before, people who take management roles in construction projects are not usually willing to talk about OS because of macho culture and the concern for being stigmatised by colleagues. It seems that PMs generally 'bottle up' their stress because of fear of being weak which is one of the leading causes of poor MH. The results of the study show that the Iranian PMs have similar issues and try to negate OS unconsciously. In Table 1, stressors that are widely identified by previous researchers cannot be observed within the top ten in the list. It seems that stressors such as unrealistic deadlines, excessive workload and lack of control are accepted as norms among PMs.

Although PMs attempt to hide their stress and approach it as a normal work-related fact, the negative impacts of excessive stress is damaging to their health. With a lack of professional support and adequate information, PMs are overstimulated by OS. While nationals' strategies and corporate policies need to be established for managing the MH of construction professionals in the medium and long term, a short-term solution is needed to promote a self-reliance culture for coping with OS among PMs in Iran. The framework developed in Table 1 can help PMs as a tranquillizer by enhancing their awareness of stressors that frequently happen in projects and give them simple recommendations to overcome those. This also creates a ground for PMs to connect and talk about their MH as they understand that working under excessive stress is not normal and expressing their experience of OS is not a sign of weakness.

## CONCLUSIONS

The Construction industry has long been known as a risky industry with H&S measures being widely promoted and implemented over the last decades to reduce accidents that threaten physical health. However, the situation is not the same for MH. While physical pains and wounds are usually visible, mental issues like stress can be hidden by people owing to existing norms such as macho culture. Excessive OS leads to a decline in PMs' performance because they carry out tasks or make decisions that reduce the productivity of the project in stressful conditions.

In Iran's construction industry, OS has been ignored and the impact has not been studied adequately. Thus, PMs understanding of OS in uncertain and unstable conditions of the country is low which in turn imposes more stress on project professionals. This study has identified 92 stressors through reviewing literature and conducting interviews and then narrowed them down into 15 highly frequent stressors

by administering a survey. For each stressor, three coping strategies have been recommended by therapists that are ranked using the TOPSIS method.

Those stressors related to communication and social aspects of construction have the highest scores for raising OS in PMs. The developed framework proposes "Clarifying duties, responsibilities and authorities", "Relaxation and meditation", "Setting work-life boundaries", "Talking to the superior", "Healthy responses", and "Reframing the issue" as effective coping strategies to overcome project-related stressors.

The outcomes of this research improve PMs awareness of OS and coping strategies and initiate discussion of PMs MH in Iran. It should be noted that the coping strategies may not be effective when PMs experience acute or chronic stress which needs professional therapy or medication. Rather the framework developed in this study helps PMs to be aware of stressors, recognise their stress indicators and distinguish possible strategies that enable them to cope with the most frequent stressors in construction. Furthermore, the results cannot be generalised without considering the context and small sample of this research. Wider studies using statistical methods are required to support the generalisability of the outcomes.

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# COMPLIANCE WITH COVID-19 REGULATIONS IN MICRO-ENTERPRISES AND SMES IN THE IRISH CONSTRUCTION SECTOR

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In Ireland, the construction sector has such major influence on growth and economic stability that construction companies were able to restart operations during the COVID-19 pandemic, albeit with the development and implementation of a set of regulations by the Health and Safety Authority (HSA) and the Construction Industry Federation (CIF) to facilitate the safe return to work on sites across Ireland. The introduction of regulations is the first step in the provision of safe working conditions in relation to the pandemic and this research addresses the need to examine the functionality of, and compliance with such regulations. It should be noted that due to the nature of the pandemic, it would be the case that the regulations will be changing due to the emergence of virus variants, infection rates, and vaccination levels so this pilot study essentially takes a 'snapshot' that examines the suitability and compliance with regulations as currently imposed on the Irish construction sector. The study exclusively focused on staff working in micro and small to medium enterprises (m/SMEs) from mid-November to mid-December 2020. Interviews, centred around a 53-part questionnaire, were completed with 30 participants from 27 construction companies. Initial findings indicated the level of compliance with the regulations to be much lower than expected due to issues such as employee behaviour, difficulty in breaking of old habits and lack of supervisory personnel. Findings also indicate that 70% of participants found conflict between the new regulations for safe working relating to the pandemic and current Health and Safety procedures, listing issues such as worker isolation, manual handling issues and obstruction of both visibility and communication by facemasks. Typically, the responsibility for implementation and enforcement of the regulations has fallen into the remit of the Health and Safety personnel in the companies. The research, limited only to companies in the Irish construction sector, has raised many questions about the suitability of the current regulations and warrants further investigation as to why micro-enterprises and SMEs have difficulty with compliance.

Keywords: COVID; pandemic; micro-enterprises; SME; compliance; confined space

The COVID-19 pandemic has had a profound impact on construction, necessitating both the introduction of regulations to facilitate safe working on site and also research on the suitability of, and level of compliance with such regulations, especially where compliance has an effect not only on-site but also has a public health aspect. How the

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pandemic has affected various industrial sectors such as construction, and how different governments have reacted to it, differs widely across the world.

In Ireland, the response to the pandemic involved the Health and Safety Authority (HSA) and the Construction Industry Federation (CIF) developing regulations to facilitate safe working practices on Irish construction sites. Currently there have been no studies undertaken to investigate the level of compliance with the current COVID-19 regulations by micro and small to medium sized enterprises (m/SME) in the Irish construction sector. This study, while recognising the inevitable evolution of regulations as the pandemic develops, is limited exclusively to the Irish construction industry context during a specific time frame of mid-November to mid-December 2020, will identify barriers to compliance and make suggestions for eliminating or reducing such barriers to improve compliance.

A detailed literature review has been undertaken to understand the current regulations (which as stated above will most likely change as the response to the pandemic develops) and establish the key factors that influence compliance.

The fact that the COVID-19 virus can spread through close contact means that it is vital that regulations, especially those relating to working in confined spaces, are formulated, implemented and monitored on sites. This study investigates tools used to assist with compliance such as auditing, despite the negative stigma attached to auditing in the construction industry. The use of spot checks could also be utilised to optimally support compliance in the construction industry (Williamson, *et al*., 2018). Other tools such as communication channels including Toolbox Talks (TbT), WhatsApp, or focused e-mail threads are also considered.

Interviews were used to gather information from 30 participants from 27 companies across Ireland. All companies that participated fall within m/SME category. The use of a questionnaire facilitated gathering of quantitative (scored and scaled questions) and qualitative data (using open ended questions to capture the experience and opinions of working professionals in the industry) to allow investigation of behaviour regarding their experience of, and compliance with, COVID-19 regulations. In the Irish context, it is paramount the construction industry complies with the current regulations set out by the regulatory authority, the HSA, and works with the recommendations from the CIF as the representative construction organisation not just to ensure on site safety but to ensure that public health is also safeguarded through appropriate behaviour and compliance with regulations on site.

## LITERATURE REVIEW

In the Irish response to COVID-19, two Government Departments, the Department of Business, Enterprise and Innovation and the Dept of Health have created a forum of members from state and business bodies to ensure that all actions in the safe-working protocol are implemented to supress the spread of COVID-19 in the workplace. In the case of the Construction Industry, regulations termed the safe working protocol are intended to augment existing Health and Safety measures on site in the hope of achieving full compliance to the new COVID-19 regulations (Department of Business, Enterprise and Innovation and the Department of Health 2020).

Strong and clear communication of such guidelines, coupled with robust yet practical enforcement encompassing training, provision of appropriate personal protective equipment (PPE), auditing and feedback, is essential in protecting construction workers from the spread of COVID-19 (Department of Business, Enterprise and

Innovation and the Department of Health 2020). For example, the CIF states that to slow down the transmission of COVID-19, a minimum distance of 2m between employees must be adhered to on-site (CIF, 2020). Employers are generally aware that they have the responsibility to comply with safety programmes but there is no evidence available showing that construction sites in Ireland operated by m/SME are in full compliance with site specific regulations set out to reduce the spread of COVID-19. This pilot study aims to provide a 'snap-shot' of compliance with the COVID-19 regulations across the m/SME in the Irish context.

The construction industry is constantly facing changes, such as adoption of new methods of communication, new equipment and new processes that bring with them new hazards. The industry is on a continuous learning curve to adapt to these changes and so it is never fully free from safety problems (Cesarini, Hall and Kupiec 2013). The emergence of COVID-19 has presented a new and dangerous public health risk that needs to be carefully managed through the development of new safety regulations, their implementation and monitoring both on site and in the community in general.

With regard to compliance, it has been reported that in safety management, both behavioural and attitudinal factors from employers and employees in the USA contribute to an increase in behavioural safety non-compliance (Jamal Khan, 2006). Historically, human factors affecting compliance consist of worker age, worker safety awareness (Alaqqad, 2009: Ismail, Doostdar and Harun, 2012), worker experience and previous exposure to accidents (Charehzehi and Ahankoob, 2012). Also mentioned are worker education, worker marital status, the knowledge and involvement of workers (Alaqqad, 2009), along with communication between workers (Zamani, Banihashemi and Abbasi, 2020). Human behaviour unfortunately cannot be programmed like a machine (Jannadi, 1995). It has been argued by (Ejdys and Halicka, 2018) that a positive attitude shown reflects a readiness to learn. However, it is key that this attitude is evident not only in staff and subcontractors on site but is supported by institutional pressure on individual behaviour to positively affect compliance in m/SME.

There are many physical tools that can also be used to assist with ensuring compliance. Signage with simple diagrams using symbols that all employees can readily understand or using barriers to prevent or control access are two effective tools that are relatively simple to implement (Alaqqad, 2009). Toolbox talks (TbTs) can be used as a potentially impactful form of supervisor safety communication on sites in the construction industry (Olson *et al.,* 2016) with the aim of explaining requirements and therefore reducing non-compliance issues. It is recognised that TbTs are a common and valued method of aiding compliance and addressing complications with safety issues (Olson *et al.,* 2016).

Compliance audits are used to assess the functionality and compliance with health and safety processes on construction sites, factoring in legislative requirements, industry best practices and the contractors own understanding of their health and safety management system (HSA Inspections, 2020). Although safety inspections carried out by officers of regulatory authorities are believed to be of importance in the prevention of accidents and compliance to regulations, there is little in-depth research on this (Saurin, 2016). Findings have also shown that there can be a negative stigma surrounding the term 'audit' and the profession of auditing (Eulerich, Kremin, Saunders and Wood, 2017). This can affect outcomes of these interventions and has

also made it difficult to attract high quality candidates for jobs in the audit role. Another study into auditing professionals in both the US and Europe identifies the profession as being morally dirty work (Ashforth and Kreiner, 2014), attributed to the intrusive and exposing nature of auditing. In more recent times, a case for more non-punitive inspections has been made although literature is limited in this area. However, a study by (Williamson, *et al*., 2018) illustrates how Australian national policy endorses and promotes a responsive approach to work health and safety, using a combination of positive motivators such as education and advice, with compliance monitoring and enforcement to promote and secure compliance to regulations.

A specific challenge for construction sites regarding compliance with COVID-19 regulations, arises when it comes to working in close contact, especially in a confined space, where it is advised to keep at least 2m from other workers when possible (CIF, 2020). Confined spaces are defined as limited or restricted areas not designed for continuous occupancy where employees enter and perform a specific task (Botti and Duraccio, 2018). It is well recognised that overcrowding increases the risk of transmission of diseases in general (Beggs and Noakes 2003) and the limited spatial environment on site was attributed as one of the core factors affecting workers health and safety (Spillane and Oyedele 2013). The main cause of accidents and fatalities in most confined spaces is the atmospheric condition (Botti and Duraccio, 2018). In Ireland, employers and self-employed persons are responsible for the implementation of health and safety measures complying with a defined Code of Practice to ensure employees are working safely in confined spaces (Code of Practice for Working in Confined Spaces 2017).

Another mechanism for facilitating compliance is the use a Safe System of Work Plan (SSWP) with the main objective to identify significant hazards associated with work on construction sites coupled with actions that ensure any guidelines set out by the HSA are highlighted and understood before work commences. It was found when reviewing the current literature that no generic SSWP currently exists for dealing with the COVID-19 crisis under the current code of practices from the HSA. Nonetheless an SSWP is effective through its use of pictograms and simple language to communicate to employees with little to no English (Health and Safety Authority, 2020). The development of an SSWP relating to the key factors for compliance to COVID-19 regulations would be a beneficial addition to the compliance toolkit on site.

## METHODOLOGY

The research methods used aimed to gather primary data through interviews conducted over a 4-week period between November / December 2020, effectively 8 months after the virus had impacted the Irish construction sector.

The selection criteria to identify suitable companies for participation in the research were as follows. The companies had to fall within the size category of micro or small to medium enterprises (m/SME) as defined in Ireland. A micro enterprise is defined as an enterprise that employs fewer than 10 employees and has an annual balance sheet/ turnover that does not exceed €2 million, with a small to medium enterprise defined as an enterprise that does not employ more than 50 employees and has either an annual turnover/ balance sheet not exceeding the amount of €10 million (SME Facts and FAQs - ISME, 2019). The companies also had to be in existence and trading in the construction sector for at least one year prior to the COVID-19

pandemic as one of the research aims was to analyse the impact of COVID-19 on 'normal' working conditions.

The data acquired was a mix of both Qualitative and Quantitative data. The interview questions were designed to gather data over five core areas in respect to COVID-19 regulations that this study aimed to investigate. These areas were: 1.) Tools to Assist, 2.)Thoughts on Guidelines, 3.)Compliance, 4.) Confined Space Works, 5.) Employee Attitude and Behaviour. As all participants are asked the same questions in the same order, the data gathered can be compared, it can also be numerically transformed and quantified (McIntosh and Morse 2015). Likert Scales were used to aid in this process and facilitate comparison as Hasson and Arnetz argue that Likert scales are more responsive and more easily understood than other methods, they also argue that Likert scales are comparable, reliable and provide valid information (Hasson and Arnetz, 2005). Industry professionals' views and opinions were gathered as a subjective reaction to the phenomena of COVID-19 through a limited number of open-ended questions, thus extending the data capture by facilitating access to the years of experience in the field and individual opinions of the participants which were considered as valuable assets to the study.

The interview data was logged anonymously with only the person's position, approximate age and gender recorded thereby allowing more truthful and accurate responses as participation carried no implications for the interviewees nor their companies' reputation. The interviews were carried out over the phone due to the limited access to sites, facilitating ease of access to participants dispersed across Ireland. As discussed by (Liamputtong, 2014) conducting interviews in this way allows access to a much greater pool of participants. The fact that the interaction is exclusively auditory and so absent of visual cues, removes any preconceived ideas or views of the interviewer that may impede the participant expressing their perspective, and finally it allows participants to participate safely which also contributes to more honest responses.

## RESULTS AND ANALYSIS

Interviews were carried out with 30 participants across 27 companies in Ireland. These interviews were based on a 53-part questionnaire focused on 5 core themes: Tools to assist, Thoughts on Guidelines, Compliance, Employee Behaviour, and Confined Spaces as highlighted in the literature review.

Tools to Assist: Of the 30 respondents asked whether they use internal auditing procedures such as spot checks for compliance, 100% answered yes. Although, on a follow up question as to whether regular spot checks were carried out, 80% indicated that spot checks were infrequently performed. Toolbox Talks (TbTs) were identified as a widely used tool to aid with explaining regulations and assisting compliance with them, 47% of participants using them on a weekly basis and 53% scheduling them once a month. Some companies increased the number of TbTs delivered to limit the number of employees in attendance and facilitate social distancing. It was found that 30% of Interviewees indicated that their companies had adapted new ways or methods of communicating information due to the current pandemic using channels such as WhatsApp groups and focused email threads. Another tool used was signage and positioning of physical barriers, 100% of participants said that physical barriers and extra signage had been erected on site and that the meanings of any pictograms or symbols new to the site were explained beforehand.

Thoughts on Guidelines: When asked were the guidelines sufficient to prevent the spread of COVID-19 on site 90% of participants agreed or strongly agreed. However, when then asked whether they found the guidelines to be suitable for onsite work and activities only 3.3% agreed or strongly agreed bringing into question the suitability of the regulations for a construction site. From the data, the main barrier to compliance for 70% of respondents was reported as 'Lack of Personnel for Supervision'. When asked if any other specific barriers were evident, 80% of participants reported issues such as "Breaking old habits", "Stubborn nature of staff and unwillingness to change" and "Older staff do as they know and find it hard to accept change when they do not believe it is the best way". Participants were asked if they had identified conflicts with established Health and Safety regulations and the introduction of COVID-19 regulations. Interestingly, issues reported that had not previously been identified or reported included worker isolation, manual handling issues, and certain items of Personal Protection Equipment (PPE) causing more hazard than benefit for workers with comments such as "masks obstructing vision" "impaired communication leading to more frequent mistakes.".

Compliance: According to the feedback from participants to the question 'Do you believe all employees understand the COVID-19 regulations onsite?', 96.7% of results showed agreement to strong agreement. Despite this promising sign, on Irish construction sites full compliance is not evident. For example, 96.6% of participants scored 3 or less on a 1-5 Likert scale, 1 being never and 5 being always, when asked do workers always wear the appropriate PPE as stated by COVID-19 regulations for specific tasks. Pressure of added paperwork or the need for extra on-site supervision due to COVID-19 regulations is leading to employees getting extra responsibilities with 42.3% of participants stating that the new regulations has added 'significant' pressure to their daily workload. To manage the extra workload, 30% of participants said extra staff were needed, with 11.1% of those companies employing 2-3 extra workers and the remaining 88.9% employing 1 extra employee. Compliance with handwashing regulations was also reported as extremely difficult to maintain according to 97% of participants.

Confined Spaces: The findings confirm that within the participant group, 40% agreed or strongly agreed that regulations relating to confined spaces were impacting on their work, the remaining 60% were either working outdoors or did not have multiple trades carrying out work in a confined space, allowing for a safe working environment. However, 100% of participants said that it is hard to break the habit of having multiple trades in the confined spaces, but this comes down to human nature and also overtime management. Interestingly, 67% of participants indicated that this issue with confined spaces did not impact significantly on project schedules. With regard to overtime, 96.7% of all interviewed participants stated that workers did not have to work overtime in comparison to pre COVID-19. This is a positive finding in relation to budgeting and costing for projects but brings compliance into question.

Employee Behaviour: Appropriate employee behaviour is of paramount importance for full compliance on construction sites in Ireland. Feedback from participants shows that 93% of employees are in favour of the COVID-19 regulations. The comfort of PPE on site was scored low, with 97.7% of participants disagreeing or strongly disagreeing that the PPE was comfortable. This led to employees not wearing masks when supposed to, and 'operatives simply forgetting' as one participant stated. There was also the negative impact of the contradiction between the 'routine' Health and Safety guidelines governing manual handling and working alone, and the COVID-19

guidelines. There was also the impact of 'old habits die hard' when it came to making the changes to work practices in line with the guidelines.

## DISCUSSION

In this research, interviews allowed the capture of insights and personal perspectives of industry professionals in the Irish construction sector. The research clearly shows that there is no single key factor facilitating or impeding compliance to COVID-19 regulations. However, several areas of interest where clear barriers and obstacles facing compliance within the sector have been identified.

As discussed by (Olson *et al.,* 2016) Toolbox talks (TbTs) can potentially play a significant role in the form of supervisor safety communication with 25 of the 27 construction companies who took part in this study stating that they used some form of TbTs. However, the implementation of TbTs differed greatly. Some sites used them on a weekly delivering relevant information on site in a timely manner. However, 53% of sites only used TbTs on monthly basis because it was presumed the relevant information would get to the intended party when it was needed, due to the small physical size of sites and limited number of employees. A similar point can be made for onsite spot checks where 100% of companies used them, indicating a belief that spot checks can be effective. Yet when asked how often they were used the answers differed greatly, from daily, to weekly or even monthly. Some companies said they wish they could use them more, but they were not a feasible option due to limited resources and inability to take on extra staff for supervision.

It was found that only 30% of respondents were using new methods of communication during the COVID-19 pandemic, Simple methods such as WhatsApp groups or focused email threads were employed, both of which are free and relatively simple to operate. However, some older staff did say it can be difficult to track information on these platforms as they are not specifically designed for this use. The perception was that specific software available on the market such as Procore or Oracle Aconex were too expensive, too complex, or did not suit the type of projects these smaller firms were working on. This research indicates that there is a lack of knowledge about purpose-built platforms that allow quick and simple contact amongst staff on smaller sites, perhaps due to the fact smaller firms cannot afford to be paying yearly subscriptions for some of the bigger platforms. In some cases, there was insufficient knowledge of communication tools that have zero cost but could improve information flow on site, enhance compliance and diminish the safety risks during the COVID-19 pandemic.

Despite a lot of things being done right, such as the provision of PPE and the relevant training on how to use the equipment, supported by TbTs and the appropriate signage on site, non-compliance issues tend to prevail. Some factors affecting compliance may prove more difficult to correct according to the data collected. Working professionals believe non-compliance is due to human nature which would fall broadly in line with previous findings on issues of compliance to health and safety regulations. As stated in the literature, compliance is essential for the government measures to work effectively (Anderson, Heesterbeek, Klinkenberg and Hollingsworth, 2020). The results clearly indicate that the vast majority, if not all, of employees understand the COVID-19 regulations and 90% agree that the regulations and guidelines are necessary yet when asked about wearing facemasks on-site, 96.7% said they do not always comply. This was attributed to ‘Old Habits’ and ‘Older staff doing as they pleased', indicating a behavioural and attitude issue where employees

must be educated and influenced over time to change their habits. The poor behaviour of older staff negatively influenced the behaviour of younger staff as they tend to follow the example set. Other issues included the physical design of PPE as a lot of the masks worn in the construction sector are not for continuous use throughout the day. Also, problems such as PPE interfering with communication or vision while completing some tasks have led to increased risk of mistakes and accidents. Similarly, worker isolation, and manual handling issues due to social distancing have created scenarios where the COVID-19 regulations create unintended safety issues. As a result, workers choose to ignore the regulations due to the regulation's lack of suitability - only 3.3% reported that the regulations were wholly suitable.

It was found that the COVID-19 regulations greatly impacted those sites where workers had to perform tasks in confined spaces. Respondents reported that it was difficult to maintain 2m social distance while working in confined spaces as advised by the CIF (CIF, 2020). This is a problem because the transmission of the disease drastically increases when humans are in close contact with one another as stated by (Beggs and Noakes 2003), this is especially the case with COVID-19. Companies working on projects that had confined spaces reported little to no delays and no real overtime being worked on projects. With the reason given very truthfully "Although the restrictions and recommendations are there most staff do not follow them as they say it is unreasonable or impossible to complete certain tasks while keeping their distance". This research showed that onsite staff in some cases simply won't or can't follow guidelines in place. The findings indicated that there were many SSWP's in use in the field in as self-created SSWP or SPA (Safe Plan of Action). These documents varied slightly from site to site, yet all had the common objective of creating a suitable, safe working environment in relation to COVID-19 before the commencement of work.

## CONCLUSION

This paper aims to highlight some of the key factors affecting compliance to and implementation of COVID-19 regulations in m/SME in the Irish construction sector. Several contributing factors have been discussed allowing valuable recommendations to be made. Tools to assist with compliance such as TbTs and spot checks have proven to be effective in the past. The results indicate that this could be true but the implementation strategy behind them is key to their impact on site. For TbTs and spot checks to deliver the intended outcome of increasing compliance on-site, they must be carried out on a regular and consistent basis. Many companies however questioned the feasibility of this and raised the issue of having neither the time nor money. This indicates that there may be reason for a subdivision of the HSA to be tasked with carrying out much simpler and quicker forms of site inspections or audits with the sole purpose of educating and encouraging staff to comply with regulations. Communication structures in smaller companies need to be revised. There is scope for the CIF to intervene here and develop a purposed built platform to allow ease of communication on site thereby facilitating compliance with the COVID-19 regulations.

As discussed by (Bévort and Suddaby, 2015), institutional pressures will impact employees and subcontractors, so it is key that the companies themselves believe in, implement, and follow the regulations as outlined. It is vital that staff in positions of management and leadership have access to as much support and training as possible so they in turn can support their employees in relation to understanding and

complying with the COVID-19 regulations. Another standout issue raised on several sites was the inability to always abide by social distancing measures due to tool sharing and manual handling, indicating the regulations themselves were not suitable. A recommendation to implement a buddy system could help to solve this issue. This would allow contacts to be easily traced while also allowing regular tasks on site to be completed as normal.

The final suggestion arising from this research paper is that a generic SSWP be developed by the HSA to be used in conjunction with the Codes of Practice that are already in place. This would allow every site to work towards the common goal of mitigating risks associated with COVID-19. There is need for further research in the area of developing regulations to facilitate the continuance of work in the face of a highly hazardous situation. It should be noted that in the time since this study was carried out the construction sector has been shut down due to a high increase in COVID-19 case numbers in Ireland, highlighting the need for the continuous development and improvement of effective and implementable safe working practice guidelines for the construction sector and monitoring of compliance with such guidelines.

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# FORTIFYING MANAGEMENT CONTROL OF HEALTH, SAFETY AND PRODUCTIVITY LOSS IN SOUTH AFRICAN CONSTRUCTION

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This paper illustrates the paradox related to the tension between production and safety, which are competing elements. The study established the impact of unsafe health and safety practices on productivity in construction. A qualitative research approach was used to establish the relationship between health and safety practices and productivity loss. The 22 interviewees who answered both closed-ended and open-ended questions were active construction workers and professionals involved in projects at the time of data collection in South Africa. Based on the results of data analysis, a direct influence of health and safety on employees and their work practices was affirmed. For example, the results showed that poor health and safety practices at work lead to absenteeism resulting from illnesses and injuries. Poor health and safety practices, in turn, lead to a loss in productivity of the workforce. Cited instances show that work pressure leads to a lack of attention and concentration. Beyond compliance to legislation by the work crew, there is a case for reinforcing management controls on construction sites in the study area. Effective health and safety risk control and the steps of its deployment must be reinforced. Management controls would help contractors to remove the burden of hazard on a particular site by identifying what must be done and what gaps in the process are to be corrected. While the results from this study provide a reason to strengthen management control, the oversight should not be excessive to avoid unintended consequences.

Keywords: H&S; loss of productivity; management control; site work; South Africa

## INTRODUCTION

Can contractors maintain high productivity and safety performance on a project simultaneously? This question has been a subject of scholarly work because of the belief that production pressure may cause adverse safety outcomes. Some scholars perceive that high levels of safety negatively impact productivity in construction, although direct influence between productivity and safety is difficult to observe (Smith, 2019). For example, when work pressure is on an upward trajectory, it is not common to see job hazard analysis (JHA) or safe operating procedure (SOP) change in tandem.

In contrast to the tension between productivity and safety view, Jia *et al. (*2017) provide an alternative perspective with two institutional logics (production and

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protection logic). Jia *et al. (*2017) suggest that construction workers will protect their interest by remaining safe as much as possible (protection logic). In contrast, their employers will show a positive disposition towards safety when workers are motivated and improve productivity (production logic). In analysing the two logics, Smith (2019) says that safety can boost high productivity, and production can motivate safer work.

The calls to emphasise the importance of safety, particularly when construction projects face production pressures (Zhang *et al.,* 2018), are premised on the realisation that managerial priorities override safety in time of work pressures (Han *et al.,* 2014). The literature shows that some contractors assume that it is impossible to meet H&S, quality, cost and time performance targets in a project simultaneously. In effect, there is a notion that a zero-sum relationship exists between the parameters as they influence each other. For example, an accelerated schedule could lead to increased cost and lower H&S status in a project (Forbes and Ahmed 2020).

Reason (2016) in "Managing the risks of organisational accidents" illustrated the tension between production and protection (H&S in this paper) to provide a means to comprehend the processes that lead to defensive failures and mishaps. He warned organisations against trading off protective gains against productive advantage. Doing so leads to the gradual decline of defences during times in which the absence of adverse events creates the view that the system is operating safely. The paradox theory explains the tension between production and safety. Smith and Lewis (2011: 382) say "contradictory yet interrelated elements simultaneously and persist over time" present a paradox. The authors stated that the interrelated elements seem logical when viewed separately but inconsistent when put side by side. However, choosing one before the other will not resolve the tension since they are inseparable (Johnson, 2014). For example, prioritising production at the expense of safety will inevitably result in an increased need for the other and intensify the tension. Therefore, organisations must strive for both elements (e.g. production and safety) at the same time (Johnson, 2014)

A descriptive study has been presented in this paper to respond to the question: How do unsafe H&S practices influence loss of productivity in construction? The purpose of the research was to establish the relationship between H&S practices and loss of productivity to propose appropriate interventions that will bridge the gap. Thus, the nature of loss of productivity has been examined. As a management function, how to control can limit the loss of productivity through effective removal or reduction of the burden of hazard.

## RESEARCH METHOD

The interpretive view adopted for the study helped the researcher collect data related to the participants' lived experiences. Being a qualitative study of activity in a situation, the researcher was located on public construction projects (Denzin and Lincoln 2008). The primary source of data was face-to-face interviews conducted using a protocol of both closed-ended and open-ended questions. The data were obtained from people in the frontline of construction by visiting sites in two provinces (Mpumalanga and Limpopo) of South Africa.

Using the same instruments, data were collected from construction sites to make the convergence of observations possible to improve confidence in the results (Huberman and Miles 2002). A purposive sampling method was used to select project sites and

the participants. The criteria for selection were participation in physical work on-site and lived experience of H&S and productivity practices in construction. The fieldworker was a registered construction management student in 2018 who was familiar with the subject. Seminar-like training was provided to the field worker before data collection to ensure easy access and ethical conduct on sites. Statistical data gathered from the closed-ended questions were analysed descriptively. Based on open-ended questions, the interviews were audio-recorded and transcribed before the thematic analysis of the textual data. The required ethical considerations were observed, including informed consent, confidentiality, the anonymity of data and voluntary participation.

During the site visits, 25 people involved in construction work were approached. Only 22, whose demographic data are shown in Table 1, participated. Table 1 shows the positions of the respondents in the company. Most of the respondents who participated in the study were directors, followed by managers, senior managers, executive directors, and supervisors. All the participants had university qualifications, and most of them had been in the industry for more than five years.

*Table 1: Background information of the respondents*

| Profile | Frequency | Percentage |
|---|---|---|
| **Position in the company** | | |
| Supervisor | 2 | 9.1 |
| Manager | 6 | 27.3 |
| Senior Manager | 3 | 13.6 |
| Director | 10 | 45.5 |
| Executive Director | 1 | 4.5 |
| Total | 22 | 100.0 |
| **Highest educational qualification** | | |
| National Diploma | 6 | 27.2 |
| University Degree | 8 | 36.4 |
| Postgraduate Degree | 8 | 36.4 |
| Total | 22 | 100.0 |
| **Length of work experience in construction** | | |
| 2-5 years | 3 | 13.6 |
| 5-10 years | 6 | 27.3 |
| 10-20 years | 13 | 59.1 |
| Total | 22 | 100.0 |

# RESULTS

## Responses to Closed-Ended Questions (Quantitative Data)

Responses to the closed-ended questions asked in the interviews have been presented in this section. The interviewees expressed different views on H&S and loss of productivity on construction sites.

The 22 interviewees were requested to respond to the questions by rating their perceptions of the phenomenon according to a 4-point Likert Scale. The scale ranged from 1 (strongly disagree [SD]) to 4 (strongly agree [SA]). Given the qualitative nature of the study and the limited number of interviewees, the data were not suitable for rigorous statistical analysis, so they have been presented in Table 2 in an accessible, descriptive format. Table 2 shows that 12 of the interviewees concurred (agreed or strongly agreed) with the idea that H&S affects productivity on construction sites and is necessary for performance improvement. This observation implies that most of the interviewees agreed with the argument in the H&S management literature. However, although most (19) perceived that loss of

productivity is caused partially by poor H&S practices, only eight interviewees strongly agreed with the statement. The interviewees' perception indicates that H&S should be considered when the aim is to increase productivity in construction.

Despite the on-site experience of the interviewees, it is notable that 6 of them disagreed when asked whether H&S is a building block of productivity. The responses showed that more than 70% of the interviewees agreed with the statement. Therefore, it can be postulated that H&S has a significant impact on productivity on project sites. Most of the interviewees concurred that it is essential to use effective H&S methods that place the workers' interests first, on-site. The perceptions suggest that adequate H&S procedures (and practices) are not dispensable when contractors are keen to increase productivity but under safe working conditions. The perceptions also indicate that people in the frontline of construction determine production outcomes, and their H&S (including well-being) is central to project success.

Eight of the interviewees did not agree with the notion that limited resources and workforce categorisation could affect H&S. However, a sizeable number among them (19) was of the view that undefined roles influence H&S problems on site. This shows that job roles need to be defined to avoid H&S issues. Proper delineation of job roles helps to maintain productivity on site.

*Table 2: Perceptions of interviewees on H&S and productivity*

| Aspect | SD... ……SA | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| H&S on construction sites affect productivity | 1 | 1 | 8 | 12 |
| H&S is required for improved productivity | 1 | 1 | 8 | 12 |
| Productivity loss is partly caused by poor H&S | 1 | 2 | 11 | 8 |
| H&S is a building block of construction productivity | 1 | 5 | 5 | 11 |
| It is vital for project managers to use proper H&S methods. | 0 | 1 | 3 | 18 |
| Workers come first when H&S in construction sites is considered. | 0 | 1 | 2 | 19 |
| Limited resources and categorization of the workforce affect H&S. | 3 | 5 | 4 | 10 |
| Undefined roles influence H&S problems | 0 | 3 | 6 | 13 |

## Responses to Open-Ended Questions (Qualitative Data)

Responses to the opened-ended questions asked during the interviews have been presented in this section. The textual data contained views on H&S and loss of productivity on construction sites. The data have been presented under themes as follows.

*Induction and training on construction sites*

The interviewees emphasised the aspect of induction and training (I&T) of workers on sites to deal with H&S problems. Most of the respondents insisted that I&T helps in reducing the loss of productivity on construction sites. The interviewees outlined several reasons why the use of I&T as a way of dealing with H&S problems leads to an increase in productivity, including the reduction in mistakes and accidents is the vital aspect which is addressed by the use of I&T on construction sites; and I&T leads to a decrease of errors because the trained workforce can carry out the assigned tasks using the required knowledge and skills, with fewer mistakes. For instance, if people work without the necessary knowledge and skills, there will be a high likelihood of errors, leading to loss of productivity through accidents or incidents (near misses) that might result. Accidents and near-miss events often lead to delays in production and absenteeism of injured workers.

Therefore, the interviewees believed that I&T is a safeguard against the loss of productivity occasioned by H&S problems.

Furthermore, the interviewees pointed out the aspect of time-saving due to appropriate I&T. Time saving potentially reduces loss of productivity. The textual data showed that if the workforce is trained, there would be fewer production disruptions on site. Some of the interviewees insisted that trained workers have the knowledge to use machinery independently; hence, supervisors would not have to spend excessive time on close monitoring of their work. I&T also helps to minimise injuries on site. This is because trained workers should be able to operate plant and equipment safely. Injuries on the job lead to the loss of productivity, which is costly to the company. So, I&T is very important in ensuring good H&S practices on construction sites. The interviewees also observed that I&T motivates workers to work safely as it gives them a sense of belonging in the enterprise. Once inspired, the workers put in more effort to maximise productivity. If workers are inducted and trained, they are motivated to strive to work hard for the organisation's success.

*Production investigations on construction sites*

The focus of this theme was on the effect of production investigations on H&S and productivity on construction sites. The interviewees were asked to express their views on whether production investigations would reduce the loss of productivity. From the results, almost all of them agreed that production investigations could minimise loss of productivity since it would help forepersons or supervisors notice unsafe H&S practices immediately, which might negatively affect the completion of tasks. Such early warning signs would assist site management in finding the solutions that prevent loss of productivity. Inquiries through quality inspections (checks) or H&S audits can identify problems that result in the loss of productivity. The discovery of the issues can also promote early corrective actions. Similar to past studies, the interviewees confirmed that H&S audits save lives and time as the officials can identify hazards and risks before it is too late to address them. For example, an interviewee said inspectors could quickly identify non-compliance with H&S regulations or policy and correct it to prevent loss of productivity.

*Loss of productivity on construction sites*

The focus of this theme was on the effect of unsafe H&S practices on the loss of productivity on construction sites. Inappropriate H&S practices are regarded as dangerous on sites yet are done by workers whilst working. The interviewees were asked to give their views on how improper H&S practices lead to loss of productivity. They said inappropriate H&S practices lead to accidents, which reduce working time and productivity. Most interviewees indicated that inappropriate H&S practices reduce production rate and efficiency in construction because the workers would be at high risk of being injured, leading to extra costs to the company.

Moreover, some interviewees mentioned that inappropriate H&S practises cause workers not to work to capacity or wholeheartedly for fear of being injured. This leads to a loss of productivity because the workers will not produce the maximum production output, of which they are capable, because they will be afraid of being involved in accidents. Therefore, based on the study's findings, it was the view of the interviewees that inappropriate H&S practices reduce overall production on sites.

Some interviewees even mentioned that diseases caused by inappropriate H&S practices affect hygiene status on a site. They cited that the lack of necessary personal protective equipment (PPE) in the form of H&S clothing can lead to asthma, which might lead to absenteeism and low task performance. Both absenteeism and low task performance in combination reduce the productivity on construction sites. The

principal concern cited by the interviewees was that there would be injuries and illnesses if workers fail to use the appropriate safety clothing. By implication, they affirmed that inadequate or inappropriate safety clothing directly impacts the workforce's productivity on construction sites.

## DISCUSSION

The results of this study underscore the role of functions of management work in the physical conversion processes on construction sites. The data also re-affirm the complicated relationship between production and protection (H&S) (Smith, 2019; Oswald *et al.,* 2019). Although researchers have advocated that the level of protection should always match the hazards of the production operations (Reason 2016), the reverse is the case in reality, especially in construction (Forbes and Ahmed 2020), where production pressures have been commonly accepted as a significant cause of accidents (Oswald *et al.,* 2019). The interviewees emphasised the need to implement I&T, production investigations (either through quality inspections or H&S audits) to address the loss of productivity by controlling the people and the process.

The interview data support the notion that productivity in construction negatively affect safety, though direct empirical influence is limited (Smith, 2019). Nevertheless, control is a critical management function because it drives the process forward. For example, a safety management system (SMS) consists of several controls which require construction managers (and other site management team members, such as supervisors) to lead the H&S effort as active members of the system. Inspections and housekeeping reviews, which remains a challenge in Southern Africa (Emuze *et al.,* 2016), are required to control the work environment. The same expectation applies to the role of committees where H&S work must be delegated, monitored and reported. The control function also extends to risk assessment, which involves identifying the likelihood of hazards becoming the source of accidents and preventing them. Essentially, identifying near-miss incidents and removing dangers and risks in the workplace falls under the H&S control function.

According to McKinnon (2014: 143), "Safety controlling is defined as the management function of identifying what must be done for safety, inspecting to verify completion of work, evaluating, and following up with safety action". The definition implies that controlling H&S goes hand-in-hand with production (Reason 2016). Oswald *et al. (*2019) unpacked and explored the link between production pressures and safety through a case construction project that shows the informal ways in which work pressure is managed. The case study found that an informal, covert and hazardous "piecework" process was used on the site in direct response to scheduling demands. In the study, construction workers were rewarded through extra income and rest breaks to complete tasks faster than expected pace in a clear prioritisation of production over safety. The safety controlling function in this case study thus requires interrogation.

A vital feature of the quality movement is that everyone in a firm shares the responsibility for quality. The same level of contributions is required for good H&S practice. Everyone on a site must share the responsibility for H&S, just as they would for quality and production. As shown in Fig 1, the Health and Safety Executive (HSE 2001) recognised that management control is essential for promoting good H&S practice. The HSE (2001) proposed three levels of management control, which are relevant to contractors in construction. Although all three levels in Fig 1 are vital to

prevent accidents, level 2 and 3 are close to what happens on a construction site.

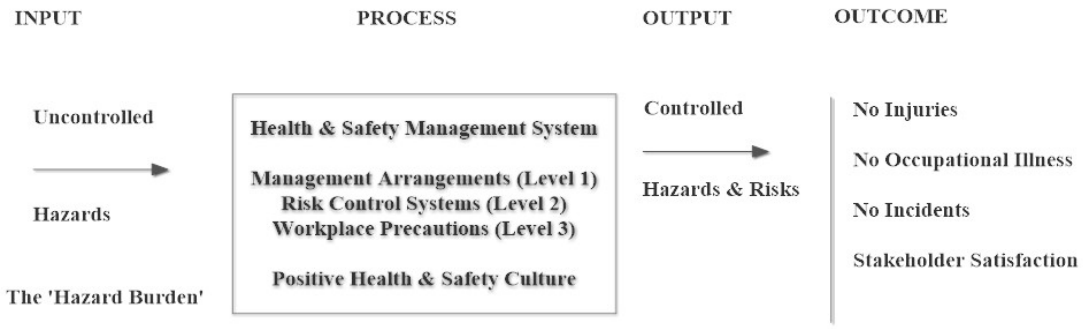


*Fig 1: Effective H&S risk control (HSE 2001: 10)*

The availability of adequate worksite precautions will prevent harm to people and damage to properties at the point of risk (2001). The idea is that if site management provides clear direction and take responsibility for the working environment, a collective effort to develop and maintain systems of risk control before the event - not on blaming individuals for failures afterwards - will evolve.

The outcome column in Fig 1 contains characteristics of an environment in which loss of productivity might not occur due to H&S lapses. However, having no injuries, occupational ill-health, incidents, and stakeholder concerns begins with converting uncontrolled hazards (inputs) into controlled dangers and risks (outputs) through SMSs, strategic directions by management (level 1), risk control systems (level 2) and worksite precautions (level 3) that inter-alia, produce a positive H&S culture. Notably, the range, nature, distribution and criticality of the burden of hazard will determine the risks to be controlled on a typical site. That is why the HSE (1997) proposed risk control systems (RCSs), which form the basis for ensuring that adequate worksite precautions are provided and maintained. Suppose the precautions are observed at the implementation stage of projects, risks associated with routine and non-routine operations, maintenance, plant and equipment, predictable emergencies, and related work can be contained. The containment of such threats leads to the outcomes in Fig 1, which are necessary to prevent loss of productivity because of incidents and accidents on construction sites. Risk control is required to promote both compliance- and behaviour-based safety. The primary approach in establishing workplace precautions includes identifying hazards that could cause harm (hazard identification), assessing the risk that might arise from identified hazards (risk assessment) and making decisions about suitable measures to control the risks (risk control) (HSE 1997).

The approach described above applies to the management control of work activities to eliminate and minimise risks within the construction process on-site. On a typical construction site, hazards are created where people interact with their task. The goal in such situations is to remove or minimise risks inside the construction site. For example, the risk control effort should cover the premises, plant and equipment, procedures and people. If the interviewees' comments in the previous section of the paper a considered, the emphasis of risk control efforts on their worksite should be on procedures and people. The effort should target the removal or minimisation of risks in job design and work procedures. Concerning people, the risk control effort should address the placement of workers (categorisation and role definitions in Table 1), their competence (knowledge and skills) for the specific task and other H&S requirements peculiar to the site. Therefore, when considering risk controls, management should

discuss the issues with their workers and focus on what is done on-site compared to legislation, regulations and industry standards (HSE 2013). The discussion should address risks that can be foreseen (predictable) through changes on a construction site and resource mobility (including people). In brief, mitigation of the loss of productivity by the outcomes in Fig 1 is possible when management techniques and practices are applied to H&S in the same way as production. The steps of management control applicable to H&S are summarised in Fig 2. Please see McKinnon (2014: 144-148) for elaboration.

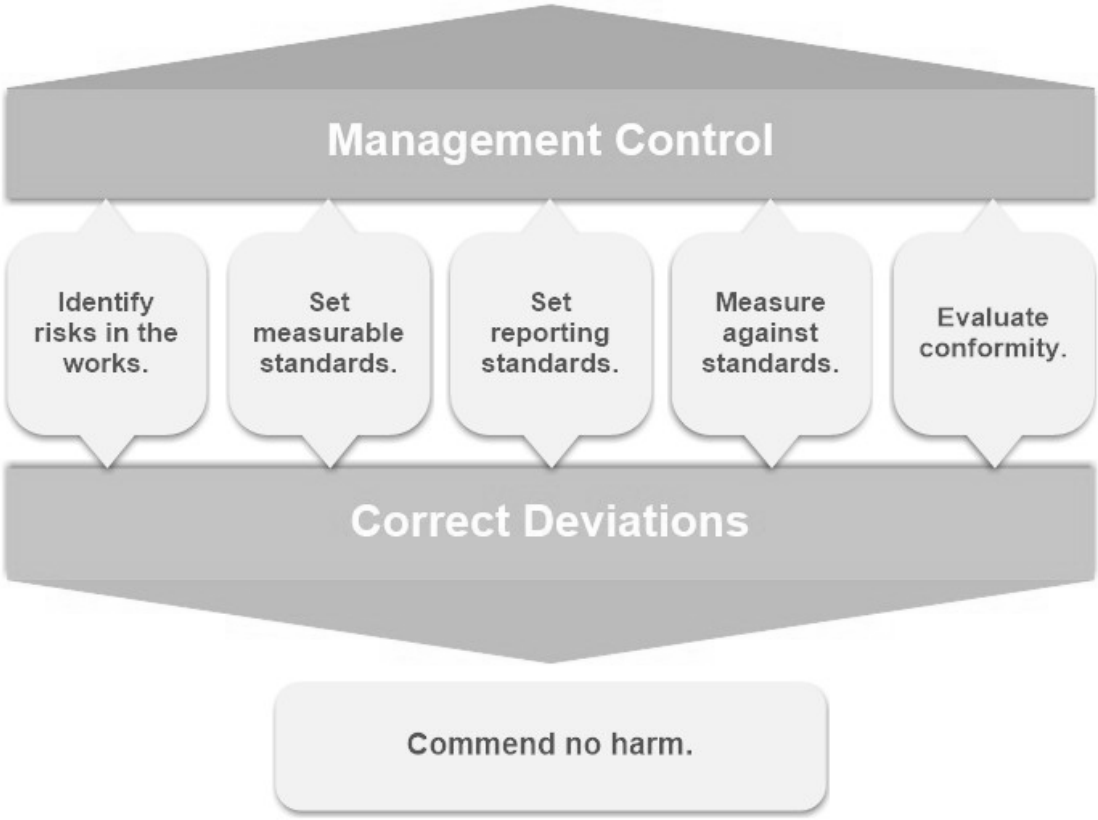


*Fig 2: Management control steps for H&S (Modified from McKinnon 2014)*

## CONCLUSION

The impact of unsafe H&S practices on the loss of productivity has been established qualitatively in this paper. The 22 interviewees affirmed that H&S has a direct influence on work practices and productivity. They reinforced the notion that poor H&S practices lead to absenteeism due to illnesses and injuries, which, in turn, leads to loss of productivity. The themes that emerged from the textual data conveyed the links between induction and training, production investigations and loss of productivity in construction. The interview data suggested that it is necessary to fortify the management function that controls production (or productivity), quality, H&S and other project parameters. An attempt to reinforce management control should however not be excessive to prevent unintended consequences leading to project failure.

There is a case for strengthening management control on construction sites in the study area (Mpumalanga and Limpopo Provinces of South Africa), which the interviewees did not cite. Management control would help contractors to identify what must be done for H&S while inspecting and evaluating the works to verify

satisfactory completion before following up with required actions. The results from this study provide a reason for engaging contractors on how they should strengthen the three levels (see Fig 1) and seven steps (see Fig 2) of the management control function to limit the loss of productivity flowing from a heightened burden of hazard and uncontrolled risks on site. As cited by some interviewees, when adequate procedures and supervision are lacking or not used, loss of productivity is likely. It is for these reasons that management should devise and deploy a risk control system (RCS) through brainstorming sessions in which reflective questions such as the following are asked:

- Are roles and responsibilities well defined on this project site?
- Do all concerned parties understand the roles and responsibilities?
- Do responsible parties have the time and resources to discharge their tasks?
- Are people held accountable for discharging H&S responsibilities?

The answers to these questions should address the H&S competence, commitment and resource requirements of the construction project to enable the conversion of burdens of hazard into controlled risks that provide a worksite where harm and loss of productivity are mitigated through the outcomes shown in Fig 1 and steps in Fig 2.

The limitation of the interview results reported in this paper is typical of qualitative studies where analytic generalisation, advocated by Yin (2014), can be expedited. However, future rigorous research will examine how contractors expedite management control regarding hazards and risks in the study area. The prospective study should interrogate effective H&S risk control (Fig 1) on construction sites and the steps taken to ensure this is a continuous process (Fig 2).

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# DO YOU WANT SOME SAUCE ON THAT? FACTORS INFLUENCING DIETARY HABITS AMONG THE IRISH CONSTRUCTION WORKFORCE

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The health, safety and well-being of the construction industry workforce has received increased attention in recent years, particularly when considering productivity on-site. However, one area that has often been neglected in construction health-related research is nutrition and diet, especially the factors influencing dietary habits. In Ireland, eating habits and lifestyle choices are changing, but when coupled with organisational factors, an unhealthy culture among construction industry operatives remains. Therefore, this study aims to identify and analyse the factors that influence dietary habits among on-site construction workers in Ireland, and document the effects, if any, diet has on their well-being and productivity. The research method undertaken is qualitatively based, encompassing ten semi-structured individual interviews with construction workers on two case study projects located throughout Ireland. Five main themes that influence dietary habits were identified: a lack of education when considering diet; time management when eating before and during working hours; peer pressure and being influenced what to eat by others; a poor standard and lack of eating facilities on-site; and the cost of food. Also, findings highlighted strategies that can be implemented to improve dietary habits, such as training and educational programmes to increase awareness of the health benefits of a balanced diet and lifestyle; improved eating facilities on-site; and employers providing subsidised nutritional meals. Overall, the key contribution of this research illustrates that many factors influence the dietary habits of Irish construction workers on-site, and with appropriate opportunities and suitable training, productivity can be increased, and the health and well-being of the workforce can be maintained, on construction sites in Ireland.

Keywords: culture, diet, health and safety, Ireland, well-being

## INTRODUCTION

Health and Safety (H&S) in the construction industry continues to receive increased attention, where the safety of workers is treated as a serious concern. According to Dempsey *et al. (*2020), overall standards have risen substantially with various training initiatives and programmes being implemented on-site. However, despite considerable improvements, the health and well-being of construction workers

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remains a cause for concern. As it is a highly manual industry, McGlone and Baker (2009) support that the construction industry has one of the highest rates of work-related illnesses across occupational groups. Injury and ill-health are susceptible, where workers face various issues related to health and well-being such as musculoskeletal conditions, mental health issues and physical health deterioration (Stocks *et al.,* 2011). Moreover, construction is a high-risk industry for work-related stress, and negative coping behaviours such as alcohol consumption, smoking and drug misuse is common (Bowen *et al.,* 2014). Another challenge, and an area of concern for occupational H&S is nutrition. Rohlman *et al. (*2018) note that work organisation and environment can affect diet and subsequently health, and nutrition plays an invaluable role in H&S performance and productivity improvements (Wanjek, 2005). Poor nutrition is one of many causes of accidents and injuries on construction sites (Okoro, 2015), and Groeneveld *et al. (*2011) concur that construction workers have poor health due to poor nutrition. Smallwood (2012) believes that research on the nutrition of construction workers is necessary as they are the most important assets in the industry, thus, research on the nutrition of construction workers is imperative (Okoro *et al.,* 2017).

However, on review of the literature, previous research fails to acknowledge and highlight the actual factors influencing dietary and nutritional habits among construction workers, particularly within the construction industry in Ireland. The lives of workers outside of work has great implications, and it is an area often taken for granted. Therefore, in the context of Irish construction site workers, it is necessary to identify and evaluate what factors influence their dietary habits, and more importantly, establish strategies that can be implemented to improve their dietary habits and overall health and well-being. To address these issues and to fulfil a gap in knowledge, it is essential to consider and generate results based on actual events that emerge, when studying an inherently complex and dynamic environment such as the Irish construction industry. Focusing on an important yet very neglected aspect of construction health, safety and well-being, this study aims to identify and analyse the factors that influence dietary habits among on-site construction workers in Ireland, and document the effects, if any, diet has on their well-being and productivity. This is achieved by incorporating a qualitative research approach, encompassing a literature review and semi-structured individual interviews, and manually assessing the resultant data using both coding and thematic analysis techniques. Thus, it is anticipated that in challenging this aim, this study will assist and aid Irish construction site workers to identify and assess the factors that influence their own dietary habits, enabling them to adopt strategies that will increase their productivity and improve their overall health and well-being.

**Diet and Nutrition of Workers in Construction**

Food and nutrition are indispensable elements of health promotion and protection, aiding human development and promoting good quality of life (de Lima Brasil *et al.,* 2016). For construction workers, Bates and Schneider (2008) note that good nutrition is essential for maximum concentration to perform mentally and perpetually demanding tasks, which Okoro *et al. (*2018) believe will prevent the occurrence of incidents, accidents, injuries, and deaths on-site. However, poor nutrition has been linked to chronic disease among construction workers (Hanna and Markham, 2019), and can be a factor which impacts on workforce performance (Okoro *et al.,* 2017). Lingard and Turner (2017) found that construction workers are prone or vulnerable to the SNAPO health risk factors of smoking, nutrition, alcohol, physical exercise, and

obesity. Further research supports that the demanding nature of construction work contributes to unhealthy food choices (Devine *et al.,* 2007) and harmful alcohol consumption (MacKenzie, 2008). Rohlman *et al. (*2018) also identity that a lack of access to healthy food for purchase on or near most construction sites is a structural barrier to a healthy diet. Other organisational factors include remote job locations (Pinto *et al.,* 2011) and the transient and informal nature of the industry, which is prone to short-term employment and job insecurity (Wells, 2007). Furthermore, Okoro *et al. (*2014) argue that regular travel between worksites means workers do not have a central workplace, resulting in an inevitably nomadic workforce (Fellini *et al.,* 2007). These barriers indirectly affect their ability to maintain a nutritional diet, and further contributes to the poor health and well-being of the workforce (Sherratt, 2017).

Research on the factors influencing dietary habits and nutritional behaviour in the Irish construction industry is scant, however, studies have been undertaken elsewhere. In Australia, du Plessis (2012) found that convenience, availability, cost of foods and colleagues in the workplace influenced construction industry apprentices dietary behaviours. Investing in workers well-being via a balanced diet resulted in improved safety and productivity on-site in Oman (Umar, 2020), and using an online nutrition training programme to promote health among apprentices was established in the USA (Rohlman *et al.,* 2018). In South Africa, construction workers had poor nutrition as a result of financial constraints, lack of nutritional knowledge and limited access to healthy foods on-site or nearby (Kolver, 2012). McGlone and Baker (2009) support that in the UK, construction workers had poor dietary behaviours due to limited on-site catering facilities and rejected healthy food due to its ability to satisfy, resulting in the consumption of high fat foods (Okoro *et al.,* 2014).

However, Thabit *et al. (*2013) investigated the prevalence and predictors of diabetes and cardiometabolic risk among construction workers in Ireland and found that a lack of healthy dietary options in the workplace contributed to poor nutritional uptake. In a general report on ill-health among Irish construction workers, Armstrong (2000) concurs that employers should focus on health as well as safety, encouraging healthy eating options on-site rather than simply 'chips and a fry'. A full Irish breakfast (a fry), is considered to be one of Ireland's most well-known traditional dishes (Mac Con Iomaire, 2003), consisting of bacon rashers, pork sausages, fried eggs, white pudding, black pudding, and toasted bread (O'Sullivan and Byrne, 2020). Mac Con Iomaire (2014) identifies and describes the Irish nation's love affair with pig meat and highlights the emergence of the 'Jumbo Breakfast Roll' during the Celtic Tiger phenomenon. The ubiquitous nature of this iconic symbol has characterised an era of dashboard dining in Ireland (Sage, 2010), and its cultural relevance was further immortalised in song by Irish comedian Pat Shortt, whose song of the same name spent six weeks at No.1 in the Irish music charts in 2006. The song describes how the breakfast items are wrapped up in a demi-baguette, 'so it could be eaten on the go by the army of builders who were so busy during the property boom they could hardly stop to eat' (Mac Con Iomaire, 2014). The first verse and chorus aptly allude to many of the organisational factors highlighted (alcohol consumption, time, convenience):

"Well I wake up in the morning and I jump straight out of bed, Grab a hold of that luminous jacket and shake off my aul porter head, Haven't time for the fancy breakfast or put muesli in a bowl, I just head to the Statoil garage for the Jumbo Breakfast Roll"

"Two eggs two sausages two rashers two bacon two pudding one black one white, All stacked like a tower on top of each other and rolled up good and tight, If you're having

some tae the milk's over there and you'll find sugar in the bowl, Says she 'Do you want some sauce on that?' says I, I do in my roll"

Share (2011) supports that the 'Jumbo Breakfast Roll' has always been closely associated with the mobile construction industry workforce as it is typically purchased at a deli counter in a convenience store, often located on a petrol station forecourt, and its consumption is not confined to the morning, but can take place at any time of the day, which suits the busy schedules of construction workers. Thus, eating habits and lifestyle choices are improving, but when coupled with organisational factors, an unhealthy culture among construction operatives in Ireland remains.

## RESEARCH METHOD

This study concentrates on the dietary habits among on-site construction workers in Ireland, and it is part of a preliminary investigation which will contribute to both academia and industry. Archer *et al. (*2016) argues that critical realism is a viewpoint concerned with providing a philosophically informed account of science and social science, which can in turn inform an empirical investigation. Thus, considering the theoretical stance and reasoning this research is founded on, a critical realism approach is adopted. A subjectivist position is applied to the ontology, as the nature of the study mainly concerns the opinions and experiences of human participants (Curran *et al.,* 2018). Regarding research logic, abduction is selected, as it encourages expansive thinking and can answer the 'what' and 'why' questions (Malhotra, 2017). Moreover, Barratt *et al. (*2011) argue the merits of case study research, as it uses contextually rich data from bounded real-world settings to investigate a focussed phenomenon. On completion of an informative literature review, the research method consists of ten individual exploratory semi-structured interviews with a variety of construction professionals, based on two construction projects situated in the Munster region of Ireland. The selection of the sites and interviewees was based on a convenience sampling strategy, as it locates convenient cases who meet the required criteria (Robinson, 2014). The unit of study incorporates individuals, as it is the most commonly used unit in social science research (Guest *et al.,* 2012). Also, McIntosh and Morse (2015) recommend semi-structured interviews as they determine people's subjective reactions to situations and extend the researcher's knowledge on the topic.

Considering ethical issues, each participant was informed of the nature of the research, its purpose, and what the resultant data will be used for. An information sheet was provided to the interviewees along with a consent form which they had to sign, prior to the start of the interviews. Confidential information such as company names, addresses, client details, etc. are not disclosed, and the identities of those involved remain anonymous. Nine of the interviewees were male and one was female, with an age range between nineteen and fifty-six. This gender ratio of more males than females is unsurprising, as it is well documented that the construction industry is male dominated (Hanna *et al.,* 2020). The first construction project, Case A, was a large residential development in Co. Cork, with five interviewees. Interviewee 1 is a Project Manager; Interviewee 2 is a Graduate Site Manager; Interviewee 3 is a Subcontracted Tradesman (Builder); Interviewee 4 is a General Operative (Builder); and Interviewee 5 is an Apprentice Builder. The second construction project, Case B was a large industrial development in Co. Limerick, with another five interviewees. Interviewee 6 is a Site Manager; Interviewee 7 is a Quantity Surveyor; Interviewee 8 is an Administration Manager; Interviewee 9 is a Subcontracted Tradesman (Electrician); and Interviewee 10 is a General Operative (Building Labourer). All ten

interviews were recorded in handwritten note format, with an average interview duration of twenty minutes, taking place on location, in the respective site office of each project.

# RESULTS AND ANALYSIS

The individual interviews commenced by gaining general background information from each participant, followed by a candid conversation about their own daily diet, and their dietary habits whilst working in the construction industry. The semi-structured interview process allowed the participants to answer the questions initially posed but provided the opportunity to elaborate on issues that they felt were necessary to discuss further. Findings from the ten interviews were combined and qualitatively assessed and summarised using both coding and thematic analysis techniques. Saldaña (2015) argues that in qualitative inquiry, a code is most often a word or a short phrase that symbolically assigns an attribute for a portion of language-based or visual data. Silver and Lewins (2014) suggest that a starting point to coding is cutting through the data, and Hilal and Alabri (2013) support that conventionally, coding is done by hand to categorise the data. As part of the initial analysis, the key words and phrases from the interview transcripts were highlighted, in preparation for the thematic analysis. Braun and Clarke (2006) identify that thematic analysis involves identifying patterns to make meaning and gain insight into a contemporary phenomenon. Analysis of the interviews was conducted by establishing emerging themes from the transcripts, including key words and topics for discussion. A concise summary of the key findings is illustrated in Table 1, with many areas covered such as individual diets, cooking habits, breakfast routines, commutes to work and the standard of welfare facilities for eating on-site.

*Table 1: Key Areas Discussed*

| Topics for Discussion | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Consider themselves to have a healthy diet | x | x | x | | x | x | x | x | | x |
| Cook their own food | x | x | x | | x | | | | | x |
| Skip breakfast | x | | | x | | x | x | x | | |
| More than a 30-minute commute to work | x | x | | x | | | x | x | x | x |
| Insufficient amount of time to eat lunch | x | x | x | x | x | x | x | x | x | x |
| High standard of on-site welfare facilities | | x | | | | | x | | x | |
| Cost of food influenced food choice | | x | x | x | x | x | x | | x | x |
| Consume alcohol weekly | | | x | x | x | x | x | x | x | x |
| Uneducated on benefits of a healthy diet | x | x | x | | | | | x | x | x |
| Choice of taste over a healthier option | x | | x | x | | x | | x | x | x |
| Eat a 'fry' at least once a week | x | | | x | | x | x | x | | x |
| Influenced by the food choices of others | x | | x | x | | x | | x | | x |
| Consider work colleagues to have a poor diet | x | x | x | x | x | x | x | x | x | x |

It is important to note that the findings from the individual interviews are specific to this research; thus, not a generalised view. Nonetheless, this study provides a foundation to explore further, supporting continuous research into diet and nutrition, in particular, the habits of construction workers in Ireland.

# DISCUSSION

## Theme 1 - Lack of Education

Six out of the ten interviewees agreed that they were not educated enough on the benefits of a healthy diet, and this was particularly evident among the older participants. Interviewee 9, who has over thirty years industry experience, stated that during his training days as an apprentice, no-one ever advised him on the benefits of a

nutritional diet, and he admitted to being 'ignorant' to any health-related initiatives on-site. Hanna *et al. (*2020) agree that for the older generation of construction workers, eschewing healthy diets and help-seeking is normative, which is perhaps linked to a conventional image of tough masculinity. The Graduate Site Manager, a recent construction management graduate from a respected Irish university, also claimed that the topic of nutrition was never taught or discussed during his four years of study. McNulty (2013) stresses that the first step towards improving nutrition and encouraging behavioural change is through nutritional knowledge and education. Wanjek (2005) corroborates that workplace campaigns are key in educating and motivating employees to eat well, and Groeneveld *et al. (*2011) identify motivational interviews and counselling sessions to encourage male construction workers to increase their fruit intake (Okoro, 2015).

**Theme 2 - Time Management**

Time to eat at any time of the working day was a key issue identified by the interviewees. 50% of the participants stated that they skip breakfast regularly, with reasons ranging from having a long commute to work and preferring to stay in bed longer for a few extra minutes. 70% revealed that their commute to work in the morning was greater than thirty minutes, with some travelling over an hour to get to the site. Kolver (2012) agrees that construction workers have poor nutrition due to long and time-consuming travel to workplaces. Interestingly, all ten interviewees stated that they have insufficient time to eat lunch on-site. Interviewee 4 remarked how he would go to the nearest shop most days to grab some hot food such as chicken nuggets and chips from a deli counter and eat it in the van as he drove back to the site. Sage (2010) supports that a culture of dashboard dining exists in the Irish construction industry, and workers who do not have enough time to eat rely on sweets, fizzy drinks, burgers, and fries (Okoro *et al.,* 2014). Thus, Wanjek (2005) states that employers should map out more time for lunch breaks, so the works can have enough time to eat.

**Theme 3 - Peer Pressure**

Workers feeling pressurised by colleagues in choosing what to eat was an interesting factor identified, with 60% of the participants being influenced by the food choices of others. Interviewee 2 (the Graduate Site Manager) discussed that because of his involvement in sports outside of work, he would bring his own healthy lunch with him on most days, but this did raise eyebrows among the older workforce. Similarly, Hanna *et al. (*2020) found that contemporary approaches to food intake on-site were still viewed as alien in the culture of construction. Interviewee 10 stated that he would go for breakfast with his colleagues some days even though he may not have always wanted to, but he did not want to feel left out among his peer group, or have his colleagues talk negatively about him for doing so. The food choices of workers are influenced by their poor dietary role models, including their peers and co-workers (du Plessis, 2012). Okoro (2015) agrees that one can be peer-pressured into eating healthily or unhealthily.

**Theme 4 - Poor Eating Facilities On-site**

Only three out of the ten interviewees believed that the eating and general welfare facilities on-site were of an acceptable standard. Interviewee 8 (the Administration Manager and the only female participant), revealed that she ate her lunch at her desk in the site office, as the canteen area was too dirty and lacked the proper facilities. McGlone and Baker (2009) concur that construction workers have poor dietary

behaviours due to limited on-site catering facilities, and Okoro *et al. (*2014) agree that nutrition also has to do with food hygiene and safety. The provision of welfare facilities such as hot water for washing before eating, safe drinking water, space to prepare and eat meals, as well as food storage units such as refrigerators, cupboards and microwaves are very essential. Thus, the availability of resources such as on-site facilities significantly influences the choice of foods eaten on construction sites (Wanjek, 2005).

**Theme 5 - Cost of Food**

The cost of food was another prominent factor identified and 80% of the interviewees discussed how the cost of food influenced their food choice. Interviewee 5 highlighted how food items that may seem low in price, add up to quite a large expense over a period of time, 'the price of a coffee and bacon sandwich in the morning might be €5, which is €25 a week, and that doesn't include the days you go for lunch. If you want a reasonably healthy lunch like a salad or sandwich, this could be €10 or more with a bottle of water…it soon adds up!'. According to du Plessis (2012), the cost of healthy food for apprentices in particular is prohibited given their low apprentice wages. The General Operatives acknowledged that they sometimes spent their money on cigarettes and tobacco at lunchtime instead of food, and the Building Labourer admitted that he looked forward to the end of the working day the most, 'I would go to the pub most evenings for a few pints, and then for a feed (dinner) at the local chipper (takeaway) afterwards'. This reflects the findings of Lingard and Turner (2017), who state that construction workers are prone to health risk factors of smoking, nutrition, and alcohol. Nevertheless, Wanjek (2005) and Okoro *et al. (*2017) support that construction employers and managers can commit to healthy eating through environmental and organisational changes on-site or nearby, such as increasing the availability of healthy foods in canteens, arranging with local food vendors to sell healthy food options at reduced prices and collaborating with organisations to provide healthy foods on-site.

## CONCLUSION

Essentially, this exploratory study focuses on factors influencing dietary habits among the construction workforce in Ireland. The safety of the construction workforce has thankfully received great attention in recent times; however, the health and well-being of all construction workers remains a cause for concern. Many organisational factors contribute to the overall well-being of workers, with nutrition playing an invaluable role in occupational H&S performance and productivity improvements. Considering the results captured from the ten individual interviews in this research, five key themes emerged, including a lack of education when considering diet; time management when eating before and during working hours; peer pressure and being influenced what to eat by others; a poor standard and lack of eating facilities on-site; and the cost of food. When analysing these influencing factors, counteractive strategies also emerged, including educational and training programmes to increase awareness of the health benefits of a balanced diet and lifestyle; improved eating facilities on-site; and employers providing subsidised nutritional meals for site staff.

However, the findings from the ten individual interviews are specific to this research; and only a concise, subjective view of the topic is produced, thus, not a generalised view. Nonetheless, this study provides a solid foundation to advance and explore further, supporting continuous research into the dietary habits and influencing factors on site workers on construction projects in Ireland. The findings in this study can be

developed further, and it is anticipated that a broader analytical context can be addressed in a subsequent journal publication, where additional theoretical points of departure and areas of discussion can be articulated. It is proposed that further studies consider the contribution that training bodies and educational institutions can make to the current and emerging workforce, to encourage and promote healthier nutritional choices. Also, further research investigating the issues surrounding the lack of proper welfare facilities on-site is suggested, and the contribution the employer can make to improve overall standards. To gain a richer understanding of current dietary habits in the industry, alternative qualitative research methods can be implemented in further research such as action research and ethnography. It is recommended that more individual interviews and focus groups seminars are considered for qualitative analysis, and a sequential selection strategy is incorporated using criterion selection, such as quota and random sampling. From a quantitative perspective, a questionnaire survey could be composed and distributed to a larger sample across other regions of Ireland to further strengthen the research. Still, this study provides a foundation for informing and confirming the validity and necessity of the research and ensuing investigation going forward. Overall, the key contribution of this research illustrates that many factors influence the dietary habits of Irish construction workers on-site, and with the right opportunities and appropriate training and educational awareness, productivity can be increased, and the health and well-being of the workforce can be maintained, on construction sites in Ireland.

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# CONCEPTUALISING SELF-DETERMINATION THEORY AS AN INDICATOR FOR IMPROVING CONSTRUCTION WORKER MOTIVATION

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The construction industry is one of UK's most important economic sectors and assessing the motivation of construction workers involves systematic application of psychological research on human behaviour to the problems of workplace H&S. This paper presents the 'bottom-up' approach to worker motivation with emphasis on construction operatives and supervisors regarding the H&S motivation for their roles. The study depicted the types of motivation using the Self-Determination Theory (SDT) as a reliable framework to conceptualise operatives and supervisors' motivation using the traffic light system. The phenomenological research conducted 22 semi-structured, open-ended interviews focusing on the theme of motivation in relation to H&S and the data was thematically analysed. The result reveals that no worker showed signs of lack of motivation (red) but rather, there were variations amongst workers undertaking their roles for either extrinsic (amber) or intrinsic (green) factors. Twelve workers discussed issues of intrinsic motivation e.g., happiness, enjoyment and satisfaction at work while 10 workers discussed issues considered as extrinsic motivation e.g., family, money, career progression, and project delivery. This study adds to existing body of knowledge around the antecedents of motivation for construction workers.

Keywords: motivation; safety; self-determination theory; intrinsic; extrinsic

## INTRODUCTION

The construction industry is one of UK's most important economic sectors and the management of construction operatives and their behaviours is fundamental to the success for better work-related performance and improved productivity. The construction operatives constitute the base of every construction project activity and, the process of motivating them and managing their safe behaviour at work is essential for the success of the industry (Bakker and Demerouti, 2008; MacLeod and Clarke, 2009; Baucus *et al.,* 2008). Assessing the motivation of construction operatives involves systematic application of psychological research on human behaviour to the issues of health and safety (H&S) in the workplace. Although behavioural safety initiatives are designed to encourage continuous improvement, it often tends to be interpreted as management 'top-down' imposing behaviours on workers and what managers think is safe behaviour. Workers at the same time view such initiatives as a

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convenient way for management to transfer their H&S responsibilities and apportion blame to the workforce (Cooper, 2001). In the real sense, motivating the workers would mean engaging the workers towards increasing their passion, enthusiasm, absorption, dedication, workforce meaningful discussions, commitment, empowerment, trust, and energy in the safe execution of tasks the workers undertake, see (Schaufeli, 2013; Lawani *et al.,* 2017; Lawani *et al.,* 2018). This paper reflects on the 'bottom-up' approach on what motivates workers to work safely and adopt the H&S initiatives based on the perception of construction operatives regarding their roles. Research continues to highlight the significance of managing H&S within the workplace and improving workforce motivation, and businesses are turning to enhancing levels of engagement within their influence towards achieving this aim (van Tuin *et al.,* 2020; Wollard and Shuck, 2011). The importance of characterising the motivation of construction operatives by adopting the Self-Determination Theory (SDT) (Gagne and Deci, 2005) lies in the perception of its applicability in predicting positive performance at work and the opportunity of improving construction Safety and Health (Lawani *et al.,* 2019). For construction workers to be motivated and to successfully engage with the principles of safety, health, and wellbeing within the workplace, the effectiveness of existing corporate OSH engagement programmes should help in characterising the types and levels of motivation using the SDT as a valid and reliable framework. Since worker engagement is linked to performance improvement and workplace productivity (Shuck and Herd, 2012; van Tuin *et al.,* 2020), it is vital to understand how all these impact on workers' motivation at work. This is important because motivation is a function of the workers' belief in what they will obtain in expending the effort. As a result of the effort, workers that are highly motivated and high in self-efficacy are intrinsically motivated to perform their jobs (Hudson, 2007).

**The Concept of Motivation**

One of the key conceptual characterisations of motivation is the SDT which is based on human motivation, development and wellness and it focuses on type and amount of motivation (Deci and Ryan, 1985; Ryan and Deci, 2000; Deci and Ryan, 2008; Gagne and Deci, 2005). It posits three universal psychological needs which are - competence, autonomy, and relatedness, and suggests that work climates that allow satisfaction of these needs facilitate both engagement in the workplace and psychological wellbeing which impacts on workplace H&S. Competence means excelling at challenging tasks and achieving desired outcomes (Skinner 1995); autonomy involves experiencing choice and feeling like initiating one's own actions (Martela and Pessi, 2018; Parmar *et al.,* 2017); and relatedness requires a sense of mutual respect, caring, and reliance on others (Baumeister and Leary 1995) within the workplace.

Motivation is the act of being stimulated to do something and it can be grouped into two subcategories: 'lack of motivation or amotivation' whereby a worker shows no desire or inspiration to act and 'motivated' where a worker is full of enthusiasm or activated towards a desired outcome (Ryan and Deci, 2000). There are theories of motivation that depict motivation as a 'unitary phenomenon' that varies from very little motivation to act to a great deal of motivation, but Ryan and Deci (2000) and Deci and Ryan (2008) clearly suggest that motivation is hardly a unitary phenomenon because people tend to have different amounts and different kinds. For example, a worker varies not only in their levels of motivation (how much motivation), but also in their orientation of that motivation (what type of motivation). The orientation of

the workers' motivation reflects their underlying attitudes and goals that give rise to the 'why' of actions. Deci and Ryan (1985; 2008) therefore clearly illustrated the different types of motivation in the SDT based on the different reasons or goals that gives rise to an action. The most basic difference identifies 'intrinsic motivation' as the doing of something because it is inherently interesting or enjoyable, while 'extrinsic motivation' signifies undertaking a course of action because it leads to a separable outcome (Ryan and Deci, 2000). Therefore, the quality of experience and performance can differ when a worker is behaving for intrinsic or an extrinsic reason.

**Theoretical Framework of Motivation**

Construction work can be considered as one of the most absorbing activities and it takes up a greater part of the worker's waking day. However, for some, the idea of work is associated with the cause of grief (workplace accidents) while for others it brings a great sense of satisfaction (Herzberg, *et al.,* 2011). There is the notion that workers that have the opportunity to play a role in H&S goal setting and decision-making that affect their work tend to accept changes more readily compared to those experiencing change without any opportunity for them to make any form of contributions (lack of engagement) or exercise their free choice (Deci and Ryan, 2000).

Therefore, studies that have been carried out regarding issues of motivation have more or less focused on job attitudes i.e., job satisfaction; worker's morale; effect of group pressures and supervisory behaviour and organisational competence on the worker (often associated with higher productivity and lower turnover) (Herzberg, *et al.,* 2011; Emelander, 2013), but not specifically on the potential benefits of what motivates construction operatives and supervisors to work safely. The framework depicts how workers in general tend to be motivated in their role; from lacking motivation which this study considers as unacceptable whatever the benefits of their role or task might be to the organisation, to the extrinsic (tolerable) and intrinsic (broadly acceptable) types of motivation in relation to workplace H&S.

*Lack of Motivation - Red*

This is when the operative or supervisor lacks any intention or drive to do things or accomplish their set task safely. When a worker lacks motivation, their behaviour also lacks intentionality and a sense of personal connection with the task i.e. not valuing an activity, feelings of incompetence, or not believing it will yield a desired outcome (Ryan, 1995; Deci and Ryan, 2000; Gagne *et al.,* 2014). An operative or supervisor that fits this description is considered to be within the unacceptable phase because they will exhibit unsafe characteristics that are undesirable within the jobsite.

*Extrinsic motivation - Amber*

When a worker engages in an activity or task to obtain an outcome that is discrete from the activity itself, it is referred to as 'extrinsic motivational' behaviour (Vansteenkiste *et al.,* 2006; Ryan and Deci, 2000). Using the SDT framework, extrinsic motives are not only partially internalised but controlled by conditions (van Tuin *et al.,* 2020). A worker does not have to progress through the continuum with respect to a particular regulation but can initially adopt a new behavioural regulation at any point and this is also dependent upon their previous experiences and situational factors (Ryan, 1995). This study refers to this continuum as the tolerable phase where construction workers are motivated to undertake their task safely because of certain conditions e.g., Health and Safety legislations (compliance).

*Intrinsic Motivation - Green*

Intrinsic motivation is related to having positive experiences that gives pleasure, support growth, and satisfy needs (Emelander, 2013). The sources for these type of motivation for construction workers include skills attainment, intellectual challenge, relationship development with others, confirming or building a positive self-image, and autonomy thus making the worker self-determined (Martela and Pessi, 2018). This study considers intrinsic motivation as the most broadly acceptable form of motivation which should be the desired goal by individuals and the construction industry towards attaining a higher level of health and safety at work. This is when the operative or supervisor is motivated to go above and beyond compliance by displaying citizenship behaviour because of the inherent satisfaction the worker derives from performing their role safely, i.e., 'wanting to' rather than 'having to'.

## METHOD

This study used already existent knowledge of motivation theory by applying it directly to construction H&S. Phenomenological research inquiry which allow participants describe their lived experiences of the phenomenon was adopted, (Creswell, 2014; Creswell, 2013; Creswell and Poth, 2017; Marshall and Rossman, 2016). The participants were construction operatives and supervisors willing to share their H&S experiences of what motivates them relative to their work. The eligibility for participation was for construction operatives and supervisors to demonstrate at least one of these qualities: someone who has knowledge of health and safety; (or) actively contributes to health and safety discussions, committees or initiatives; (or) a health and safety champion; (or) a worker who is keen about health and safety matters.

The study implemented semi-structured open-ended interviews to allow for the emergence of themes from the operatives and supervisors. Access to construction workers was facilitated by contractors whose senior personnel were involved as expert Steering Group for a wider study and participation was voluntary. The interviews assessed the operatives' description and perception of their workplace H&S initiatives and their motivation for their roles, and these were mapped into the SDT continuum by adopting the traffic light RAG system (Fig 1).

The continuum starts from lack of motivation and the most basic distinction is between intrinsic motivation, which refers to doing something because it is inherently interesting or enjoyable, and extrinsic motivation which refers to doing something because it leads to a separable outcome (Deci and Ryan, 2000). The SDT reflects the variation not only in the level of motivation (i.e., how much), but also in the orientation of that motivation (i.e., what type) based on workplace H&S experiences. Research has shown that the quality of experience and performance can be very different when a worker is behaving for intrinsic or extrinsic reasons (Gagné and Deci, 2005).

To assess the motivation of workers regarding their role in relation to H&S within the workplace, the feedback from the operatives and supervisors were used in assigning the worker's motivation based on the framework (Fig 1). Feedback that reflects only 'lack of motivation' are grouped in the red zone (unacceptable or non-self-determined). Feedback that reflects strong emphasis on 'extrinsic motivation' but does not go beyond compliance are grouped in the amber zone (tolerable). Lastly, feedback that strongly emphasises issues of 'intrinsic motivation' and more are grouped in the green zone (broadly acceptable or self-determined). The findings

however revealed that none of the 22 workers showed any signs of lack of motivation but rather, there were discrepancies amongst workers undertaking their roles for either extrinsic or intrinsic H&S-related factors. Hence, grouping the workers along the motivation continuum based on their feedback showed that 12 workers discussed issues of intrinsic motivation (green) related to happiness, enjoyment and satisfaction at work in relation to their workplace H&S experiences while 10 workers discussed issues considered as extrinsic motivation (amber) related to issues of family, money, promotion etc.

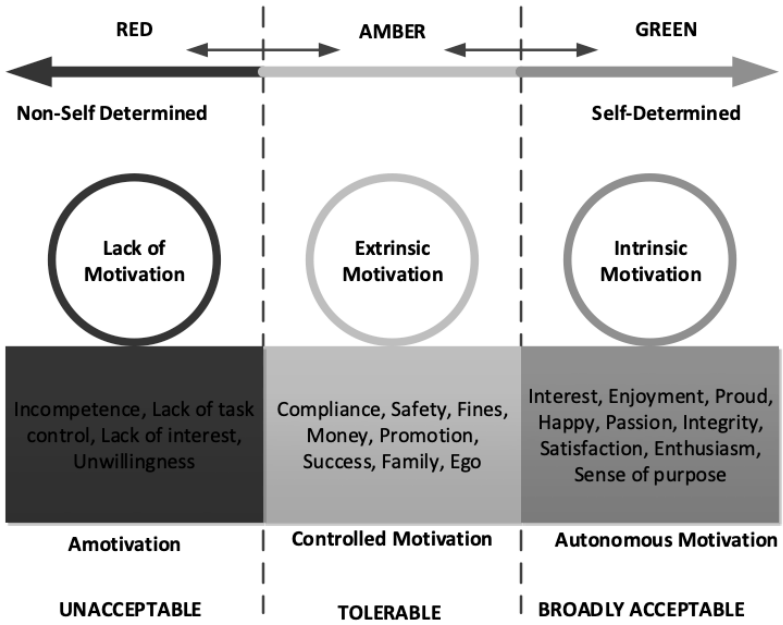


*Fig 1: The RAG H&S motivation continuum; adapted from (Ryan and Deci, 2000)*

*The traffic light system was used to group the workers as follows:*

*Red: Signifies lack of motivation which predicates an unacceptable worker behaviour.*

*Amber: Signifies extrinsic motivation which is a form of tolerable behaviour regarding their work because of certain conditions e.g., H&S legislations.*

*Green: Signifies intrinsic motivation which is a broadly acceptable behaviour because of inherent satisfaction and their citizenship safety behaviour.*

Table 1 shows some extracts from the interviews related to extrinsic and intrinsic motivational statements.

Extrinsic Motivation (Amber): The findings indicate that participants that have witnessed unsafe acts within the workplace tend to demonstrate improved safety compliance, and this motivates them to work safely. The participants indicated that working away from home over an extended period of time and knowing that their loved ones are expectant to see them return home safely makes them motivated to adhere to workplace H&S rules. The workers were also wary of being involved in work-related accidents that could result in disablement, fines and prosecutions or even imprisonment. There is a general assumption that some operatives do not regard H&S as a priority when undertaking their tasks because of price work (self-employed).

However, the findings indicate that the operatives were relatively motivated to comply with H&S rules because of their awareness of the current prosecutions in relation to health and safety breaches. The workers within the extrinsic continuum also indicated

that any break in their ability to consistently earn money as a result of workplace accidents would negatively impact on them providing for their families, keeping up with their mortgages and other financial commitments. Therefore, issues of price work associated with wanting to get the job done quicker to earn more money was not considered a priority or a motivational driver.

*Table 1: Extrinsic and intrinsic motivational comments by participants*

| Extrinsic Motivation | Intrinsic Motivation |
|---|---|
| "I've seen too many unsafe acts; I mean bad stuff. I am more careful nowadays than when I was years ago. I feel better for working safely; you should be working safely all the time." | "You feel proud of yourself that you can do the job and do it safely to go home every evening knowing that you've done your job" |
| "I am motivated to work every day because of Fridays when I need to go home. There is no need or reason to do something dangerous, if it takes 3 times longer then that's what it takes." | "I am happy to see the end of the day and I want to see the start of the following day, it's as basic as that." |
| "I work for my kids, that's why I work away; I live in Belfast, and I work here so I can earn some money so at the end of the day I'm doing it for my family, I don't intend to come to work today and break my arm because, I ain't gonna get paid for six weeks" | "It makes me feel good knowing that I am doing the job safely. I turn up to work put in a solid day's hard graft and makes me feel that I have achieved something for the day, go home and come back next day and do the same again" |
| "Money motivates me in the work I do. You've got to think of yourself, and everyone round about your work. Working safely makes me feel a lot better because you're doing your job safe" | "I want to do well, I am just driven doing a good job, I enjoy my work. Safe, more comfortable, confident in what you're doing and know you'll be home at night" |
| "Providing for my family is the most important motivation, making sure we have roofs over our heads, money. As a person I want to do the best I can and make sure I'm doing things right and safely and make sure I work my way up the ladder; I've got aspirations." | "No…. you can't work if you're not healthy or safe. I enjoy the work. It's easier to work safely. Makes the job easier and makes me feel good, knowing that you're reducing accidents" |

Aside the psychological and physical trauma associated with workplace accidents, these workers understand the significance of H&S as part of their roles and are keen to keep a steady income stream, free from any form of disruption because their ability to consistently earn is the key factor that keeps them motivated. The workers also indicated that their motivation and reliance on their work teams to work safely and the integration of health and safety in their work activities mitigates dangerous working practices e.g., not taking shortcuts to get the work completed ahead of schedule. However, the absence or lack of onsite supervision can sometimes inadvertently lead to breaches of site H&S rules leading to work-related incidents. Using this framework, the feedback from the 10 workers within the controlled motivation

continuum were founded on their experiences and situational factors (Deci and Ryan, 2000), by exhibiting these extrinsic characteristics as rationale behind their motivation. Workers were extrinsically motivated for various reasons e.g., families and money, career progression, safely delivering on projects etc. It has been identified that workers might originally get exposed to a task because of an external regulation (e.g., a safety reward), and if the worker perceives the reward as not too controlling, such exposure might allow the worker to experience the task's intrinsically interesting properties, resulting in an orientation shift (Ryan and Deci, 2017).

Equally, a worker who has identified with the value of a task might lose that sense of value when working under a controlling manager or supervisor and withdraw into an extrinsic level (Gagné and Deci, 2005), and this could lead to reduced engagement, work-related strain and burnout (Van den Broeck *et al.,* 2013; Lawani *et al.,* 2017). The attitudes of the workers could also be associated with the different types of extrinsic motivation e.g., the more controlling factors are in place, the lesser interest, value or effort the workers will display. This is where the bottom-up behavioural safety change and top-down cultural change merge to drive the motivation of workers towards becoming more intrinsic because of the management commitment, leadership and workforce engagement.

Intrinsic Motivation (Green): The workers with intrinsic motivational characteristics were those on more permanent roles and they considered H&S as a priority in their day-to-day activities. The intrinsically motivated workers think that involvement of their colleagues in determining how a job could be performed safely gives them that sense of purpose because it allows everyone to use their skills and their knowledge of construction tasks towards managing risks. These workers were passionate about their role, and they exude enthusiasm in the safe delivery of projects because of their cognitive qualities and their capability to successfully integrate their H&S initiatives. The workers indicated that management goal setting and involvement tends to bring about improved site safety while management commitment brings a sense of purpose and integrity which ultimately encourages the bottom-up safety initiatives.

However, to sustain autonomous motivation within the workplace, the workers suggested that there must be a robust and developed safety infrastructure in place that embrace the workers and management safety initiatives towards maximising worker motivation. Furthermore, workers within the intrinsic continuum are more likely to be offered increased levels of training within the workplace to boost their safety performance, and they have a greater chance of influencing others to act safely. 12 workers displayed intrinsic motivational characteristics based on their feedback by alluding to their level of job satisfaction e.g., feedback and engagement within the workplace, the safe systems of work in place, enjoying their jobs, finding their job interesting due to the positive relationship with other workers, pride, and the autonomy they derive while undertaking their roles safely rather than for some separable outcomes.

These workers described their passion and enthusiasm to safely accomplish their roles above and beyond the legal requirements (exhibiting citizenship behaviour) and all these align with self-determined qualities as shown in Fig 1. The workers however indicated that experiences related to work-related threats, poor safety culture and practices, deadlines, and task completion pressures could sometimes diminish autonomous motivation as they see it as controlling their behaviours (Van den Broeck *et al.,* 2013). Feedback from participants indicated that although many construction

work activities are not intrinsically interesting, devising strategies such as monetary rewards as a central motivational strategy might seem more practical and appealing to workers but this will only mean controlling their motivation. Alternatively, long-term initiatives that could improve workplace H&S, empowerment and engagement of workers towards becoming more self-determined will be more beneficial for workers to sustain intrinsic motivation. Furthermore, the basic psychological needs of the workers in terms of their needs for competence, autonomy and relatedness (Parmar *et al.,* 2017) need to be adequately addressed. Workers that are self-determined demonstrate broadly acceptable qualities and traits in the execution of their tasks, and also embrace the bottom-up and top-down management initiatives. However, sustaining this level of autonomous motivation within the workplace requires everyone to consistently influence others and to attain superior safety performance.

## CONCLUSION

Studies that consider the mediating role of motivational characteristics of construction workers in relation to workplace H&S are not that common. The eligibility for involvement in this study indicated the significance of participants being involved or aware of workplace H&S. Therefore, there was no indication of lack of motivation, unacceptable characteristics or a non-self-determined worker amongst the participants. Although this study identified that no participants demonstrated qualities in the red or unacceptable side of the framework, some construction workers however undertake some tasks despite evidence of their lack of competence or lack of motivation based on their behaviours in relation to H&S. Also, a worker that has been identified as showing positive attitude to the task and H&S values needs to be fully supported and engaged or they might end up losing that sense of value under a controlling supervisor or manager and move along the continuum into amotivation. For example, the more the workers feel they are being controlled the less interest, value or effort they will show regarding their roles, and the more the tendency to become less motivated in successfully delivering on their roles.

Workers that demonstrate extrinsic motivational qualities should be engaged and empowered in their roles to achieve a sense of purpose, have personal interest in their roles, are enthusiastic and enjoy their work towards becoming autonomously motivated or self-determined. Many work-related activities undertaken by operatives and supervisors are not intrinsically stimulating and the use of participation and engagement within the workplace to improve the bottom-up and top-down management strategies could enhance intrinsic motivation and yield positive results. Although, the use of monetary rewards as an instrument of social control is a central motivational strategy that seems practical and appealing to most workers, over a long term, this might be unsustainable for the organisation and also prevent the need for workers to aim towards autonomy.

Incentivising workers' motivation for objectives such as productivity and safety might not necessarily lead to enhanced motivation or an improvement in OSH practices. This is because workers with autonomous motivational qualities will naturally undertake their workplace roles as it aligns with what the workers find interesting, exciting and engaging. This RAG framework therefore shows the variability of what makes construction workers motivated to safely undertake their roles and the importance of management ensuring that workers with intrinsic tendencies sustain such qualities whilst workers within the extrinsic continuum are empowered,

challenged and engaged to move along the sliding scale towards becoming more self-determined or autonomously motivated.

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# HOW DO NON-WORK INDIVIDUAL FACTORS AFFECT WORKER WELL-BEING IN THE CONSTRUCTION INDUSTRY? A SYSTEMATIC REVIEW AND META-ANALYSIS

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Despite the infrastructural developments worldwide, the construction industry is characterised as a stressful industry in which workers suffer from high rates of psychological distress, anxiety and other mental health problems, thus construction workers' psychological well-being (PWB) is a major concern. Although non-work individual factors, including workers' personality, marital status, and non-work experience (such as family support) have been found affecting their work behaviour and PWB, there lacks a holistic nomological network of the underlying associations between these factors and PWB. Therefore, the focus of this paper is to provide a better understanding of the conceptualization of PWB within the construction community and more specifically, to review empirical research on how individual factors affect workers' PWB. We began with clarifying the concepts of PWB and introducing a three-category taxonomy: hedonic, eudaimonic and negative PWB. Through a systematic review of the literature, we then summarised theories and research on how individual factors influence workers' PWB with this three-category taxonomy. An integrative framework was developed with a taxonomy of non-work individual factors and their relations with the three types of PWB. At last, a meta-analysis was conducted to quantify the relations. The findings of this study offer new insights on the main concerns of construction workers' well-being and point to future research on individual and non-work environment support that would improve well-being outcomes in the construction community.

Keywords: meta-analysis; non-work; individual; psychological well-being; systematic

## INTRODUCTION

Construction workers' psychological well-being (PWB) is a major concern for the construction industry worldwide (Bowen *et al.,* 2014; Cao *et al.,* 2020), in which workers suffer from high rates of psychological distress, anxiety and other mental health problems (Chan *et al.,* 2020; Pidd *et al.,* 2017). Non-work individual factors, including workers' demographics, personality, and support received from family play a vital role in their work behaviour and PWB (Sang *et al.,* 2007; Tijani *et al.,* 2020).

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However, the pattern through which these non-work individual factors affect employee PWB remains unclear, calling for a systematic review in this domain. This review research aims to better understand the concept of PWB within the construction community and how non-work individual factors affect worker's PWB. This systematic review provides not only an integrative framework to differentiate different types of PWB, but also a detailed demonstration of the research literature on how individual factors relate to each type of PWB. At last, a meta-analysis is conducted to quantify the relations.

**Definition**

Our review focuses on individual attributes and their impact on PWB of the construction workers. PWB refers to "subjective experience and functioning" (Grant *et al.,* 2007: 53). It has received rising attention and were found related to non-work individual factors, such as age, personality, and previous experience (Bowen *et al.,* 2014; Lian and Ling 2018).

We build upon Inceoglu et al.'s (2018) category of PWB, which includes three types: hedonic, eudaimonic, and negative. The first two types of PWB: hedonic and eudaimonic, both indicate positive functioning. Hedonic PWB emphasizes the subjective experience of pleasure, comprising contentment, comfort, satisfaction, and serenity (Gallagher *et al.,* 2009). Eudaimonic PWB emphasizes subjective vitality, includes positive feeling of aliveness and energy, personal growth, learning and vitality as captured in the concept of thriving (Gallagher *et al.,* 2009). As opposed to these two positive types of PWB, other psychological symptoms and negative well-being indicators, including stress, work-family conflict, and mental health problems and many others, form the third category of PWB: negative PWB (Kotera *et al.,* 2020; Lingard *et al.,* 2012).

Research on how individual factors influence PWB are rooted in the theories of personality and well-being (DeNeve and Cooper 1998) and family interference with work (FIW) (Greenhaus and Beutell 1985). Workers' physical health conditions (Plante and Rodin 1990), marital status (Al-Aameri 2000), and other demographic characteristics (Clark 1997) were found impacting construction workers' experience at work, thus in turn their PWB. On the other hand, factors related to workers' experience in the off-work domain, such as family responsibility (Scandura and Lankau 1997) and relationship with partner (Lambert 1991) could also affect their attitudes and identity at workplace, in turn their satisfaction and engagement. Therefore, in reviewing research in the literature, we broadly categorize non-work individual factors into three aspects: (1) demographic characteristics of workers; (2) personal attributes of workers, including personalities, individual experiences and behaviours that could affect their PWB; and (3) supports that workers received from family that might shape their identity at work.

## METHODS

To synthesize the existing wide body of research related to the relationship between non-work individual factors and PWB in the construction industry, the analysis in this study was performed with three phases: Phase 1: selection of research papers; Phase 2: bibliometric analysis and Phase 3: meta-analysis. Phase 1 paper selection sets the boundary conditions of the study with inclusion and exclusion criteria clearly identified for the eligible studies (Booth *et al.,* 2016). Phase 2 bibliometric analysis offers descriptive summary results of the reviewed articles with their journal sources,

theory used, research methods as well as keywords. Phase 3 meta-analysis further examines the relationship between non-work individual factors and three types of PWB variables. Web of Science Core Collection (WOS) and Google Scholar database were used for initial searching. The initial research string was defined using Boolean operators "AND" and "OR". Related PWB keywords include: "well-being", "wellness", "satisfaction", "psychological health", "mental health", "pleasure", "happiness", "burnout", "emotional exhaustion", "stress" and "strain".

Initial paper screening process was conducted by reading the abstracts. In this stage, two selection criteria were applied: (1) only peer-reviewed journal articles were kept for further analysis to ensure the quality of the articles; (2) only articles with PWB related keywords mentioned within the scope of construction industry in their abstracts were kept. As a result, 351 papers were selected for further review. The next step of paper selection is to keep the ones that studied the impact of non-work individual factors on the PWB of construction workers. Therefore, on assessing the full text of the 351 articles, only papers that involve empirical studies where PWB variables were measured as outcome variables and non-work individual factors as predictors were kept. By applying this approach for eligibility check, a total number of 20 articles were finally selected for further analysis. To obtain a static and systematic flow of the research on PWB in the construction industry, the bibliometric analysis was performed to map and visualize the bibliographic information of the 20 articles.

## FINDINGS

*Journal sources*

The reviewed 20 articles come from 13 journals, in which the Journal of Construction Engineering and Management published the most related articles (N = 8) with a total citation of 254. Another 12 articles are from 12 journals, samples of them are International Journal of Project Management, Built Environment Project and Asset Management, Construction Economics and Building, Construction Management and Economics, International Journal of Construction Management, International Journal of Integrated Engineering, International Journal of Managing Projects in Business, Journal of Occupational Health Psychology, and Work and Stress.

*Keyword analyses*

Keywords represent the core contents of existing studies and describe research topics within a given domain. Co-occurrence of keywords demonstrates the inter-closeness among them. By using "Keywords" and "Fractional counting" in VOSviewer as recommended by Van Eck and Waltman (2017) and by setting the minimum occurrence of a keyword at 2, 56 out of a total of 154 keywords were selected initially. Before this analysis, we removed general keywords such as "construction" and "engineering." The final visualization of co-occurring keywords generated from VOSviewer displays that the occurrence of the keyword "age" was obviously the highest, indicating high focus on this construct. The high frequency constructs in the reviewed papers also include mental health, emotional exhaustion, demand, attitudes, and gender.

*Use of theory, research methods and empirical samples*

Among the 20 reviewed papers, 16 lacked a theory to explain the linkages between non-work individual factors and PWB. Conversation of resources (COR) theory (Hobfoll 1989) is prevailed in the current literature (N = 3), which was employed to explain the relationships between predictors (e.g., work interference with family,

family role overload) and PWB (e.g., life satisfaction, burnout) (Cheung et al., 2018; Lu et al., 2019). Interaction theory (Lewin 1951) was used by an article, examining the predictive power of age gender and personal values on job satisfaction (Panahi et al., 2016). As to the research methods used in the reviewed research. Structural equation model (N = 5) was used most frequently to analyse the relationships between PWB and non-work individual factors, followed by hierarchical regression analysis (N = 3), and correlation analysis (N = 3). The distribution of the countries or regions, where empirical data were collected in the reviewed papers were also analysed. The number of samples from the Australian (N = 5) and Chinese (N = 5) construction industry ranked the first, followed by the United State (N = 3) and United Kingdom (N = 3). Only one paper used samples from different countries to test the construction professionals' PWB (Cheung et al., 2018).

**The Relationship Between Non-Work Individual Factors and PWB**

A thorough examination of the relationship between non-work individual factors of the construction workers and their PWB was conducted based on the 20 papers selected.

Non-work individual factors were found affecting construction workers' hedonic PWB by influencing their job satisfaction and life satisfaction in general. Çelik and Oral (2019) discussed in their study that the personality traits of the construction workers showed a positive effect on their job satisfaction levels, and this relationship were partially mediated by work commitment factors and professional commitment. Similarly, Panahi *et al.,* (2016) demonstrated that personal values of construction professionals, as well as the personal and organizational values conflict significantly affected their job satisfaction, moreover, demographic variables of the construction workers explained significant contribution of the variance. More prevailing impact of demographic characteristics, including gender, age, experience and job tenure on employee PWB were widely discovered (Shan *et al.,* 2016). Lian and Ling (2018) explored the influence of personal characteristics on quantity surveyors' job satisfaction, and they claimed that those who were married, older, and more experienced were associated with lower job satisfaction comparing to singles, younger, and less experienced.

Sang *et al.,* (2017) further claimed that female architectural professionals showed a higher level of job dissatisfactions and concerns, indicating poorer occupational health and well-being than their male colleagues. With data collected from 771 blue- and white-collar employees in the construction industry in Australia, Zacher *et al.,* (2014) showed that employees in their late 20s to early 40s had lower job satisfaction than younger and older employees and this curvilinear relationship was fully mediated by work characteristics of time pressure and co-worker support. Besides personality and demographic factors, family issues of the construction workers were found negatively affecting their life satisfaction as well, the negative impact of family-role overload was identified by Lu *et al.,* (2019).

Non-work individual factors of the construction workers are associated with their eudaimonic PWB through the impact on work-life balance and mental health. The influencing mechanism of construction workers' non-work individual factors to their mental health is complex (Dong 2018; Sutherland and Davidson 1993). Dong (2018) explored the factors influencing mental health of migrant workers in the construction industry, where frustration was identified as the risk factor, sleep status and family support the protective factors.

Sutherland and Davidson (1993) revealed the significant differences of Type A and Type B personality on the mental health of construction site managers and Type A exhibited significantly poorer levels. Besides, high tobacco smoking was also associated with poor mental health (Sutherland and Davidson 1993). Notably, although female is widely believed as the more vulnerable party in the construction community (Kamardeen and Sunindijo 2017; Sang et al., 2017), they showed greater capacity in striking a work-life balance and 'switch off' after work (Sang et al., 2007).

*Table 1 Non-work individual factors and the three types of PWB.*

| Non-work individual factors | Hedonic PWB | | Eudaimonic PWB | | Negative PWB | | | References |
|---|---|---|---|---|---|---|---|---|
| | Job satisfaction (7 articles) | Life satisfaction (1 article) | Mental health (2 articles) | Work-life balance (2 articles) | Stress (5 articles) | Burnout (5 articles) | Psychological symptoms (2 articles) | |
| ***Demographic characteristics*** | | | | | | | | |
| Gender | √ | | | √ | √ | √ | √ | Bowen et al. (2014); Kamardeen & Sunindijo, (2017); Panahi et al. (2016); Sang et al. (2017); Sunindijo & Kamardeen (2017) |
| Age | √ | | | | √ | √ | | Bowen et al. (2014); Lian & Ling (2018); Panahi et al. (2016); Zacher et al. (2014) |
| Profession | √ | | | | √ | | | Bowen et al. (2014); Panahi et al. (2016) |
| marital status | √ | | | | √ | | √ | Kamardeen & Sunindijo (2017); Lian & Ling (2018) |
| ***Personal characteristics*** | | | | | | | | |
| Job experience | √ | | | | | | | Lian & Ling (2018); Shan et al. (2017) |
| Personality | √ | | √ | | √ | √ | | Celik & Oral, (2019); Cheung et al. (2018); Federle & Maloney (1992); Kamardeen, & Sunindijo, (2017); Leung et al. (2008); Sutherland & Davidson (1993) |
| Frustration | | | √ | | | | | Dong (2018) |
| Smoking | | | √ | | | | | Sutherland & Davidson (1993) |
| Language barrier | | | | | √ | | | Leung & Chan (2012) |
| Physical health | √ | | √ | √ | | | | Dong (2018); Holden & Sunindijo (2018); Shan et al. (2017) |
| ***Support received from family*** | | | | | | | | |
| Family role overload | | √ | | | | | | Lu et al. (2019) |
| Relationship satisfaction (spouse/partner) | | | | | | √ | | Lingard (2004) |
| family support | | | √ | | | | | Dong (2018) |
| poor home environment | | | | | | √ | | Naoum et al. (2018) |

Besides, non-work individual factors of the construction workers were found associated with their negative PWB, job stress and burnout are two examples of

negative PWB that received much attention. Bowen *et al.,* (2014) claimed the unique contribution from gender, age and profession in predicting occupational stress among construction professionals. More specifically, Kamardeen and Sunindijo (2017) demonstrated that professionals with a status of separated, divorced, or widowed were more easily suffering from severe anxiety, depression, and acute stress; and female professionals reported more anxiety and depression comparing to their male counterparts. Notably, although Type A behaviour was found associating with lower level of mental health (Sutherland and Davidson 1993), Leung *et al.,* (2008) found that Type A behaviour might buffer construction professionals' stress level because of the potential job achievement and satisfaction. As to job burnout and its sources, Cheung *et al.,* (2018) found that workaholism predicted two perspectives of job burnout, emotional exhaustion and depersonalization. Naoum *et al.,* (2018) further discussed that job burnout was positively related to poor home environment. Notably, Lingard (2004) found positive relationship between burnout and relationship satisfaction with spouse/partner. One possible explanation is that, when people derive great fulfilment and satisfaction in their spouse relationship, they place more importance on their family life, thus the inability to spend time with each other due to work demands may strengthen the feelings of burnout, highlighting the fact that job burnout lies in both work and nonwork experiences. Table 1 presents the relationship between non-work individual factors and the three types of PWB.

**Meta Statistics**

Next, a meta-analysis was conducted to quantitatively summarise how each category of predictors relates to construction worker PWB. Because meta-analysis involves synthesizing effect sizes from 2 or more studies to generate robust effect size estimates, we treated the category of "Personal Characteristics" and "Support from Family" each as one predictor, combining the specific individual predictors under each category. This allows us to quantitatively compare the strength of prediction at the category level in predicting construction worker PWB. Because demographic predictors are rather distinct, age, gender, and marital status were treated as separate predictors. We were not able to meta-analyse the effect size for profession due to its insufficient sample size.

Pearson's correlation r was chosen as the principal measure of effect size. In cases where a correlation value was not included, effect sizes (e.g., Cohen's d or t-score for mean difference comparisons) were converted into correlation r using the formulas described in Wilson and Lipsey (2001). In the end, the meta-analysis included a total of 26 effect sizes from 12 articles. We followed Hunter and Schmidt's (2004) methods for the focal meta-analysis, adopting a random-effects model to estimate between-study variance. Each raw correlation was weighted by sample size (i.e., r) and corrected for internal consistency reliability (i.e., ρ). When the reliability coefficients were not obtainable, mean reliability of the construct was imputed using the formulas developed by Raju *et al.,* (1991). Meta-analysis results were reported in Table 2.

As shown in Table 2, all categories of factors demonstrated correlations with construction worker PWB that were in the moderate range. Specifically, age was positively correlated with PWB ($\rho = 0.122$), indicating that older workers in general enjoy better PWB compared to younger workers. Gender (male = 0, female = 1) was negatively correlated with PWB ($\rho = -0.190$), suggesting that female construction workers have worse PWB compared to male construction workers. Marital status was

shown to have a major influence on construction workers' PWB (ρ = -0.376), and those who are married have worse PWB than those who are not. Characteristics related to worker themselves (i.e., Personal Characteristics), including working experience, personality, and physical health conditions, have a substantial influence on worker PWB (ρ = 0.294). Breaking down each category, the corrected meta-analytic correlation estimate was 0.424 between worker experience and PWB, 0.310 between personality and PWB, and 0.263 between physical health and PWB. All these results indicated that demographic and personal factors are important predictors of PWB in the construction industry and deem more attention.

Lastly, support from family factors, including family roles, home environment, marital satisfaction, were also moderately related to worker wellbeing (ρ = 0.150). Although confidence interval estimates suggest that this point estimate was insignificant, a closer examination of existing estimates revealed the existence of one outlier. Specifically, Lingard (2004) found that relationship satisfaction was positively related to burnout (i.e., negatively related to PWB). The author also pointed it out as a counterintuitive finding and discussed that one possible explanation was that couples who are satisfied with their marriage may place a higher value of spending time with each other, thus the inability to spend time with each other due to work demands may serve as additional sources of burnout. Combining this result with the finding that marital status was negatively correlated with construction workers' well-being, it would be an important future research revenue to explore what kind of support non-work environment could provide to help improve their well-being outcomes.

*Table 2: Meta-Analytic Correlations for the Relationships Between Each Predictor Category and Wellbeing.*

| Factor Category | k | N | r | SD (r) | ρ | SD (ρ) | 95% LCI | 95% UCI |
|---|---|---|---|---|---|---|---|---|
| Demographic-Age | 4 | 1559 | 0.122 | 0.115 | 0.122* | 0.105 | 0.009 | 0.235 |
| Demographic-Gender | 6 | 1778 | -0.179 | 0.114 | -0.190* | 0.109 | -0.289 | -0.091 |
| Demographic-Marital Status | 2 | 112 | -0.376 | 0.005 | -0.376* | 0.114 | -0.382 | -0.369 |
| Personal Characteristics | 10 | 1631 | 0.254 | 0.105 | 0.294* | 0.087 | 0.223 | 0.365 |
| Support from Family | 4 | 612 | 0.127 | 0.228 | 0.150 | 0.252 | -0.112 | 0.413 |

*Note: K = number of studies; N = total number of sample size; r = uncorrected correlation; ρ = corrected correlation; 95% LCI and UCI = lower/upper boundary of 95% confidence interval; *significant (confidence internal did not include zero); We based all interpretations on corrected correlations as they reflect 'true' relationships that are free of measurement error.*

# CONCLUSIONS

The construction industry is characterised as a stressful industry, workers' PWB is a major concern. Previous review studies on construction workers' well-being usually focus on one aspect of PWB, such as stress (Tijani et al., 2020), strain effects (Bowen et al., 2021) and mental health problems (Chan et al., 2020). There is a lack of frameworks that aim to define different groups of PWB and quantify relationship between PWB indicators in different categories and their predictors. Thus, this study fills this gap by summarising the current PWB studies in the construction industry and sorted them according to a pre-defined categorization of indicators. More specifically, among the predictors of PWB outcomes, this study narrowed its focus on the impact of non-work individual factors on PWB indicators. This study is the first to both

qualitatively and quantitatively review extant research on how non-work individual factors influence different taxonomies of PWB.

Through a systematic review, an integrative framework was developed with different types of PWB: hedonic PWB, eudaimonic PWB and negative PWB as well as their respective associations with non-work individual factors. A meta-analysis further demonstrated the moderate impact of these non-work individual factors on workers' PWB. The findings of this study shed light on the development of coping strategies and mechanisms for the PWB of the construction workers. Coping strategies to protect construction workers' psychological health and mitigate negative outcomes must extend beyond the work environment and take into consideration of work-family interface. Demographic characteristics and personal attributes of the workers must be considered when devising strategies to boost well-being outcomes in the construction community.

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# INVESTIGATING THE INFLUENCE OF FACILITIES MANAGEMENT FACTORS IN COMMUNITY AREA ON QUALITY OF LIFE OF THE ELDERLY

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The decline in fertility and mortality makes aging a global problem. Elderly accommodation has become the most important place to ensure the satisfaction of the elderly in their later life, as aging in place is the choice of majority of elderly in China and many countries /districts. The facilities management (FM) for elderly includes indoor, common area and community, while it is still largely remained unknown how the FM factors in community area affects the quality of life (QoL) of elderly. This paper aims to reveal the effect of FM factors in community area on elderly's QoL. A theoretical model of FM-QoL interactions for elderly in community area is proposed based on a solid literature review. Empirical data were collected through questionnaire survey, and subjected to a series of statistical analyses, including reliability test, correlation and regression analysis. The final results show that: 1) the elderly's psychological QoL were positively predicted by distance and ventilation in the community; 2) distance in the community had positive impact on social QoL of elderly; and 3) it was interesting to find that no FM components in community area could affect the elderly's physical QoL. Based on this result, suggestions were proposed to improve the FM in community area for elderly, such as reduction of distance between residential buildings and public facilities, creating fresh air by planting more trees and regularly emptying rubbish cans, and so on. This paper contributes to reveal the influence of FM factors in community area on the QoL of elderly, and its research findings should be helpful for the policy makers, facilities managers and academics to effectively improve FM in community area for better QoL of elderly.

Keywords: aging in place; community environment; elderly; FM; quality of life

## INTRODUCTION

The increase of life expectancy and the decline of death rate made aging society become a global issue (Harper 2019). The United Nation defines a country/region become an aging society when its people aged over 60 (65) years old accounts for more than 10% (7%) of total population. According to the latest statistic in 2019, elderly over 60 in China is 25,388 million accounting for 16.6% of its total population (National Bureau of Statistics 2020), which indicated that China has already become an aging country. It is predicted that people over 60 years old in China will increase to 32.8% in 2050.

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Aging in place is the inevitable result of China's social and economic development. Built environment consists of indoor, common area and community. Although it is identified that indoor and common area FM factors can affect the elderly's QoL (Leung *et al.,* 2019; Ma et al.2018), there is short of research studying the relationship between FM in the community and elderly's QoL. In fact, elderly spent certain time in the community, as community activities, including shopping and taking exercise, are essential for their daily life. It should be noticed that the role of individual unit flat, common areas and community are different for elderly, as FM in the community is complex and changeable which is more difficult for the elderly to control. In addition, the impact range of FM in the community is larger, which can affect more elderly's QoL.

To uncover the impact of the FM factors in community area on elderly's QoL from the FM perspectives, current pilot study aims to establish a model for the complicated relationship among the elderly's QoL and related FM factors in community area. On the basis of previous studies (Leung and Liang 2019), the FM factors in community areas were divided into space management (distance, privacy et al.), building services (ventilation, security et al.) and supporting facilities (finishes, hygiene et al.). A questionnaire survey was administered among over 40 elderly and the collected data were subjected to a series of statistical analyses, including reliability test, correlation and regression analysis. The integrated model was developed based on the congruence of the results of all statistical analyses.

## LITERATURE REVIEW

### Quality of Life of the Elderly

With the improvement of living standard, attention to elderly's well-being has gradually shift from material requirements to broad aspects, such as subjective psychological and social satisfaction. It is of great significance to focus on QoL, which is a comprehensive reflection of individuals' well-being and life satisfaction (Leung and Liang 2019). The most widely used definition of QoL is proposed by the World Health Organization (WHO) as individuals' perceptions of their status in the context of the culture and value system in which they live and in relation to their goals, expectation and concerns.

The three important aspects of elderly's QoL are physical, psychological and social QoL. Physical QoL refers to an individual's perception of his own health, such as pain, sleep disorder, mobility, etc. (Leung and Liang 2019); psychological QoL is used to measure the mental health of the elderly, including their feelings, emotions, and moods etc. (Leung *et al.,* 2020); and social QoL mainly refers to the interpersonal relationship between the elderly and others (including family members, neighbours, friends, etc.).

With aging, elderly generally has declined physical functions, such as decreased sensory ability, inflexible body, and slow response. It has been claimed that the elderly are more likely to have poor psychological QoL. Lack of social participation will lead to a decrease in cognitive function (Levasseur *et al.,* 2015), and even increase the death rate (Machielse and Duyndam 2020). In addition, as a vulnerable group, the QoL of elderly is subjected to influence of built environment (Zhang *et al.,* 2020). With the decline of body function, the elderly's requirements for environment (such as distance, security etc.) will improved a lot. Thus, it is important to continuously monitor and adjust the relationship between elderly and FM factors.

### Facilities Management (FM) Factors At Community Levels

In recent several years, aging in place has been repeatedly emphasized by the national policy in China (Todd *et al.,* 2016). FM factors can significantly affect individual's well-being, especially for elderly residents (Cheng *et al.,* 2019). FM refers to the practices of organizing environment, assets and people within it to meet the needs (e.g., well-being and satisfaction) of the people; it often includes three groups of factors: space management, building services and supporting facilities (Leung *et al.,* 2020).

Space management refers to the management of available resources, including the number of the users, the requirements of the space, etc. (Leung and Liang 2019). Distance and privacy are important FM factors in the community area of space management. Distance to green spaces, health care and public transportation service are all related to residential satisfaction of elderly (Jelokhani-Niaraki *et al.,* 2019). While it is common to be exposed to the open environment in community (e.g., filmed by CCTV on street), feeling of privacy is likely to restrain negative emotions of elderly (Fleming *et al.,* 2014).

Building services refers to a set of technical systems which can meet certain building function requirements, and typical building services factors include ventilation, security and so on. A polluted environment is bad for elderly's health, especially in the community, as bacteria would breed rapidly. Fresh air is the primary consideration to improve the elderly QoL. In the community, security should be one of the major concerns of elderly, and it has been claimed that poor security may harm for elderly's QoL.

Supporting facilities in the community also play a significant role in elderly's daily life. Finishes with bright color and good aesthetic would encourage elderly staying in the community, prompting social interactions among elderly. Hygiene in the community, which concerns community cleanliness and residents' attitude toward environment, determine the willingness of elderly to stay in the community, and poor Hygiene Can Also Increase the Safety Risk of Elderly (Kwan *Et Al.,* 2016).

### Conceptual Model

On the basis of literature review, a theoretical model displayed the interactions between FM factors in community area and QoL of elderly were established (see Fig 1). It hypothesized that three groups of FM factors in community areas, including space management, building services and supporting facilities, could affect QoL of elderly (e.g., physical, psychological and social QoL).

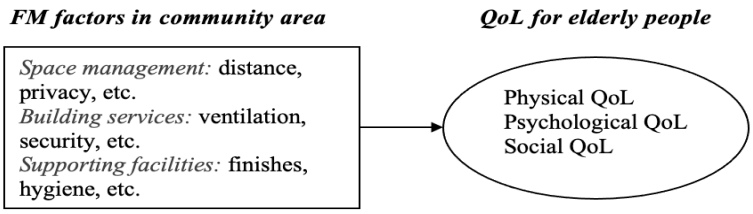


*Fig 1: Conceptual FM-QoL model for elderly in community area*

## METHODOLOGY

A questionnaire survey was administered among the elderly living in urban and rural areas in southwestern China to collect data for testing the conceptual model.

Questionnaire survey has been regarded as an appropriate method to examine the relationship between FM and QoL for elderly (Leung and Liang 2019; Yu *et al.,* 2017). The questionnaire was designed based on valid scales of previous studies, and mainly included three parts: (1) the demographic information of elderly (such as age, gender, education etc.); (2) the elderly' QoL level, covering physical QoL (e.g., concerned about physical health etc.), psychological QoL (e.g., being fun everyday etc.) and social QoL (e.g., not having enough company etc.); and (3) the satisfaction with FM components in community, including space management (distance, privacy etc.), building services (ventilation, security etc.) and supporting facilities factors (finishes, hygiene etc.). The elderly's satisfaction with FM components in community area and their QoL level were valued by a five-point Likert scale ranging from **1(**very unsatisfied/strongly disagree) to 5 (very satisfied/ strongly agree). Studies have proved that use of five-point Likert is appropriate for elderly to indicate their opinion (Leung *et al.,* 2016; Zhang and Li 2019).

To ensure the quality of the data collection, a purposive sampling technique was applied (Cooper and Schindler 2006). Only the elderly who met the following criteria were invited to complete the questionnaire: (1) aged 60 and over (i.e., definition of elderly by United Nations) (United Nations 2018); (2) has lived in current residence for more than 3 months (to minimize the impact of relocation adjustment) (Bekhet *et al.,* 2011); and (3) possesses adequate cognition to comprehend and respond to the questions (Baltes 1987). A face-to-face interview with elderly was conducted by the elderly's family members. Finally, over 40 valid questionnaires were obtained. Of the respondents, 31.7% were male, while 68.3% were female. The number of elderly aged 60-69, 70-79 and 80 or above was 65.9%, 24.4% and 9.8% respectively. Their overall education level is not high (51.2% elderly only had primary school education level). Most of them (over 90%) have lived in current residence for more than two years.

After the data collection, a series of statistical techniques, including reliability test, correlation analysis and regression analysis, were applied to examine the relationship between FM factors in community area and elderly's QoL. The interior consistency of the related FM components in community and QoL factors were tested by reliability analysis; the strength and direction of relationships between two variables were measured by correlation analysis; and regression analysis showed the individual impact of FM in community on elderly's QoL by establishing models about the relationship between a set of independent variables (i.e., several FM components in community) and dependent variable (i.e., one QoL factor).

# RESULTS

## Reliability Test

A reliability test was conducted to examine the degree of freedom from random error between the QoL and FM factors in community. Cronbach's alpha value at 0.60 set as the benchmark for the inclusion of factors. During the reliability test, it was found that the Cronbach's alpha value of ventilation(F3) was increased significantly from 0.292 to 0.714 after reversing two questions of it (i.e., this is a polluted neighbourhood and residents' health is threatened by pollution in this neighbourhood). Finally, all FM components in community and QoL factors had a high alpha value, ranging from lowest at 0.693 for physical QoL(Q1) to the highest at 0.871 for privacy(F2).

### Correlation Analysis

A Pearson correlation analysis was used to explore the strength and direction of the relationship between FM in community area and QoL of elderly. The results showed that: 1) psychological QoL (Q2) was positively correlated with distance (F1: 0.394; $P < 0.05$), privacy (F2: 0.333; $P < 0.05$), ventilation (F3: 0.391; $P < 0.05$), security (F4: 0.342; $P < 0.05$) and hygiene (F6: 0.336; $P < 0.05$); 2) social QoL (Q3) had a significant and positive correlation with distance (F1: 0.380; $P < 0.05$); and 3) it was interesting to find that physical QoL (Q1) had no significant relation with all FM factors in the community.

### Regression Analysis

To examine the unique influence of each FM factor in community area on QoL of elderly, a standard regression analysis was applied in the study. Studies claimed that demographic factors can influence the QoL of the elderly (Kim 2016; Qin *et al.,* 2020). Thus, the effect of demographic factors should be controlled in the regression analysis. In the regression models of current study, one of QoL (e.g., physical, psychological, social QoL) was entered to the model as dependent factor, while demographic factors (including age, education and gender) and all FM factors were respectively entered into the first block and second block of independent factors in the model. A total of two regression models were established (Table 1). The Model 1 shows that Psychological QoL (Q2) was positively predicted by distance (F1) and ventilation (F3), and this model accounted for 32% of the variance. As shown in Model 2, distance (F1) positively affected Social QoL (Q3), and a total of 14.4% variance was explained by the model.

*Table 1: Regression model for FM components in community area and QoL factors of the elderly*

| | | | | | | | | ANOVA | |
|---|---|---|---|---|---|---|---|---|---|
| Model | B | S.E. | Sig. | VIF | R | R2 | ΔR2 | F | Sig. |
| 1. Psychological QoL | ← | | FM Components in community area | | | | | | |
| (Constant) | 0.963 | 0.654 | 0.150 | - | 0.584 | 0.341 | 0.247 | 3.618 | 0.010 |
| F1 - Distance | 0.363 | 0.125 | 0.006 | 1.008 | | | | | |
| F4 - Ventilation | 0.380 | 0.125 | 0.004 | 1.024 | | | | | |
| 2. Social QoL | ← | | FM Components in community area | | | | | | |
| (Constant) | 0.794 | 0.708 | 0.269 | - | 0.398 | 0.159 | 0.065 | 1.697 | 0.172 |
| F1 - Distance | 0.411 | 0.167 | 0.019 | 1.007 | | | | | |

*Notes: ΔR2 = increased R squared; Dependent V = Dependent Variables; Independent Vs = Independent variables; S.E. = Standard Error; VIF = Variance Inflation Factor*

## DISCUSSION

To ensure the reliability of the results, final conclusions of this paper were only made based on the congruence of the results of all statistical methods (i.e., the reliability test, correlation analysis and regression analysis) (Table 2). A FM-QoL model for elderly in community area was established (see Fig 2). The model showed that: 1) one of space management factors (i.e., distance) could positively predicted the elderly's psychological and social QoL; 2) ventilation, as building services factor in the community, imposed positive impact on psychological QoL of elderly; and 3) it was

interesting to find that no supporting facilities components could affect the elderly's QoL.

*Table 2: Correlation and regression results for FM components in community area and QoL factors of elderly*

| | Physical QoL | | Psychological QoL | | Social QoL | |
|---|---|---|---|---|---|---|
| | correlation | regression | correlation | regression | correlation | regression |
| F1-Distance | -0.142 | 0.135 | .394* | 0.041* | 0.380* | 0.050* |
| F2-Privacy | 0.111 | 0.283 | .333* | 0.178 | -0.009 | 0.301 |
| F3-Ventilation | 0.001 | 0.812 | .391* | 0.014* | -0.002 | 0.648 |
| F4-Security | -0.152 | 0.110 | .342* | 0.510 | 0.132 | 0.389 |
| F5-Finishes | -0.157 | 0.275 | 0.276 | 0.481 | 0.285 | 0.258 |
| F6-Hygiene | 0.063 | 0.046* | .336* | 0.486 | 0.302 | 0.316 |

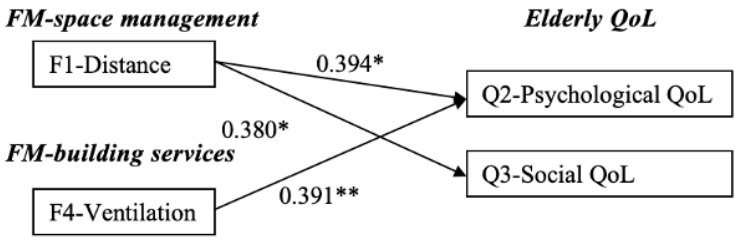


*Fig 2: A FM - QoL model for elderly in community area*

→ Represents a positive relationship revealed in correlation and regression analysis

## Space Management and QoL

The final results showed that distance had a positive effect on psychological and social QoL of elderly respectively. The distance factor in the community was concerned with the distance to various public facilities nearby, including the distance to nearest shopping mall, to nearest park/square, and to nearest gym/sports centre. In fact, distance to public facilities is essential for elderly's daily life, as it determined whether elderly's daily needs are easily satisfied. Thus, it is unsurprised to find the connection between distance and psychological QoL. Furthermore, with the decline of mobility (Iancu and Iancu 2020), appropriate distances in community encourage the elderly from participating in social activities and would lead to improved social QoL.

Considering congruence between correlation and regression analysis, no relationship between QoL and privacy in community was confirmed in this study. This finding is different from those of previous study (i.e. privacy restrictions may lead to negative emotions of elderly) (Leung *et al.,* 2017). Perhaps, elderly knows that community is a public open space, and thus, being photographed by security cameras in the community will not make them feel uncomfortable. They may also have already perceived it is hard and insignificant to protect privacy in the community.

## Building Services and QoL

It was found that there existed a positive interaction between ventilation in community and psychological QoL of elderly. This finding is consistent with those of previous research that claimed ventilation in individual unit flat and common area could

positively affect elderly's social QoL (Leung *et al.,* 2017; Leung and Liang 2019). A dirty environment with polluted air would cause bacteria breed and spread rapidly, which is harm for the elderly's health. In fact, most of Chinese elderly think it is good to stay in environment with clean air, and when they breath fresh air in the community, they may feel pleasant. Therefore, it is reasonable to found high satisfaction with ventilation in the community led to high psychological QoL of elderly.

The security in the community was concerned with low crime rate, and safe neighbourhood etc. Good security can ensure that the residential environment under control and was safe for elderly. The previous research indicated that security of common area could affect elderly's psychological and social QoL (Leung and Liang 2019). However, no relationship was found between security and the elderly's QoL in this study. Criminal rate against elderly in Chinese city is usually not high, and most of elderly mainly come out in the daytime. The elderly also does not stay in community for very long time, and thus, they may gradually regard that safety is not a significant issue in the community.

**Supporting Facilities and QoL**

It was interesting to find there exist no direct interaction between supporting facilities and the elderly's QoL. The finishes in the community were concerned with materials and building details and so on. Different areas with different materials and detail design may not be noticed by elderly, because of their slow response and poor visual function. In addition, not all of them are construction practitioners, there is no need for them to pay attention to the building material and detail design. Thus, it reasonable to find no direct between finishes and the elderly's QoL

Hygiene in the community concerning cleanliness of streets, and residents' attitude or behaviours (such as respecting environment, avoiding dirtying the place in the community etc.). A clean and pleasant environment is one of the most important needs for elderly (Yung et al.2016). Study has shown that hygiene in common area affected elderly's QoL (Leung and Liang 2019). However, no direct interaction between hygiene in community area and QoL of elderly was found in this study. Perhaps, elderly generally stay in a private space (i.e. individual unit flat and common area) for longer time than in public one (i.e. community area). Elderly are normally able to control the hygiene in individual unit flat and common area (by frequently cleaning and emptying rubbish cans). However, in the community, it is not easy for elderly to keep cleanliness, as elderly can't control other residents' behaviour and attitude related to hygiene. In this regard, elderly may consider the community hygiene as unimportant factors that imposed no effect on their QoL.

**Recommendations**

*Practical Recommendations*

The finding of this study has indicated a significant relationship between FM in the community and the elderly's QoL. Thus, some effective suggestions for appropriate design and management of related FM components in community area are proposed to developer, designers, facilities managers, and other related groups, so as to improve elderly's QoL and well-being.

Unlike individual unit flat and common area, elderly often need to travel longer between residential buildings and public facilities, and thus, effective measures should be taken to shorten the related distance. For example, a sufficient number of benches

should be arranged beside the road so as to compensate the decline of elderly's body function. Furthermore, the elderly's travel behaviour in the community should also be observed in order to set more suitable spatial arrangement between residential buildings, and markets, parks and other public facilities. Attention should also be paid to ventilation in the community. In order to ensure the elderly to keep good emotion, it is recommended that streets should be frequently cleaned, and rubbish cans should also be emptied frequently. More trees should also be planted to filter polluted air and create fresh air for elderly in the community.

*Research Limitations and Future Research*

Although this research may involve potential biases, some remedial actions have been taken to ensure the reliability of the final results: 1) the extensive literature review about FM and QoL was taken to ensure the theoretical basis of current study; 2) the questions in the questionnaire are adapted from previous validated scales; and 3) the high alpha values for all factors indicated the high degree of internal consistence. It is reasonable to infer the current results have certain reliability.

Current study conducted a questionnaire survey to collect data from 41 elderly. Although there is no sample size requirement for reliability test and correlation analysis, the sample size of current study may not be sufficient for regression analysis. Indeed, insufficient sample size may cause issues like generalisability and bias in the results (Pallant *et al.,* 2016). However, it should be noted that all the elderly were selected based on strict criteria, which should have ensured certain level of representativeness to the total population of Chinese elderly. In addition, the final conclusion of the study was made based on the results confirmed by both correlation and regression analyses. Adoption of the within-method triangulation should also be helpful to ensure the reliability of the final results (Berg 2001).

The current research adopted a quantitative method (i.e., questionnaire survey) to investigate the effect of FM components in community area on three important aspect of elderly's QoL. According to between-method triangulation, case study using qualitative research methods (such as focus group and interview methods) for specific community are recommended to cross-check with current quantitative research results.

It was interesting to find that there were no FM factors in community area could affect the elderly's physical QoL and no supporting facilities could impose effect on QoL of elderly. As the current pilot study only studied the direct effects of some representative FM factors in community area on the elderly's QoL, future research is recommended to incorporate more possible influencing factors and investigate the complex mediating and/or moderating effects between FM factors and QoL of elderly. This will enhance our understanding of the interactions between FM and QoL of elderly.

## CONCLUSIONS

The current study set out to examine the influence of FM in community area on the QoL of elderly. Based on the congruence of multiple analyses, the final findings show: 1) the elderly's psychological QoL can be positively affected by distance and ventilation in the community; 2) distance in community imposed positive impact on social QoL of elderly; and 3) no relationship was found between FM in community area and physical QoL of elderly. Practical recommendations were made to improve the existing FM in community area, including reduction of the distance between residential buildings and public facilities by arranging enough benches on the

roadside; frequently emptying rubbish cans and planting more trees to create fresh air, and so on. This study was able to confirm that FM in the community can significantly affect QoL of elderly, which enhance our understanding of the relationship between FM and QoL of elderly.

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# CONSTRUCTION OCCUPATIONAL SAFETY AND HEALTH INCIDENT REPORTING, RECORDING, MONITORING AND MANAGEMENT IN UGANDA

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The construction industry is prone to many Occupational Safety and Health (OSH) incidents and responsible for high fatality of workers. Despite their high frequency and severity, construction incidents are usually underreported. The level of incident reporting is largely dependent on the nature of the reporting process. In this paper, we describe the current OSH incident recording, reporting, and management process in Uganda and identify weaknesses in the process that provide an opportunity for improvement, which could, ultimately, lead to better OSH performance. The research involved process modelling of the as-is/current process, based on content analysis of existing literature, and verification and analysis of the process model through interviews with OSH subject matter experts. The findings reveal that the current OSH incident, reporting recording, monitoring and management process is comprised of four sub-processes: Workplace Incident Reporting, Management, Recording and Compensation (WIRMR&C); Hospitisation (HOS); Incident Reporting to Police (IR2P) and National Incident Reporting, Management and Monitoring (NIRM&M). Several weaknesses such as: lack of centralized recording of construction OSH incidents; and lack of provisions for reporting minor OSH incidents at national level were identified. We suggest that these weaknesses should be addressed with a national web-based OSH incident recording, reporting and monitoring system.

Keywords: safety incidents; incident reporting; process modelling; Uganda

## INTRODUCTION

The construction industry is affected by many setbacks in as far as Occupational Safety and Health (OSH) is concerned. It is considered one of the most dangerous industries on basis of accident frequency (Lubega, *et al.,* 2000). In Europe, the construction industry contributes 30% of fatal industrial accidents, yet it employs only 10% of the population (Peckit, *et al.,* 2004). Construction fatalities account for 30-40% of industrial fatal accidents in Japan and 50% in Ireland (Peckit, *et al.,* 2004). In Kampala, the capital of Uganda, about 4% construction workers suffer workplace injuries and the resultant fatality rate is 84 in every 100000 workers (Irumba, 2014).

It is important to note that most of the statistics on OSH accidents are often incomplete and unreliable because under-reporting is common (ILO, 2012). The

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deficiency in reporting and monitoring leads to underestimation of incidents. Underestimation of OSH incidents occurs when organizations fail to record employee injuries and illnesses (organizational-level under-reporting) and report to the authorized bodies or when employees fail to report injuries and illnesses occurring at the workplace (individual-level underreporting) to the relevant officers (Probst and Estrada, 2010).

Many OSH incidents on construction sites in Uganda are not documented, reported, or investigated by the relevant authorities because of a number of factors including among others, a rudimentary reporting and monitoring system. The current OSH incident reporting in Uganda still relies on a letter delivery system, involving cumbersome documentation, high transportation, and handling costs and 'delays in conveyance of information' (DOSH, 2018). Such a system frustrates both the reporters of incidents and the enforcers of OSH, thereby affecting process of reporting and monitoring OSH incidents. This culminates into underreporting and underestimation of OSH incidents in Uganda's construction industry. According to Okwel *et al.,* (2019), reporting of accidents to the authorities is considerably low (about 24%) and it is apparent that occupational illnesses are not reported (Alinaitwe, *et al.,* 2007). This failure to report and address OSH incidents eventually leads into recurrence and the problem is aggravated. Consequently, many construction accident victims are not helped or compensated by their employers in a deserving manner and the enforcing bodies have limited means of tracking such instances. This study was thus carried out to help in addressing the problem of underreporting of construction OSH incidents in Uganda. The objectives of this study were: 1. To describe the current process of OSH incident reporting, recording, monitoring and management in the construction industry, 2. To identify the weaknesses in the process 3. To suggest measure(s) to improve incident reporting in Uganda's construction industry.

*OSH in Uganda's Construction Industry*

Uganda is not cushioned from the issues that affect all other developing countries especially in Africa in as far as OSH is concerned. Literature suggests that the construction industry is top on the list of the three most hazardous workplaces in Uganda (Authman, 2010). Other statistics based on empirical research suggest that construction is the second largest contributor of workplace injuries in Uganda (Lubega, *et al.,* 2000; Irumba, 2014;). In comparison to other industries or sectors in Uganda, the average number of compensated accidents from construction based on data collected from workers compensation between 1996 and 1998 was nearly the highest, with an average slightly less than that of compensated accidents from the manufacturing sector (Lubega, *et al.,* 2000). The study further found that on the basis of fatality, the construction industry is the most dangerous. However, to be able to draw such a conclusion there would be need for adequate data to be collected over a long period to increase reliability of OSH injury statistics in Uganda.

According to Alinaitwe *et al. (*2007), there were a number of causes of accidents on construction sites from the year 2001 to 2005 and these included; burns, chemicals cuts, dust, electricity, falls, being hit by an object, machines, suffocation, trauma, vehicles, accounting for 4.5%, 0.4%, 7.8%, 1.1%, 1.1%,14.9%, 50.2%, 10%, 0.4%, 1.5% and 8.2% of the 269 construction incidents reported at labour offices in all districts in Uganda respectively. Being hit by object was the greatest contributing cause of accident injuries in construction. In a study by Irumba, *et al. (*2014), the results showed that the three most prevalent causes of accidents in Kampala are mechanical hazards (i.e., struck by machines, vehicles, hand tools, cutting edges etc.),

being hit by falling objects and falls from height. Because most of the studies are done in different locations and in isolation, and at different times, there is no consensus on the single most accident injury cause in Uganda.

Collapses at building construction sites are major occurrences that have led to many fatalities in Uganda (Mwakali, 2006; Musoke *et al.,* 2008; Ssempogo *et al.,* 2008; Okwel, *et al.,* 2019;). Each building collapse usually accounts for many casualties at a go (Ministry of Works and Transport., 2004; Alinaitwe and Ekolu, 2014). A total of 54 building collapse deaths and 122 injuries in just four years (2004 - 2008) were counted in Uganda (Alinaitwe and Ekolu, 2014). More recently, at least 15 people were fatally injured after a the three-storied building collapsed while under construction (Atuhaire, 2020; Olukya, 2020). Another 6 workers were also killed because of the collapse of a four-storey building (Kirabo, 2020). While most accidents from collapse of buildings in busy urban centres attract attention, other accidents that happen on different sites do not and, as such, are not reported. As such, decision making concerning improvement of OSH and accident prevention in the industry becomes rather complex. Therefore, there is need for a well-developed system to aid the capturing of OSH incident data, monitoring of incidents and generating statistics to inform decision making about construction OSH in the country.

## METHODS

To achieve the objectives of this study, process modelling (PM) was used. PM was done to describe the current system or process of reporting, recording, monitoring and managing OSH incidents in Uganda's construction industry. PM involved process discovery through extensive content analysis of peer reviewed literature and the OSH legislation in Uganda, process mapping using Business Process Model and Notation (BPMN) 2.0 in Microsoft Visio 2016 (OMG, 2011; Hangos and Cameron, 2001; Silver, 2011) and process verification (Dubois *et al.,* 2013). The developed process model was internally verified to check its consistence with the BPMN 2.0 rules of process modelling and then empirically verified through semi-structured interviews administered to Subject Matter Experts (SMEs). The SMEs were presented with the developed as-is process model for verification and thereafter asked to discuss the as-is process, highlighting its prevailing weaknesses. The SMEs were selected purposively based on their level of experience in OSH incident reporting, management and monitoring. The experience of all the SMEs interviewed was at least 5 years thereby increasing the internal validity of the responses. The SMEs comprised two Labour Officers (LOs), two Health and Safety Officers (HSO), two OSH Inspectors, one Police Officer and one Medical Personnel. All the data obtained were analysed qualitatively and possible solutions, based on the findings, proposed.

## RESULTS AND DISCUSSION

### *The Process of Reporting, Recording, Monitoring and Managing Construction OSH Incident*

Results from process discovery showed that the major sub processes in the reporting, recording, monitoring and managing of OSH incidents in Uganda are; Workplace incident reporting management, recording and compensation sub process (WIRMR&C); Hospitalisation of Victim sub process (HOS); Incident reporting to the Police sub process (IR2P) and; and the National Incident Reporting, Management, Monitoring sub process (NIRMM) (see Fig 1).

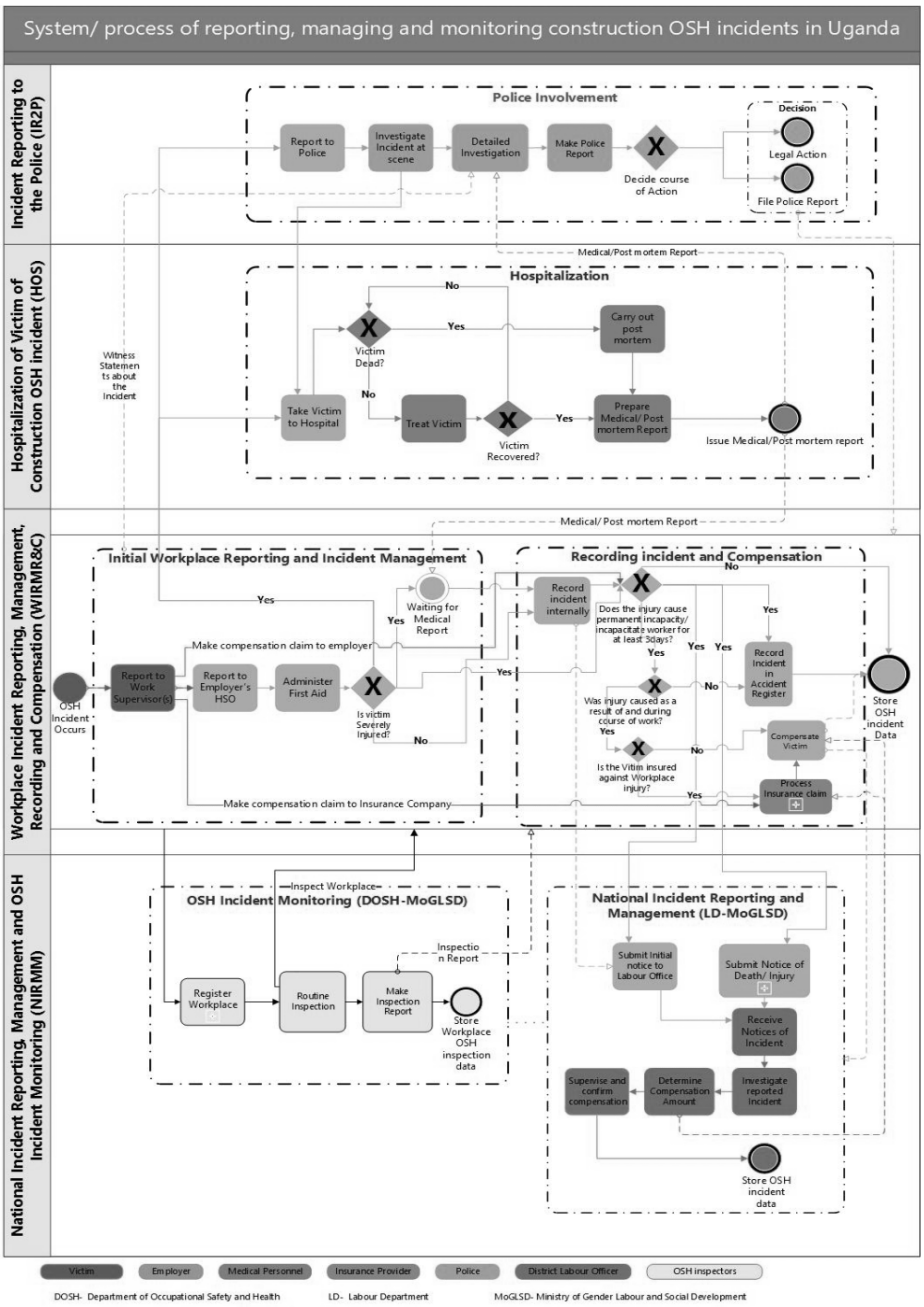


*Fig 1: As-is process of reporting, recording, monitoring and managing OSH incidents*

*Workplace incident reporting management, recording and compensation sub process (WIRMR&C)*

This sub process is subdivided into two parts i.e., Initial workplace incident reporting and management: and Incident recording and compensation.

*Initial workplace incident reporting and management.*

When an OSH incident occurs on a construction site, the victim or witnesses of the incident immediately report to the work supervisor(s). This report is done verbally as it is assumed that there is proximity between the victim or witnesses and the work supervisor(s). The supervisor then reports the incident to the Health and Safety Officer (HSO) who is directly concerned with managing OSH on the construction site. The HSO may also receive the report directly from the victim or witnesses. On receiving the incident report, the HSO administers First Aid (FA) to the victim. After administration of FA, the HSO assesses the level of injury and then decides whether

or not to hospitalize the patient. In case there is no injury, or the injury is minor i.e. (injury for which first aid suffices), the HSO can proceed to record the incident internally.

*Incident recording and compensation*

This part of the WIRMR&C sub process starts with recording of the incident internally in a format specified by the individual construction organizations where it occurred. The internal record is made so as to capture as much raw information about the accident as soon as it occurs, and it is usually as comprehensive as possible. It also forms a basis for the company to learn from incident and thus perform better in as far as OSH is concerned, going forward. After recording the incident internally, the HSO records the details of the incident in the accident register by the employer which is mandatory for all construction sites as provided by the Factories Act (1953). Incident recording ends when the employer stores the incident record for future reference.

The process of compensation is either initiated by a claim from the victim that suffered injury during an OSH incident, or the person entitled to compensation in case of death or by an employer in the event that the victim is insured (Workers Compensation Act, 2000). In instances where the victim is insured against workplace/ occupational injury, s/he may make an insurance claim for compensation immediately after the incident occurs or allow the employer to claim on his/ her behalf. The insurance provider then goes ahead to process the claim and decide on whether to grant it, differ it, or reject it. The processing of the claim includes assessment of the validity of the claim, checking if the insurance covers such injury and whether the injury was sustained during the course of employment. In instances where it is established that injury suffered by the victim warrants compensation, and that such injury was sustained during the course of work, but the injured victim was not insured against workplace injury, the employer goes ahead to compensate the victim, an amount that the statutes deem fit or, an amount agreed to by or an amount mutually agreed between the employer and the victim with the notification of the LO (Workers Compensation Act, 2000). The compensation process is deemed complete when the victim or claimant is compensated.

*Hospitalisation Sub process (HOS)*

Hospitalisation is done in case of severe injury and in cases where there are no medical personnel to attend to the victim's injuries. It starts with taking the victim to health facility for treatment or postmortem in case of death. It is the responsibility of the employer to take the victim to hospital. The costs of Hospitalisation at this point are borne by the employer as provided by the Section **11(**1) of the (Workers Compensation Act, 2000). Once the victim is hospitalized, the employer waits for a medical report but can proceed and record the incident internally (see Fig 1).

*Incident Reporting to Police Sub process (IR2P)*

In instances of severe injury leading to immediate death of the victim the HSO reports to the Police upon occurrence of the incident. The Police then go ahead to investigate the incident on site, and thereafter take the victim to hospital for a postmortem to the hospital. The Police then initiate a thorough investigation of the incident by collecting information from witnesses and the medical report from the Hospitalisation sub process. This is then followed with a detailed report about the incident which is availed to all stakeholders in hard copy form on request.

*National OSH Incident Reporting, Management and OSH Incident Monitoring sub process (NIRMM)*

This sub process is divided into two parts: National OSH incident reporting and management; and OSH Incident monitoring

*National incident reporting and management*

National incident reporting is also known as Organizational incident reporting (Probst, *et al.,* 2019). National OSH incident reporting is done in instances where the incident is of such magnitude to warrant compensation to the victim, i.e., either results in permanent incapacity; or incapacitates the worker for at least three consecutive days from earning full wages at the work at which he or she was employed. It commences with notification to the area Labour Officer (LO), who is an officer under the Labour Department (LD) of MoGLSD. This notification is expected to be done immediately after the incident has occurred. The Workers Compensation Act under Section 10 (1) provides that "….after the happening of an accident causing injury to a worker of such a nature as would entitle him or her to compensation under this Act, the employer shall, at once, report the accident either by telephone, telegram, telefax or telex or any other reasonable means to the labour officer of the area; and the report shall be followed immediately by a written report of the accident before the worker has voluntarily left the employment in which he or she was injured ". The employer is also required to give a formal notice of the incident in a manner specified by the 'Minister' (Factories Act, 1953). The LD Form 31 and is the formal tool used for notification to the LO in case of an accident-causing injury to a worker. In case of death as a result of the incident, the LD Form 78 is also submitted along with the LD Form 31 (Alinaitwe *et al.,* 2007). These forms are completed manually and then delivered by mail of hand delivery to the District Labour office (Workers Compensation Act, 2000). Once these notices are submitted the LO, incident management at State level begins. OSH Incident management at National level is done by the LD under the Directorate of Labour, Employment, Occupational Safety and Health of the MoGLSD. After receipt of the notice, the LO launches an investigation into the reported incident to the effect that it is established the compensation due to the victim (see Fig 1). This investigation may include interviews with the victim, medical examinations by registered medical practitioner to determine the level of incapacity and assess disability as a result of the incident and to establish the compensation due to the victim. The LO then communicates to the employer and/ insurance company about the compensation due and supervises the process of compensation. Finally, a comprehensive report is written, by the LO and the incident data filed for future reference at the LD.

*OSH incident monitoring*

Monitoring of OSH incidents in the construction industry is done by DOSH which works in collaboration with the LD. Monitoring involves inspection of the construction workplace by OSH inspectors regularly or upon the occurrence of an incident to assess whether OSH incidents are managed in a proper manner as provided for in the OSH legal framework. For instance, the OSH inspector on work inspection checks the accident register to ensure that incidents in the workplace are recorded in the accident register and that appropriate action was taken to ensure that appropriate action was taken to compensate or provide remedies to the victim. Inspections are also done so as to assess the OSH environment before registering workplaces in order to limit the likelihood of occurrence of construction OSH incidents.

On presenting the process model describing the process of reporting, recording, monitoring and managing construction OSH incidents in Uganda, the SMEs found the process correctly represented by the researchers. However, a modification was suggested to the WIRMR&C sub process by a HSO to include post incident management at workplaces. This modification was included in the final process model (see Fig 1).

**Weaknesses Identified in Reporting, Recording, Monitoring and Managing Construction OSH Incidents**

From the interviews with the SMEs, the following weaknesses were identified in the as-is system of reporting, recording and management of construction OSH incidents:

*Lack of reporting to the Labour Department*
Due to the inattention, lack of awareness of legal reporting requirements and burden of completing paperwork, most of the HSOs and site workers do not report accidents occurred in the sites via notice of accident form to the respective LOs. "They consider that involvement of the LO would create additional distress", said a LO. Further, it was revealed unavailability of a stringent monitoring process for following up the law has debilitated the need of reporting. According to one of the interviewed LOs, some contractors find the penalty given for the failure of reporting incidents to the LO affordable and would rather not report OSH incident but pay if later discovered. According to the Workers Compensation Act (2000), failure to report an incident according to the LO attracts a fine of only 10 currency points. One of the interviewed HSO said that *"... some contractors opt to settle the incident amicably with the victim without reporting the case to the LOs for the sake of protecting their public image"*.

*Lack of reporting of minor incidents*
As per the (Factories Act, 1953), it is compulsory for all factories and construction sites to report accidents and injuries caused to a worker if the worker is absent for three working days due to an OSH incident. Therefore, the accidents that categorised under “less than three working days from earning full wages at the work” are not reported to any authorised body as there is no legal requirement in the law. Many organisations also do not pay attention to reporting and recording such minor incidents or near misses at the workplace and this usually leads to recurrence and/ escalation into major accidents because no strategies are developed to prevent or counter them.

*Unavailability of a centralised recording of incidents*
The current incident reporting, recording and management system is decentralised, with all stakeholders maintaining their own record of each reported incident. It was thus observed that, instituting a centralised recording system is a burning need to formalize a precise and efficient reporting and recording process which is considered as one of the main causes of incident under reporting. There is lack of integration between relevant authorities concerned with National incident reporting and monitoring. For instance, the DOSH and LD do not share an OSH incident database.

Only the employer can give notice of incident to National OSH Managers
National level OSH incident reporting is a mandate of the employer as per the legal framework that governs OSH in Uganda. As such the current system does not provide for third parties to make notices about construction accidents to the LD. This implies that the reporting of an incident that occurs at a workplace remains to the discretion of the employer, which at times encourages underreporting of OSH incidents.

*Poor relationship between Insurance companies and the Labour Department*
Many construction employers have insured their employees against the liability of workers' injury. Therefore, in a case of an OSH incident which warrants compensation the employer informs the LO and the insurance company simultaneously in order to claim the compensation for the victim(s). Even though the insurance companies should have an information flow between them and the LD, they are not bound to maintain a proper affiliation with the LD during such information sharing.

Poor relationship between Hospitals, Police and Labour Department
The Hospitals, Police and the Labour department are fundamental institutions that handle different aspects of incident management and reporting. However, these usually carry out their investigations independent of each other and many times have contradictory findings. The sharing of information between them during investigation of a construction OSH incident is also limited by a number of factors including, bureaucracy and the politics surrounding the incident, as put by an OSH inspector. Also, a delay in investigations by one of the institutions may affect the management of an OSH incident. *"…the police investigations take long to complete, and the police report depends on the medical reports…we only submit a police report of the incident in hardcopy to the labour office on request"*, said the Police officer. *" Information sharing among these institutions therefore needs improvement"* said a LO.

**Suggested Measures for Improvement of the Reporting System/ Process**

As discussed above, the current process of reporting, recording and managing construction incidents has a number of loopholes which could be responsible for incident underreporting and poor incident record keeping at workplace and national level, which makes the process of monitoring the OSH in the construction industry a rather complex endeavour. As such the current process is inadequate in addressing the issue of underreporting and management of construction OSH incidents in Uganda. These challenges are not unique to Uganda as studies curried out in developing economies are seen to have similar challenges (Nawarathna and Nayanthara, 2014). Recommendations are thus made for the design of a web-based incident reporting and monitoring system to facilitate incident reporting and management in Uganda's construction industry. The recommended system should be designed in such a manner that it has a centralized relational database; user interphases for the envisaged users; allows for user registration and security as suggested by a LO; ensures anonymity of reporters (especially whistle-blowers) as suggested by a HSO; provide for reporting of minor incidents; and it should be compatible with the OSH legal framework of Uganda as suggested by the Police Officer, the 2 LO and an OSH inspector. Such a system would address the issue of timely delivery of incident reports and encourages better recording and retrieval. Additionally, being web-based would make the system accessible to reporters in all parts of Uganda, thereby improving the practice of incident reporting. The web-based systems have been found effective in improving OSH incident reporting and management in developed countries. For instance, in the UK, the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) was revised in 2013 and an ICT web-based system put in place to capture data on OSH incidents. This improved the reporting and management of OSH incidents (HSE, 2013; Ellis Whittam, 2017). If considered, the recommended system would go a long way in addressing underreporting and improving OSH management.

## CONCLUSIONS

This research was conducted in pursuit of three objectives: to describe the current process of OSH incident reporting, recording and management in the construction industry; to identify the weaknesses in the process; and to suggest measure(s) to improve incident reporting in Uganda's construction industry. The as-is system was described. Generally, the as-is system is rather reactive and there is poor data storage that does not facilitate effective statistical analysis of incident data and decision making on OSH in the country. The weaknesses identified in the as-is system included: lack of reporting to the LD; decentralised recording; lack of provisions for reporting minor incidents, to mention a few. The researchers suggest that some of these weaknesses can be tackled through the design and implementation of a web-based incident reporting and recording system. The proposed system would need to be commensurate with the legal framework that governs OSH and provide additional benefits such as instant statistical reports about OSH and whistle-blower reporting.

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# MENTAL HEALTH AND SUICIDE PREVENTION PROGRAMS IN THE U.S. CONSTRUCTION INDUSTRY

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Each year 20-25 percent of the general population meets the criteria for a mental health diagnosis in the United States. This research focuses on the increase in mental health issues and suicide in the U.S. construction industry. A 2016 report, released in 2020 by the U.S. Centre for Disease Control (CDC), placed the construction industry as second among all other industries in suicide rate. This research seeks to quantify awareness of mental health and suicide as issues affecting construction employees within the U.S. construction industry, identify awareness of the particular risk factors facing U.S. construction workers which increase mental health and suicide in the industry, qualitatively evaluate the effectiveness and adequacy of existing mental health and suicide awareness/prevention programs, and qualitatively assess if the benefits of instituting comprehensive mental health and suicide awareness/prevention programs outweigh the costs of such programs. Data was collected utilizing an anonymous survey distributed to construction managers, safety professionals, professional organizations, labour/trade organizations, and field employees within the construction industry. A total of 103 respondents completed the survey. The research identifies differences that exist among the different professional roles in the U.S. industry, with respect to awareness, effectiveness, adequacy, and risk factors. An analysis of the data also identifies differences between types of construction organizations (general contractor, subcontractor, etc.) and size of the organization. The research is important to the future of the industry and will help identify where additional focus is needed in mental health treatment and suicide prevention in the U.S.

Keywords: safety; health; resilience; mental health; stress

## INTRODUCTION

The workplace is taxing, both physically and mentally, as a result of intensified demands on construction projects (Abdelhamid and Everett, 2001; Love *et al.,* 2009). The construction industry is characterized by high rates of work-related accidents, intense deliverable deadlines, as well as a current crisis with a skilled trades shortage (Arndt *et al.,* 2005; Campbell, 2006; Olsen *et al.,* 2012; Delvinne *et al.,* 2020). Mental health (MH) remains a global burden and not restricted to a particular race, culture, society or status (WHO, 2013). There have been rigorous studies highlighting this crisis the world is facing, particularly focused in the United Kingdom, Australia, New Zealand. The United States has begun work towards contributing to the

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literature focusing specifically on the MH crisis of those in the U.S. construction industry; however, gaps remain and must be addressed for the future of the industry.

The aim of this research was two-fold. First, the study investigated the awareness of MH and suicide as issues affecting construction employees specifically in the United States. This research also explored the prevalence and effectiveness of suicide prevention programs in the construction industry. The study employed an anonymous online survey instrument to collect response data from employers, labour unions, and other industry partners. Research on the prevalence and effectiveness of MH and suicide prevention programs in the construction industry is significant in that it provides empirical data on how well the industry is reacting to the increase in construction suicides. This research endeavours to add data to this critical subject so construction industry leaders in the United States may better train their staff on the importance of recognizing suicidal behaviours and MH issues. Early intervention of workers experiencing mental distress will reduce the risk of suicide.

## LITERATURE REVIEW

Mental health issues and suicide have a tremendous impact on the U.S. workplace. Depression is estimated to cause 200 million lost workdays each year at a cost to employers of $17 to $44 billion. In a three-month period, individuals with depression miss an average of 4.8 days and suffer 11.5 days of reduced productivity. Unfortunately, nearly 80% of employees experiencing psychological distress are not receiving treatment, and less than 8% of adults with both a mental health and substance abuse disorder receive treatment (Lipari, 2018). Suicide also has tremendous economic costs for individuals, families, and employers. The U.S. Centres for Disease Control and Prevention (CDC) estimates that suicide and suicide attempts cost the nation approximately $70 million per year in medical and lost productivity costs alone (Peterson *et al.,* 2020).

"Stigma associated with mental ill health still remains the number one challenge in the construction industry" (Janusonyte *et al.,* 2019). A study by Eyllon *et al. (*2020) demonstrated workers experiencing mental health problems experience internalized stigma and shame regarding their mental health, which may exacerbate their distress and symptomology. This internalized stigma was found to be a deterring factor in pursuing mental health services, such as attending a mental health clinic for fear of outing their mental health status by entering the facility. A survey of construction workers in the United Kingdom found that 68.2% of workers feel comfortable talking about physical health issues or concerns, but only 52.4% do not feel comfortable discussing mental health concerns (Campbell and Gunning, 2020). The stigma in the U.S. construction industry, particularly towards MH, remains a key factor towards workers seeking treatment.

The suicide rate for all occupations in the United States was reported as 27.4 per 100,000 male workers and 7.7 per 100,000 female workers (Peterson *et al.,* 2020). Categorizing occupational employment data is imperative to find root issues within the workplace. A Morbidity and Mortality Weekly Report (MMWR), published in January 2020, indicated that the suicide rate among individuals in the 'Construction and Extraction occupation' was 49.4 per 100,000 male workers and 25.5 per 100,000 female workers (Peterson *et al.,* 2020). The data in the report was based on data collected from 32 out of 50 states in 2016. A staggering reality: individuals employed in these occupations have a considerably higher risk of suicide. Furthermore, for

individuals employed in Architecture, Engineering, and Construction Management occupations, which are closely related to the Construction and Extraction occupations, the rate is even higher. A study by Greenwood (2017) found construction workers are six times more likely to die from suicide than from a fall from height in the United States.

The U.S. demographic of the construction industry is currently largely white, middle-aged males without a college education. This demographic population is a 'high risk of suicide' group according to current research. Numerous articles were reviewed regarding the stigma associated with mental health and mental health treatment among various demographic populations (Kotera *et al.,* 2019; Nwaogu *et al.,* 2019). Consider also that the construction industry consists of significant U.S. military veterans (Briggs *et al.,* 2020), whose suicide rate is 1.5 time greater than non-veterans (Wolfe-Clark and Bryan, 2017). Compounding risk factors attributed to demographics are multiple other contributing risk factors resulting in a high number of suicides in the construction industry. These include a stoic attitude towards mental health, time spent away from home, access to lethal means, chronic physical pain resulting in drug use/self-medicating, and higher than average alcohol dependency (Stone *et al.,* 2018). These factors all contribute to a suicide rate in the construction industry that is five times greater than the workplace fatality rate and four times greater than the suicide rate of the general population.

The high rate of suicide in the construction industry is not limited to the United States. Countries such as Australia, New Zealand, and the United Kingdom also report significant increases in construction worker suicides and, in many cases, lead the world in suicide prevention programs. An Australian construction worker is six times more likely to die from suicide than an accident at work. Young Australian male workers are well over two times more likely to take their own lives than other young Australian men (Kinchin and Doran, 2017). There has been an increase in mental health and suicide prevention programs specific to the construction industry in the last five years or so in the United States. On World Suicide Prevention Day in 2015, the Carson J Spencer Foundation in partnership with the National Action Alliance for Suicide Prevention and RK (a Denver, Colorado-based construction company) published the first Construction Industry Blueprint: Suicide Prevention in the Workplace. The Construction Financial Management Association (CFMA) in Phoenix, Arizona hosted the first construction industry suicide prevention regional summit in the United States in 2016. While endeavours to improve mental health in the construction industry is noted, the United States is in its infancy in this work and the lives of many are at stake.

## METHODOLOGY

This paper first analysed the literature to investigate the existing state of worker mental health and suicide prevention programs within the United States construction industry. A thorough review of the high-risk suicide factors for construction workers and current mental health and suicide prevention programs instituted in recent years was utilized for survey development.

After completion of the literature review, the data collection phase commenced. A survey was employed to collect data from construction industry professionals relative to the prevalence and effectiveness of mental health and suicide prevention programs within the construction industry in the United States. The survey questionnaire was divided into the following blocks for analysis: (1) General Information and

Demographics, (2) Mental Health and Suicide Awareness, (3) Effectiveness of Mental Health and Suicide Awareness/Prevention Programs, and (4) Impact of Mental Health and Suicide in the Industry. The survey sought to determine awareness of mental health and suicide in the construction industry, if organizations have instituted specific mental health and suicide awareness/prevention programs, and how they promote such programs to field employees. The survey was distributed to approximately 1,500 contractors, professional organizations, labour unions, and trade organizations throughout the United States via Qualtrics survey software.

## RESULTS AND ANALYSIS

### Response Rate and Demographics

A total of 103 respondents completed the survey. The survey respondents were 72% male and 28% female. Additionally, 49% of survey respondents worked for a large business (greater than $50M in annual revenue) while 51% worked for a small business (less than $50M in annual revenue). Table 1 contains further demographic results from the respondents.

*Table: Survey respondents' demographic distribution by organization and position in industry*

| Organization Affiliation | % | Role / Position in Industry | % |
|---|---|---|---|
| Labor Union/ Trade Organization | 14% | Management & Administrative | 78% |
| Professional Organization | 12% | Safety Professional | 13% |
| Subcontractor | 19% | Field employee | 6% |
| General Contractor/ Const. Manger | 53% | Other | 3% |
| Other | 2% | | |

### Awareness of the Crisis of Mental Health and Suicide

Questions were formulated on a Likert scale for the survey questions regarding awareness of mental health and suicide as problems in the construction industry. The response options ranged from 1 - Strongly Disagree to 7-Strongly Agree. For MH awareness, the male respondents averaged at 5.8, whereas female respondents averaged at 6.1. For suicide awareness, male respondents averaged at 5.1, while female respondents were averaged at 5.6. When comparing the data of awareness based on gender, the data indicated female respondents show stronger agreement that both mental health (0.3 delta) and suicide (0.5 delta) are problems in the construction industry than males.

When studying the level of agreement that mental health and suicide are critical problems facing the construction industry based on the position in industry, it was not surprising that Safety Professionals demonstrated the strongest awareness level (6.2 / 5.5). Fig 1 illustrates the results of the variation in agreement of these problems based on the position in the organization the respondent identified. The lowest awareness of suicide as a problem was among field employees.

Survey respondents were asked to rank five industries in order from highest suicide rate to lowest suicide rate. The data indicates that the survey respondents accurately identified construction as having one of second highest suicide rates when compared to other industries.

The final question regarding mental health and suicide awareness asked the respondents to rank the risk factors inherent to the construction industry on a scale of

0 (no impact) to 10 (high impact) with respect to their impact on construction worker suicide (Fig 2).

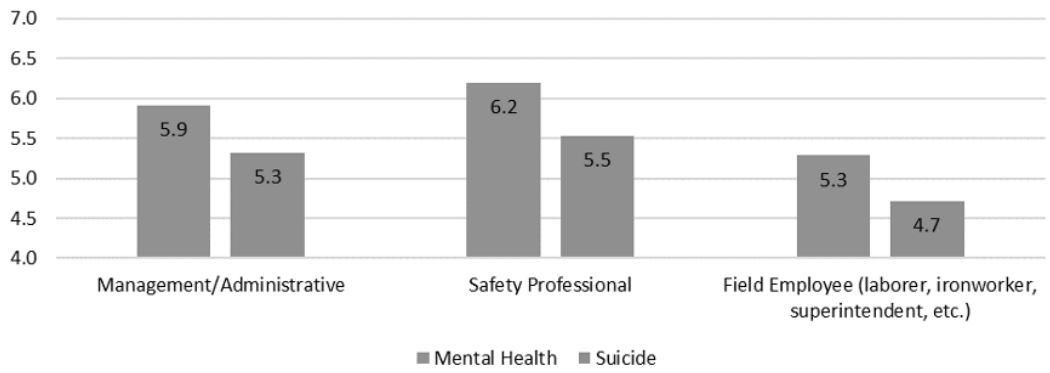


*Fig 1: Level of agreement of per respondent's role in the organization*

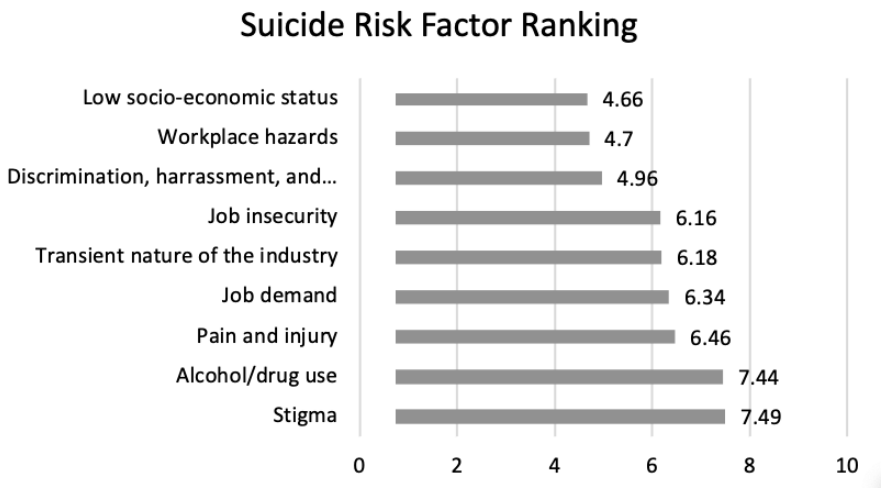


*Fig 2: Suicide risk factor ranking per respondents*

The top four suicide risk factors as identified by the survey respondents are Stigma (7.49), Alcohol/Drug Abuse (7.44), Pain and Injury (6.46), and Job Demand (6.34). Previous research identifies these factors as the leading risk factors for suicide indicating that the survey respondents are aware of the leading risk factors in the construction industry (Bachman, 2018).

**Mental Health and Suicide Awareness/Prevention Programs**

Survey respondents were asked if their organization offers mental health treatment, including alcohol/drug abuse programs, for field employees. Possible answer choices were: 1) Yes, as part of their health care program, 2) Yes, as part of a separate Employee Assistance Program (EAP), 3) No, our field employees are offered these programs through their labour/trade union, and 4) No, we do not offer these programs to our field employees. The responses were bucketed into a Yes and No bucket to evaluate the data.

As illustrated in Fig 3, General Contractors, Professional Organizations, and Labour/Trade Organizations offer these programs often. Interestingly, the organizations classified as Subcontractors or Specialty Contractors only offer these programs in less than half of the organizations.

In this study, small businesses were classified in alignment with the United States Small and Midsize Business (SMB) definition as an organization with an annual revenue less than $50M, and large businesses were classified as annual revenue more than $50M. Data regarding the mental health and suicide awareness/prevention programs offered by organization when analysed by size in revenue (Fig 4) revealed that larger organizations offer more mental health and suicide awareness/prevention programs when compared to smaller organizations.

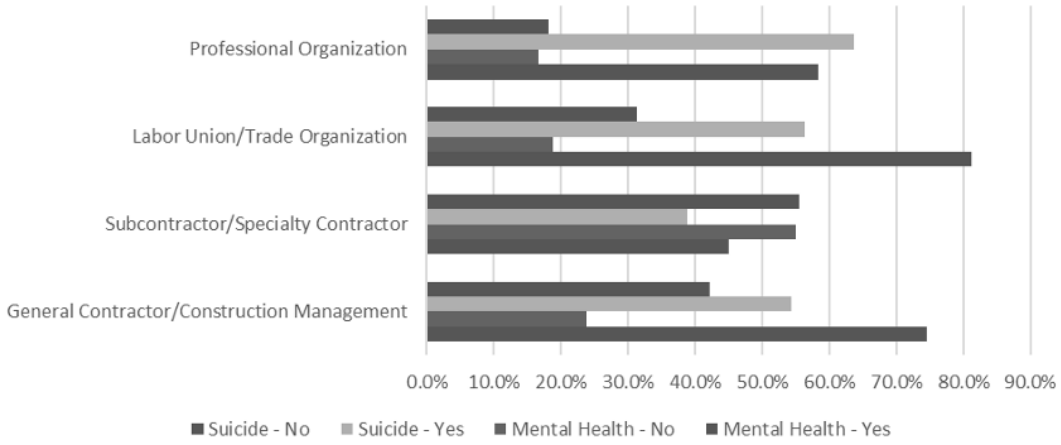


*Fig 3: Offered programs by organization type*

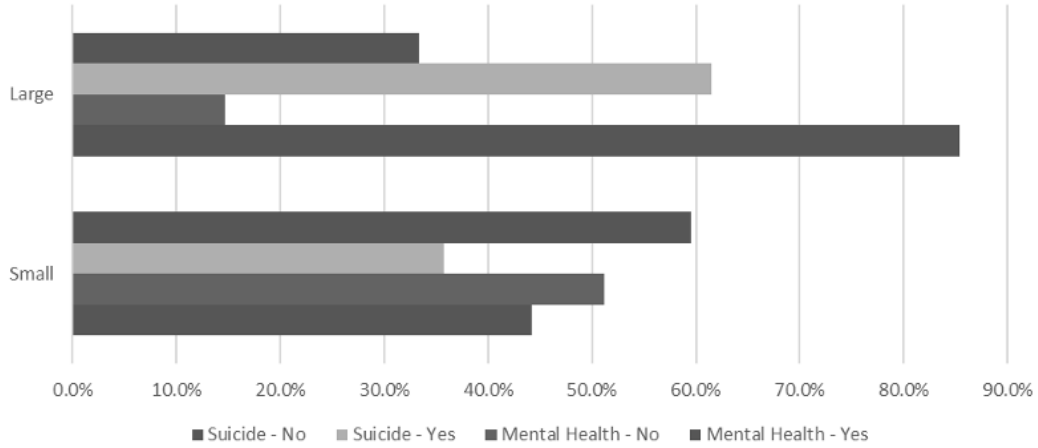


*Fig 4: Offered programs by organization revenue size*

Survey respondents were asked if they considered the mental health and suicide awareness/prevention programs offered by their organization effective. Respondents rated the effectiveness of their organization's programs on a Likert scale of 0 - Not Effective to 4 - Extremely Effective. The rate of effectiveness was averaged at 2.3 amongst all respondents. Subcontractors reported the lowest effectiveness rate at 1.8 out of 4. Field employees rated the effectiveness of their organization's suicide awareness/prevention programs lower than any other role (see Table 1 for role types in this study).

How organizations promote the use of their mental health and suicide awareness/prevention programs (Table 2) was also important in understanding effectiveness. Survey respondents were asked to select the methods their organization uses to promote the use of these programs.

Toolbox talks and jobsite posters/materials were by far the most popular method used to promote mental health and suicide awareness/prevention programs to field employees. Over 50% of organizations utilize these methods. Interestingly, less than 1 in 5 organizations use mandatory training for field employees as a method to increase awareness.

*Table 2. Promotional methods for mental health awareness and suicide prevention*

| Mental Health | % | Suicide | % |
|---|---|---|---|
| Jobsite materials | 27% | Jobsite materials | 28% |
| Toolbox talks (safety meetings) | 30% | Toolbox talks (safety meetings) | 31% |
| Email/ Text | 20% | Email/ Text | 21% |
| Mandatory Training | 13% | Mandatory Training | 17% |
| Other | 10% | Other | 3% |

## CONCLUSIONS

Measuring general awareness with respect to mental health and suicide prevention in the construction industry was captured through this study. Female respondents showed a higher awareness to the issue compared to males, which aligned with the findings of Kotera *et al.,* (2019) but demonstrates issues due to the high male population in the U.S. construction industry currently. Both male and female respondents correctly indicated that the construction industry ranked second of all industries with respect to suicide rate. However, correctly stating the rank of the industry compared to other industries may not equate to knowing the actual number of suicides within the industry. This was not addressed in this research, and further research towards understanding if people within the industry know the actual numbers of suicides could be beneficial. The survey respondents also demonstrated awareness of the risk factors affecting the mental health and suicide of construction workers (Stone *et al.,* 2018) which indicates one promising indicator as a result of this study. Those top four risk factors identified were Stigma, Alcohol/Drug Abuse, Pain and Injury, and Job Demand. This illustrates study participants are aware of the top risk factors facing the industry.

Field employees showed the lowest awareness of mental health issues and suicide within the construction industry. Overwhelmingly, jobsite posters/materials and toolbox talks are the preferred method to raise awareness of mental health and suicide to construction field employees. Increasing mandatory training for field employees may raise awareness and serve as a positive intervention tool to combat the prevalence of suicide and mental illness in the U.S. construction industry. Currently, only 12% of organizations provide mental health mandatory training and 17% provide suicide awareness/prevention mandatory training.

The effectiveness and adequacy of mental health and suicide awareness/prevention programs was rated higher at U.S. construction organizations with higher revenue. This suggests that more efforts need to be placed at construction organizations with lower revenue. Furthermore, subcontractors and specialty contractors rated both effectiveness and adequacy of their programs lower than all other organization types. Additional efforts to establish programs at subcontractor and specialty contractor organizations would likely increase effectiveness and adequacy. Safety professionals rated mental health and suicide awareness/prevention program adequacies lower than all other roles/positions within organizations. As safety professionals are typically the individuals responsible for instituting these programs in their organization, it is

concerning that they feel the programs are not fully adequate to deal with the issues. Additional resources provided to safety professionals would likely improve adequacy of these programs.

Higher revenue organizations agree more than lower revenue firms regarding the benefits of such efforts outweighing the expense costs. This may be related to the resources available to higher revenue organizations to institute mental health and suicide prevention programs to educate and raise greater awareness. Not surprisingly, field employees and labor/trade organizations scored higher than other roles and organizations when asked about the benefits outweighing the costs. Field employees and the labor/trade organizations that represent those positions are most at risk with regards to mental health issues and suicide, and it is understandable that they would see the benefits of instituting these programs, regardless of the cost. Additional research is needed to quantitatively determine the benefits of instituting programs versus the cost of programs. No previous studies of this nature, specific to the U.S. construction industry, were found during the literature review. As more data on industry-specific suicides becomes available from the CDC, an assessment on the cost-benefit of mental health and suicide awareness/prevention programs should be conducted.

The research was limited by the low volume of survey responses. While over 1500 survey requests were distributed, only 103 (6.8%) responses were received. The research indicates that more efforts are needed to raise awareness of mental health and suicide in the construction industry, especially to subcontractor/specialty contractor organizations and lower revenue construction companies. Existing efforts to raise awareness may not be as effective at increasing awareness as believed. Industry organizations should consider jobsite engagement programs that are currently in use in other countries to promote mental health and suicide awareness/prevention. Further research should be considered when updated data on industry suicides is released from the CDC. The research should compare future data to the 2016 industry data and again look at ongoing awareness and effectiveness of existing programs.

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# A COMPARISON OF ACCIDENT CAUSATION MODELS (ACMS) AND MACHINE LEARNING (ML) FOR APPLIED ANALYSIS WITHIN ACCIDENT REPORTS

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Machine learning (ML)-supported accident prediction models appear as an alternative to the much older accident causation models (ACMs). ACMs represent a simplification of accident processes and resulted loss and play an important role in accident investigations and identifying potential risk factors. This effort investigates ACMs and ML results of accident reports analysis in relation to each other and aims at comparing the latter based on their level of causes, the relationship between causes, and the predictability of severity. A framework of understanding of these main processes and their challenges is provided, which is also used as a methodological framework for the comparison. The comparison is based on a desk study of literature and material on the two types of models. ACMs are different in typology, levels of causes, and the logic through which the analysis of the events that have taken place is conducted. Many ML prediction models in construction not only provide predictions but also result into structures of features which work as predictors, e.g., decision trees. ACMs and ML are different in the task they perform. ML models in the literature are focused on predicting the severity of an event while missing the identification of prevention measures. ACMs focus on the occurrence of unwanted events and lack the ranking of important features. Finally, ML analysis of accident reports need ACMs as a theory to shift focus to risks instead of severity, while interpretable ML algorithms (e.g., RF) appear more capable of complex representations of contributing factors. An unsolved issue is the random element involved in most accident processes.

Keywords: accident causation model; machine learning; occupational accident

## INTRODUCTION

Recently, there has been a noticeable increase in the number of publications about the topic of ML in the construction industry, including occupational accidents and safety during construction (Xu *et al.,* 2021), and structural health monitoring and job safety management (Hou *et al.,* 2021). This trend was also observed in publications on applied ML for the analysis of archival data and surveys of work-related accidents (Sarkar and Maiti 2020). On the other hand, accident causation models have guided analysis and learning from accidents for many years. ACMs play an essential role in

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identifying causes and processes in which events take place (Kjellen and Albrechtsen 2017, Fu *et al.,* 2020).

ML and ACMs have been equally criticized. ML was found to be shortcoming in interpretability, data quality concerns, the need for concrete use cases and the lack of required integration with domain and expert knowledge (Vallmuur 2015, Bilal *et al.,* 2016), as well as generalizability (Xu *et al.,* 2021, Sarkar and Maiti 2020). ACMs are different in typology and levels of analysis and have been questioned in terms of their components, accident path representation and their applicability (Fu *et al.,* 2020).

So far, the literature on ML applications within the domain of accidents reports has been focused on analysing and experimenting with algorithms without the perspective of ACMs as a theorical lens. The role of the theory of ACMs is not being adequately addressed in the current literature. The structure and components of ACMs provide attention to the important factors for prevention purposes and guide the process of ML analysis and use cases. Similarly, ACMs have not been examined in relation to the contribution of ML applications in understanding accidents. The availability of large volumes of data has the potential of not only unfolding causes behind accidents but also contributing to the development of added value to ACMs. Therefore, this research will investigate the role of ACMs as a theoretical framework for the ML results of analysed reported accidents in the construction industry, as well as what can be learned about ACMs from ML. We conduct a comparative desk study of the literature covering ML application to accident reports in the construction industry and ACMs in terms of their level of causes, the relationship between causes, and the predictability of severity. This will contribute to conceptualizing ML models in the lens of ACMs.

# METHOD

The article is based on a desk study of the literature of applied ML in the analysis of construction accident reports and ACMs. The literature review and discussion were done in a synthesized problematization method (Alvesson and Sandberg 2011). The ML models are based on a literature review and the systemization of the purpose of the ML, the included features, and the ranking of important factors. ML has been applied for the prediction of severity, the classification of accident causes, and the extraction of information from textual data. The themes are presented for an in-depth analysis. ACMs were selected based on crossing the models which were reviewed by Kjellen and Albrechtsen (2017), Fu *et al.,* (2020) and Woolley *et al.,* (2019). Three models were selected, based on the types of ACMs and their common application in the construction industry.

## Accident Causation Models

ACMs are simplified representations of the process in which risk result in accidents and loss (Kjellen and Albrechtsen 2017). ACMs have been used in accident investigation and analysis to uncover how and why accidents happen. In the construction industry and in occupational accidents contexts, there are a few models that have been commonly applied. Woolley *et al.,* (2019) reviewed the most common accident causation theories in the building industry. The review revealed that linear models are more dominantly used in the construction context when compared to nonlinear system-based models. The linear models included ones such as the Domino Model. The models that the Woolley *et al.,* (2019) refer to as complex linear and

organizational factors-related, include the Swiss Cheese Model (SCM), and the Systems Model of Causation.

Hopkins (2014) reviewed the paradox of major accident investigations. The author distinguished between two meanings of accident causes: sufficient causes and necessary ones. Necessary cause or the but-for one is the factor that without having existed, an accident would not have happened. Moreover, Hopkins (2014) illustrated that most ACMs are formulated within this logic (such as the SCM) and that the but-for logic works best with technical factors, but it becomes harder to assign a necessary cause with organizational distant factors because they are subject to expert judgement. Woolley *et al.,* (2019) also found that distant regulatory and association's related factors were not present in the construction context. Although accident analysis is done for the purpose of learning, they do not seem to be designed to make recommendation for future accident prevention, nor do they identify relationships between company, management, and staff levels as higher levels of causes. This article will focus on the SCM as a linear model, and the Bow-Tie model as energy-based model (Fu *et al.,* 2020).

**The Swiss Cheese Model (SCM)**

SCM (Reason 1997) is an energy-based model, according to the classification of Kjellen and Albrechtsen (2017), but categorized as a linear model in the review by Fu *et al.,* (2020). A linear model is one that consists of stages or levels of causes and corresponds to a chain of logical sequence that can be clearly examined. The paradigm of SCM (see Fig 1) explains accidents by giving an understanding of event occurrence through barrier failures all the way, starting from organizational factors to unsafe acts. Errors and violations function as active failures at the end of the system, while the latent conditions are the ones that exist but are undetected because the barrier had not been activated. The logic of the SCM is that accidents happen when a combination failure exists on all levels together at once. If a barrier was active at one of the levels, the accident could have been prevented. The first level starts with top level decision makers, followed by designers and planners, line management, operations and maintenance, and local faults (Fu *et al.,* 2020).

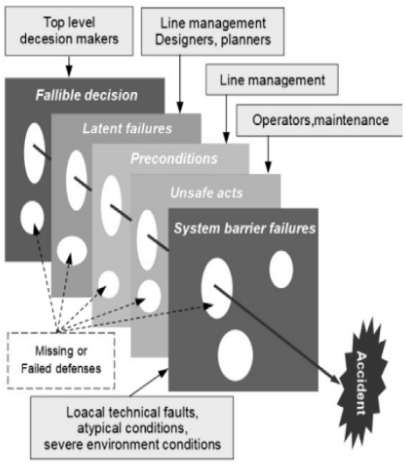


*Fig 1: SCM, Fu et al., (2020)*

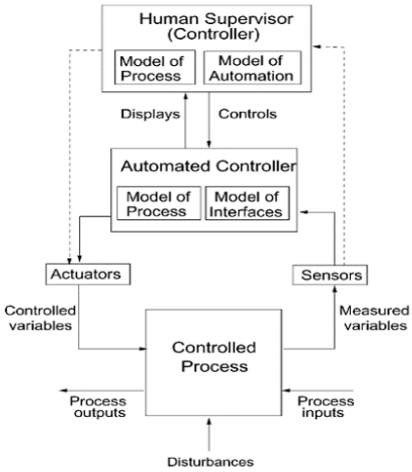


*Fig 2: STAMP, Fu et al., (2020)*

**Systems-Theoretic Accident Model and Processes (STAMP)**

The STAMP model (see Fig 2) is known to belong to the system-based causation models (Kjellen and Albrechtsen 2017), and is categorized as nonlinear (Fu *et al.,*

2020). This model's paradigm views accidents as being caused by dynamic equilibrium of system control that exist within an adaptive socio-technical system (Leveson 2004). The model consists of three key components (constrains, control loops and process models, and socio-technical levels of control) (Leveson 2004). Constraints are enforced throughout the interactions of the hierarchy of the system's operations and travel downwards for operation control. Moreover, the model is characterized by feedback loops that travel upward through the levels of the hierarchy of the system. The levels of system included are inspired by Rasmussen's (1997) socio-technical system models but with adding a parallel side that is concerned with system development beside the system operation. Accidents in the STAMP model are caused by failure at one of the main components of the models: either safety constraints are not adequately enforced (which might be influenced by a lack of proper control and process plan, or inadequate coordination), or accidents can be caused by inadequate control execution or feedback information (Fu *et al.,* 2020).

**The BOW-Tie Model**

The BOW-Tie model (see Fig 3) is a practical analysis model. The model analysis starts by identifying a hazard that exists in the organization or the surrounding environment. The hazard is in central connection to the second component of the model, which is the top event that is at the centre of the BOW-Tie. The model is built around this top event as threats and consequences should be identified. Accordingly, prevention barriers are then identified on the left side of the top event to combat their corresponding threats. In the same fashion, recovery barriers are placed after the top event. Threats are defined as whatever causes the top event to occur, and the more elaborate the analysis of threats, the more consequences are taken in consideration. The model suggests that barriers prevent the threat from causing the top event to happen, or in the case of that happening indeed, the consequences could still be prevented (Fu *et al.,* 2020). Interestingly, the model does not assume that prevention barriers always function, but there might be a failure that is caused by an escalation factor.

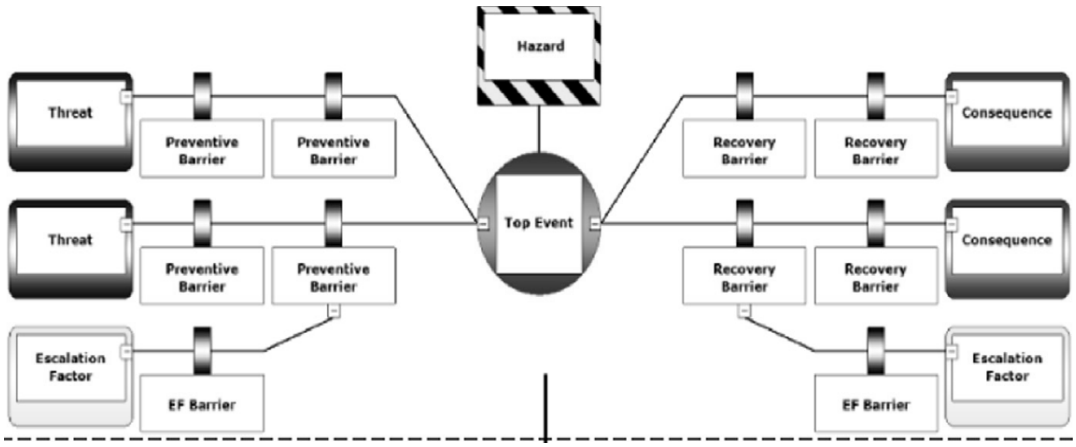


*Fig 3: BOW-Tie, Fu et al., (2020)*

The three chosen models represent a variety of common models in accident causation and understanding. The SCM is levelled and assumes failure on all levels to cause the accident. The BOW-Tie model assumes failure to prevent a particular threat to cause the accident. The STAMP model is more procedural and assumes that safety constraints and feedback loops are needed to be enforced to prevent hazardous events.

## Machine Learning and Accident Data Analysis

The purposes of ML analysis within the domain of accident reports can (based on our conception) be divided in two different categories: A classification of accident severity, and a classification of accident type and information retrieval. The predictive ML models in both categories are further analysed below in terms of the purpose of the model, algorithms they utilized, the factors that were involved in the ML modelling, and their importance ranking compared to the output variables. The results of the review are summarily presented in Table 1.

## Classification of Accident Severity

*ML algorithms*

Shrestha *et al.,* (2020), analysed the accident reports using ML as a method for the classification of severity and accident-related features. The multiclass support vector machines (SVM) and the results were organized into four different categories (upstream precursors, energy source, accident type and injury severity) (Shrestha *et al.,* 2020). Zhu *et al.,* (2021) used accident investigations which were organized into six subsystems, 16 factors, and 39 subfactors (see Table 1). Ayhan and Tokdemir (2019) used artificial neural networks (ANNs) and conventional multiple regression for accident outcome prediction using a total of 149 attributes which were discretised into the main causes' categories (see Table 1). The accident outcomes were categorized into 7 different classes (namely, At Risk Behaviour, Near Miss, The Incident with Partial Failure, The Incident requiring First Aid, The Incident requiring Medical Intervention, Lost Workday Cases, Fatalities) (Ayhan and Tokdemir 2019).

In terms of models' accuracy, considerable differences were found between training and testing accuracy; the testing accuracy dropped by 50% for the fatality class (Ayhan and Tokdemir 2019). Zhu et al.'s (2021) best accuracy results were achieved by the AutoML algorithm, with 70% accuracy. However, a misclassification problem was observed when the algorithm mistakenly classifies a large accident as a minor one Zhu et al.'s (2021). Choi *et al.,* (2020) used the value of the Area Under the Receiver Operating Characteristic Curve (AUROCC) metric; the RF achieved 0.9198 which is considered as excellent, as the ideal value of AUROCC is 1.

*Factors and feature ranking*

Shrestha *et al.,* (2020) coupled accident causes with accident severity. For example, pre-existing medical conditions were found to result in the most fatalities, although they happen in lower frequencies. Another approach was to rank features according to the level of importance and in relation to accident consequence severity, by using the Pearson correlation coefficient, Random Forest (RF) and principle component analysis (PCA) (Zhu *et al.,* 2021). Feature ranking resulted in three different rankings in each of the latter methods, however, the common features are the type of accident (i.e., fall, electrocution, etc), Accident reporting and handling, Training and examination, and Safety culture (Zhu *et al.,* 2021). Choi *et al.,* (2020)'s RF ranking of factors showed that the month in which accidents happen is the highest-ranking factor, followed by the employment size, age, day, and service length. However, the employment size was observed to be highly ranked in all algorithms. The latter factor was showing to be correlated to high accident rate in smaller projects while the level of fatality being increased in the project over 2000 employees (Choi *et al.,* 2020). Ayhan's and Tokdemir's (2019) choice of algorithm did not allow for feature importance demonstration. The prediction results of ANNs are less explainable compared to other algorithms that indicate feature importance. However, the conventional multiple

regression (which is a more interpretable algorithm) was not successful compared to the ANNs, based on R-square and mean percentage errors as performance criteria.

## Classification of Accident Causes and Information Retrieval

### *ML algorithms*

Zhang *et al.,* (2019) used single and ensemble classification algorithms for the classification of 11 accident causes; the causes were extracted from accident reports by a natural language processing (NLP) algorithm. In addition, the objects mentioned in the passages of reported text were also extracted. However, it was found that the performance of the NLP was not satisfactory (Zhang *et al.,* 2019). Another approach was to classify accident causes in combination with relevance to accident severity (Zhong *et al.,* 2020, Kim and Chi 2019). Kim and Chi (2019) exhibited a prototype for extracting the cause of an accident (hazard object), location (hazard position), when the accident occurred (work process) and the result (accident result). They also identified the semantic roles and rules for the accident components in relation to the accident result and used the conditional random field (CRF) classification algorithm (Kim and Chi 2019). Kim and Chi (2019) exemplified their prototype by using a tower crane fall query. The information retrieval prototype was represented in terms of a statistical analysis of extracted information from the accident textual reports. Accident categories have also been analysed based on their causes and merged with weather related data and classified into four accident categories (Falls from height, Collision by objects, Rollover, Falling objects), (Kang and Ryu 2019).

*Table 1: Summary of ML models, data source, algorithms, and purpose*

| Reference | Data source | Algorithms | Purpose |
|---|---|---|---|
| Shrestha *et al.,* (2020) | 1200 accident reports | SVM | Classification (severity/accident type/energy source/ Upstream Measures) |
| Zhu *et al.,* (2021) | 571 investigation reports | LR, DT, RF, SVM, NB, KNN, MLP, AutoML | Predict severity of accident |
| Ayhan and Tokdemir (2019) | 17285 accident reports/ Construction sites | ANNs, Conventional multiple regression | Prediction of accident outcome |
| Choi *et al.,* (2020) | 137323 injuries and 2846 deaths | RF, AdaBoost, LR, DT | Predict likelihood of fatality |
| Zhong *et al.,* (2020) | 2000 accident reports | CNN, SVM, NB, KNN, data mining | Classification of accident type/Severity and causes |
| Zhang *et al.,* 2019 | 1000 accident reports | DT, KNN, NB, SVM, LR, Ensemble | Classify accident categories |
| Kim and Chi (2019) | 4263 accident reports | CRF | Information retrieval |
| Kang and Ryu, (2019) | 6374 accident investigation | RF | Classification of accident categories[2] |

[1] *Logistic regression (LR), Naïve Bayesian (NB), k-nearest neighbour (KNN), multilayer perceptron (MLP), Adaptive Boosting (AdaBoost)*

### *Factors and feature ranking*

The combination of a Convolutional Neural Network (CNN) and data mining provided deeper insights (see Table 1). Latent Dirichlet Allocation (LDA) and Word Co-occurrence Networks (WCN) data mining methods were used to identify correlations between retrieved causal variables and to visualize the information (Zhong *et al.,* 2020). The data mining methods provided the organization of the results as a main topic (ex. collapse of an object) and the corresponding actions (ex.

Collapse of object, Falls Work, Protect) and objects (ex. Subway, Construction, Fracture, Equipment, Scaffold, Crane). Furthermore, the WCN method showed insights into accidents and severity, for example scaffolding accidents are infrequent but tend to be sever and likely to result in a fatality (Zhong *et al.,* 2020).

The application of RF also revealed correlations thanks to the feature ranking possibilities (Kang and Ryu 2019). The assailing materials, original-cause materials, unsafe behaviours, protective equipment, unsafe states, work contents, and diagnosis names were ranked highest on the scale of feature importance, whereas weather related variables were not found influential in the classification of accident types. Kang and Ryu (2019) further examined feature importance for every accident type. For example, work activities before falling were installation or maintenance of mechanical equipment and facilities but most fall accidents were caused by workers not wearing safety protective equipment.

## ANALYSIS

This research aimed at investigating the role of ACMs in the application of ML in the field of reported construction occupational accidents. At the same time, identify the relevant gained learnings from ML in relation to ACMs. The BOW-Tie model (see Fig 3) is useful in the analysis of threats, hazards, consequences, the top event and the prevention barrier. By comparing the BOW-tie typology to the ML model components, it can be observed that according to Shrestha et al.'s (2020) categorization, upstream precursors can be relative to threats while energy type to hazards, severity to the consequences and type of accident to the top event. Similarly, some components of the BOW-Tie model can be found in Zhang *et al.,* (2019) and Kang and Ryu (2019). Accident type can be categorized as a threat or a hazard. Zhong *et al.,* (2020) and Kim and Chi (2019) presented a linkage between accident types and the accident consequences. Furthermore, the application of data mining resulted in finding and visualising the relationships between causal variables (Zhong *et al.,* 2020). The main topic in Zhong et al.'s (2020) analysis can be considered like the typology of threats in the BOW-Tie model and the corresponding actions to the top event, and the objects (such as the scaffolding) like hazards. The latter features were linked to the consequences which is one step closer to the exhibited representation of the link between threats and consequences in the BOW-Tie model. Kim and Chi (2019) illustrated a more explicit setup for accidents' features, thanks to the semantic roles and rules of accident components. Simultaneously, it can be found that some factors and functions in the ML model are different from the structure of components and relationships within the BOW-Tie model. Zhu *et al.,* (2021) for example identified causes into categories related to the organization, safety training and contract management while the BOW-Tie model encompasses the immediate threats. Although the ML representation of causes and their relationships can identify a link to between the hazard and the consequence (Shrestha *et al.,* 2020, Zhu *et al.,* 2021, Choi *et al.,* 2020, Zhong *et al.,* 2020, Kang and Ryu 2019), which is similar to the structure of the BOW-Tie model. But a major difference can be found in the ranking of features importance that can only be found in the ML representation.

The SCM explains accidents by the concept of barrier failure that exists in multiple levels of the organization and influences human error down the chain. The SCM shows to be comprised of higher levels of causation compared to the ML illustrations of accident causes. The factors related to machinery, workspace, energy sources and weather (Shrestha *et al.,* 2020, Zhong *et al.,* 2020, Zhang *et al.,* 2019, Kim and Chi

2019, Kang and Ryu 2019) all exist within the first layer of the SCM (see Fig 1). Attributes of human factors, risky behaviour, occupation (Kang and Ryu, 2019, Choi *et al.,* 2020, Ayhan and Tokdemir 2019) can be categorized into the second layer of the SCM. Only one effort in the reviewed literature (Zhu *et al.,* 2021) has used variables related to the upper levels of the SCM. The contract management variable (Zhu *et al.,* 2021) belongs to the top-level decision-making layer. However, the results feature ranking showed that the type of accident, Accident reporting and handling, Training and examination, and Safety culture are the most influential factor in accident severity predictability. In terms of the mechanism in which accidents occur in the SCM logic, failure should happen on all the levels at once. The presented ML literature attempts to couple the accident-related features with the severity in some type of a direct relationship (Shrestha *et al.,* 2020, Zhu *et al.,* 2021, Choi *et al.,* 2020). However, the nature of this relationship remains ambiguous. The RF algorithm showed the biggest potential in understanding relationships between ranked features, but this will need visualization of the ML model structure and the features that result from using the algorithm. Moreover, the use of data mining methods (Zhong *et al.,* 2020) seems promising in visualizing relationships between causal variables, but the factors used in Zhong *et al.,* (2020) only cover the bottom level of causation, which does not reveal much about the SCM.

There are two major differences between the analysed ML literature and the SCM and the BOW-Tie. Both ACMs have defence barrier activation as a requirement for prevention. Secondly, a common feature in ACMs is that they do not differentiate the consequence of accident severity, but only focus on the occurrence of an accident. It is evident that all ML models do not consider neither the prevention barrier nor the barrier failure. Shortcomings in identifying prevention is not necessarily originating from ML but it could have been noticed if ACMs were used as a framework of the data analysis. It has been acknowledged that accident investigations might skip the preventive recommendations (Hopkins 2014). Suggesting measures that are further from the accident's technical circumstances becomes subjective and lacks concrete evidence - although Hopkins (2014) suggested recommendations can be reasonably made, even in the absence of evidence going beyond the particular case. This seems problematic because the consistency of the single report is then maybe compromised.

ACMs assume and promote severity as a stochastic element and impossible to be predicted. On the contrary to the reporting schemes that allow for reporting for the level of severity. Industrial reports sometimes encourage to report lost days which can have an impact on what the company reports. This tendency to focus on severity is reflected in the ML examples reviewed in this article (Shrestha *et al.,* 2020, Zhu *et al.,* 2021, Choi *et al.,* 2020, Ayhan and Tokdemir 2019). Although the ML literature claims success in predictions but the internal validity of 63% and 70% seems arbitrary and needs further proof of prediction success. Therefore, what should be focused on in the ML application is to find alternatives to severity classifications such as the modelling of risks, learning more about the prevention process, and most importantly, to prevent the accident from happening foremost by adopting the paradigms of ACMs.

ACMs had been constantly reviewed and more causation layers were introduced. More remote levels of causes which are further from the accident environment (e.g., regulations and governmental causes such in the STAMP model (see Fig 2)). The STAMP model is designed into feedback loops and constrains. Although Zhu *et al.,* (2021) featured higher levels of causation but the levels of causation of the STAMP model extend back to governmental and regulatory levels. In the construction

industry, the STAMP model had not been detected (Woolley *et al.,* 2019). This might be due to that system thinking was not used in accident investigations and causation analysis. Furthermore, system models are diverse and lack the conceptual unity that would allow their use in qualitative accident predictions (Grant *et al.,* 2018). The causes of accidents in the STAMP model are procedural and they seem applicable since the model component are identifiable functions in almost every work situation. But the latter miss the definitions of simple measurement and a benchmark of comparison, especially for the personnel doing accident investigation.

## CONCLUSIONS

By the review of ML and ACMs in relation to each other, it can be found that ML analysis of accident reports can learn from the components of ACMs to identify prevention measures. For further impact and concrete use cases, ML development needs to be guided by ACMs. Most importantly, the prevention component which is represented in the BOW-Tie and SCM models would have been detected if ACMs were used as a framework. The ML results appear to be more of a descriptive nature and especially useful in the classification of accident type and severity as well as information retrieval. However, a valuable contribution is found in defining the relationships between hazards, accident types and severity. Future ML analysis is suggested to be more focused towards the mapping of risks rather than classification of accident types and severity. The adaptation of ACMs such the BOW-Tie model could aid ML models to be developed further from severity and more towards the identification of risk and heir corresponding prevention barriers. Moreover, ACMs can be improved by the ranking of features and visualisation properties offered by data mining and the more explainable ML algorithms such as the RF. This conclusion would also mean that it is better deemed suitable to use more explainable ML algorithms rather than variations of ANNs. Knowledge about the importance of causation levels in ACMs would probably fill the gap of reporting distant factors. The more is known about the relationship of further factors from the construction site, the more these factors will be detectable by reporting personnel. The analysis points to a very important gap in the practice of the reporting of prevention measures, because unless the reporting include suggestions for how an accident can be prevented, less can be learnt from past experiences.

The paper is limited by the types of ACMs which were analysed. ACMs are within a developed field and different models could be analysed in a similar manner. The ML models are analysed in terms of algorithms, factors, and feature ranking only. Future research can highlight an in-depth analysis of the structure of algorithms to be compared with ACMs structure.

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# THE PERCEPTION OF MENTAL HEALTH IN SMALL TO MEDIUM ENTERPRISES IN THE WELSH CONSTRUCTION INDUSTRY

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Mental health poses a significant problem in the UK with 1 in 4 people annually experiencing a mental health condition. Men continue to account for three-quarters of suicide deaths, with construction trade and semi-skilled men presenting with higher-than-average suicide rates. Employers have a positive role to play in improving the nation's mental health and to promote positive mental health within the workplace to improve productivity. Small to Medium Enterprises (SME's) dominate the UK private sector, accounting for 99.9% of the business population; construction is the largest industrial sector in terms of SME numbers. This paper presents an exploratory study investigating the perception of mental health within the small and medium enterprise construction sector in Wales. The paper highlighted that within most SME's there is a workplace culture stigmatizing mental health. There remains a reluctance within the workplace to openly discuss mental health. Efforts need to address the grassroots level to increase awareness and openness. Legislative change is required to further encompass mental health, thereby giving (mental health) parity with physical health in safety law. Furthermore, curriculum changes are needed to embed mental health as part of current trade and related educational provisions.

Keywords: health and safety; mental health; small businesses; well-being

## INTRODUCTION

This paper presents an exploratory study investigating the perception of Mental Health (MH) within the small and medium enterprise (SME) construction sector in Wales. The UK private sector is dominated by SMEs that accounts for 99.9% of the business population. Construction is the largest industrial sector in terms of SME numbers (DBIES, 2018, p.1), with the construction industry in Wales having the largest proportion of SMEs compared to the other home nations; 92.4% compared to 86.7% in the UK (Welsh Government, 2019). MH poses a significant issue in the UK; 1 in 4 people experience a MH related problem annually, highlighting the impact of MH issues on wider society (Mind, 2019). In 2019 the UK suicide statistics surged at a 21-year high, following half a decade of decline, with men continuing to account for three-quarters of suicide deaths (Bulman 2019, ONS 2020). The construction industry was identified as the third most stressed sector in the UK with 82% of workers experiencing stress at some point each week (Farrell 2018). The industry has tight deadlines, low profit margins, hazardous working environments and job insecurity,

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resulting in tradespersons suffering from some of the highest rates of poor MH (Hobden 2019). Kantar (2019) identified in Wales, 2 in 5 people felt uncomfortable talking to an employer about a MH illness. Construction employees are three times more likely to discuss physical illness over MH with their employers. The Construction Industry is an almost perfect example of the difference by which society sees and treats physical and mental health. Due to men's inability to discuss or ask for support in the workplace, there is a pervasive culture of machoism (Turner *et al.,* 2017; Morris *et al.,* 2019; Morris 2019, Nair 2019). Poor MH is especially prevalent among those working at smaller companies as, a "perfect storm" has developed; the combination of stigma, and a belief that adequate support will not be provided if MH issues are raised (Alderson 2018). SMEs are more agile and adaptable than bigger businesses and perhaps better placed to provide a more inclusive and supportive work environment. (McWilliam 2018). They have a moral and ethical responsibility to help employees, by offering support where necessary (PCB 2018, Kelly 2019).

## LITERATURE REVIEW

Mental health is difficult to define; it is generally accepted that mental wellbeing allows a person to manage everyday stresses whilst contributing to work and integrating within wider society (Newman 2017; NHS Wales 2019; WHO 2019).

ONS (2019: 2) demonstrated males aged 45 to 49 years had the highest age-specific suicide rate and rates amongst under 25-year-olds have generally increased in recent years. Research confirms that people with a diagnosed MH problem are at a higher risk of suicidal thoughts and behaviour (Beghi, *et al.,* 2013; Chesney, *et al.,* 2014; Bradvik 2018). Studies into men's mental health show that while some progress has been made, men feel worried or low more regularly than ten years ago and are consequently twice as likely to feel suicidal. (Hafal 2021).

Within the 1.4 million cases for long term work-related ill health reported to the HSE, 660,000 people reported stress, depression, or anxiety as the cause. The dominant causes being high workloads, high pressure and high responsibility. Small and medium-sized businesses perform less well at supporting their employees to report work-related MH (Best 2019). Larger businesses experienced greater rates of reporting, on average 32% higher reporting rates, whereas small businesses experience 22% below average reporting rates on MH. (HSE 2019: 7). According to the Public Attitudes to Mental Illness in Wales survey (Kantar 2019) 2 in 5 feel uncomfortable talking to an employer about a mental health diagnosis.

Rice-Oxley (2019) demonstrated that construction trades are suffering from the highest suicide rate per 100,000 persons, echoing the ONS statistics. Men working in construction are four times more likely to commit suicide than men on average (Chesterfield 2019; Lingwood 2019).

Employers have a duty of care to their employees. This has been described by numerous parties, (Benstead 2019; Clark 2019) and is reinforced by the Health and Safety at Work Act (HASAWA)1974. It places legal duties on employers to ensure, so far as is reasonably practicable the health, safety and welfare at work of all employees. Addressing the MH aspect, the TUC (2019) have interpreted this to include employers addressing any issues that may cause a worker to have suicidal thoughts, including, stress, bullying etc. Fear (2018) described poor MH in the construction industry as 'the silent epidemic'.

Despite the link between MH and suicide, work-related suicide is not reportable under the Reporting of Injuries, Diseases, and Dangerous Occurrences Regulations (RIDDOR) 2013. HSE (2019a) state first aid provision must be 'adequate and appropriate', proposing businesses should consider ways to manage mental ill-health in the workplace. Public Health England have announced an investment of £15 million to train one million people in basic MH 'first aid' skills (Ward, 2019). Healthcare in Wales is devolved to the Welsh Government and this initiative has yet to be replicated in Wales. Currently, there are no legal precedents involving an employer being prosecuted after a worker has taken their own life due to work pressure (TUC 2019). Corr (Administratrix of The Estate of Thomas Corr (Deceased)) v IBC Vehicles Limited (2008) is the only case of civil liability that demonstrated the chain of causation concerning a suicide. The HSE emphasises how current legislation specifically deals with serious failures in the management of physical health and safety, with little consideration to MH. However, with the knowledge of risk to health, comes a legal duty and responsibility to ensure that the work environment does not increase the risk of causing psychiatric harm (Hailstone 2018, Chesterfield 2019). SMEs are slow when it comes to offering support addressing MH first aid needs (Beverly 2019).

The Considerate Constructors Scheme website (CCS 2018) described how there is currently a lack of information and awareness regarding MH at work. The Lighthouse Club and Mates in Mind work collaboratively with the CCS to provide support services to the construction industry. They seek to address the stigma of poor MH and promote positive mental wellbeing across workplaces, focusing on construction. Chesterfield (2019) argues construction workers are at high risk of developing MH problems due to the industry's attitudes towards MH. In small companies, this risk is much greater due to less resources invested in MH training (Beverly, 2019). Aronsson, Gustafsson, and Dallner (2000: 503) describe the concept of 'presenteeism', where workers continue to attend their workplace despite ill health, indicating an under-emphasis of their own well-being. Stevenson and Farmer (2017: 24) suggest that even with conservative assumptions {regarding costings} the costs of presenteeism to employers are huge.

Cost of mental ill-health to employers in the UK is estimated to be between £33 billion and £42 billion a year (Stevenson and Farmer 2017: 24). Occupational ill-health in construction costs employers £848 million annually, with primary causes including stress, manual handling issues and physical demands (PCB 2018). The approximate cost per employee is between £1,205 and £1,560 per annum as a result of MH issues. (Stevenson and Farmer 2017: 24)

There are legal, financial, and moral cases for improving MH in the construction industry. Chesterfield (2019)

## METHODOLOGY

The literature review revealed that MH is a clear and tangible stigma for the construction industry. The secondary data collected was reflective of large companies within industry and highlighted a gap in the research; SME's do not get the same representation.

To understand the perception of SME owners in Wales towards MH, data was gathered through a qualitative approach using semi-structured interviews. This study adopted an interpretivist perspective, examining the attitudes of MH held by those

responsible for SMEs. Taking the themes under investigation, a questionnaire was designed using predetermined open-ended questions, allowed further discussion to emerge from the dialogue between interviewer and interviewee (Bowen 2005).

For this exploratory study, 9 interviews were conducted. The research variables considered valuable when identifying the sample pool were; scale of the company (5 to 75 employees), industrial experience (minimum of 5 years), area of work (South Wales), and the age parameter (24-70 years old) of the interviewees. All the participants manage their own companies within the domestic construction sector. Of equal importance was a willingness to explore the relationship between the employer and employee with regards to MH. Purposive sampling was used to select nine (8 male /1 female) participants who met these criteria.

An information sheet was issued to all participants prior to the interviews taking place. It explained the purpose, so participants had a clear understanding of the field of research. Informed consent was obtained prior to interviews being undertaken. Interviews were conducted face to face using Microsoft Teams, with each interview lasting around 30 - 40 minutes. All interviews were transcribed, then apportioned into sentences or paragraphs, providing practicable elements to identify key thematic pillars. This enabled evidence-based referencing to identify thematic trends embedded in the data, allowing for the determination of consistency against the findings of the literature review.

## FINDINGS

The interviews conducted with the participants discussed their perception of the mental health of their employees and the wider construction industry. The questions addressed issues identified within the literature review and focussed on attitudes and awareness of mental illness, and SMEs duty of care to their employees and support available for mental well-being.

*Perceptions of Mental Health*

Stevenson and Farmer (p29, 2017) reported 'the stigma of disclosing a mental health condition is still a significant barrier to employees seeking support.' The responses supported this stigma was widespread within the construction industry where a 'man-up' culture was prevalent. All participants agreed that there was a stigma surrounding mental health in this male dominated industry. The oldest participant (over 65 yrs) explained 'in his day, people did not have MH issues'. He regarded mental ill-health as blanket to hide behind and believed that bureaucracy (such a legislation) was holding the industry back. This view wasn't widely held by the rest of the participants and could be symptomatic of a social stereotype generated by age and outdated views. However, the other participants identified that machoism was a significant issue with men not wanting to be perceived 'as weak'. This viewpoint supports the under reporting of MH issues in SMEs (Best, 2019), and helps in understanding why male tradesmen and semi-skilled workers pose a higher than average suicide risk (Rice-Oxley, 2019; Chesterfield, 2019; Lingwood,2019).

The majority of those interviewed agreed they did not discuss MH in the workplace, noting their staff were not interested in discussing the topic. They suggested there was a reluctance to talk about MH both from their perspective as well as their staff, as there was a perceived shame attached to struggling with mental health and admitting to needing help. It was suggested that this was largely gender driven, with one

participant stating, 'men are not allowed to talk about MH' and would be 'embarrassed'.

Those participants who had actively discussed MH with their employees or subcontractors were the younger of those interviewed. They noted that discussion was usually generated by an external trigger, for example MH issues on social media. Another participant commented that age was a potential factor in the willingness to discuss MH, and it was noted that the oldest and younger interviewees were most reluctant to discuss mental health issues; the reasons driving this reluctance was very different. The older participant (over 65) had out-dated views reflective of his generation, whilst the younger (24 -30) demonstrated traits of machoism. One participant referred to MH as a 'shadowed subject', referring to the taboos surrounding mental ill-health. The participants aged between 30-50 years were most tolerant and felt that this was because they had a greater experience of life and had seen others within their social and professional network struggle. Only two of the participants demonstrated a positive attitude towards discussing MH, and these were within this age group. However, one of them identified that discussing mental health was a divisive subject, and some of their employees would be uncomfortable to approach it. They felt there was a 'lack of tolerance' surrounding mental health, although believed that attitudes are changing for the better. This was corroborated by another participant in this age group who also thought that over the last 10 years there had been a move towards a more positive mindset.

One participant believed their employees would approach them if they were suffering from mental ill health, however there was nothing to back this up as the subject had not been discussed.

All of those interviewed agreed that the MH stigma needed to be removed. Some suggested that this may be achieved using more prominent campaigns to lessen the barriers for men talking about mental health. Others considered the value of providing opportunities to discuss MH, in both formal and informal settings with work colleagues as well as professionals.

*Mental health provision provided by SMEs*

Half of the SMEs interviewed acknowledged they had no formal support provisions in place for their employees' mental well-being. Only two of the participants said they had offered MH support. This was in the form of informal conversations, rather than a structured response. Both had helped signpost appropriate MH provision for their staff. The one was very proactive and saw his role as much more than an employer. He used the word 'lifeline' to explain how he has supported two of his staff on different occasions. This confirmed that SMEs are slow in the provision of support for MH (Beverly, 2019), although some SMEs are progressive in their attitudes and do foster a supportive culture MH.

One respondent raised concerns that there was a lack of MH provision and support for the owners of the SMEs.

*Awareness of mental health campaigns*

All those interviewed agreed there has been an improvement in the awareness of mental health over recent years. The participants were asked to explain the different sources that exposed them to MH awareness. All participants identified that social media, in particular Facebook, had played the largest part in raising their awareness of mental health. Other interviewees also identified more traditional outlets such as television, pamphlets and posters in welfare facilities on site. However, it was noted

that these opportunities are limited or non-existent in the small-scale domestic contractor setting. One participant raised concerns over the disparity between those working within the domestic sector and those on commercial construction sites. He explained that as a domestic contractor he simply did not have the same exposure to MH information as would be commonplace a large construction site where posters would be displayed in the canteen, and other staff facilities. He also mentioned that there was a lack of resources for most small SMEs. He mentioned that traditional media, such as magazines was his primary source of information on this topic. Others noted that the awareness of MH has been assisted further by high profile people such as celebrities, sport players and members of the royal family talking openly about their mental health struggles.

The participants were then asked to express their awareness of MH campaigns, in particular those run by Lighthouse Club and Mates in Mind. These two charities' aim to raise the profile of mental health in construction whilst providing ongoing support provision such as counselling. Amongst the participants there was limited awareness of these construction specific MH campaigns, with only two who were aware of them. This highlighted a lack of visibility of these campaigns amongst the SMEs, and supports Ward (2019) who identified there is a need to understand the perceived presence and impact of the current campaigns. By contrast, the remaining participants all had encountered some form of a non-construction mental health campaign. Some interviewees expressed a negative outlook on the impact of these campaigns, with one participant stating that this focus on MH was 'holding industry back'.

SMEs have a duty of care to their employees, and this includes their mental as well as their physical health (TUC, 2019). However, there was a lack of awareness of legislative duties related to MH, amongst the interviewees, although most conceded that MH may be covered under HAWASA 1974 or the Equality Act 2010. There was just one participant that understood their legal duties, explaining this was because of previous experience.

*Cost of Mental Health*

All participants agreed that staff absenteeism had a significant impact on cost, the ability to deliver projects, and also impacted the rest of the team. They explained that the cost implications of MH on SME's is higher because of the smaller workforce. One small scale SME interviewed noted that 'everyone is considered vital to the business' when there is only a small team. Another identified 'it is too hard to remove anyone to alleviate pressure.' This corroborated the 'presenteeism' phenomenon, where, despite complaints and ill health that should prompt rest and absence, their staff keep turning up to work (Aronsson, Gustafsson, and Dallner, 2000, p. 503). This is further supported by the research of Stevenson and Farmer (p.2017, p.24), and Beverly (2019) that levels of reporting of MH amongst SME's is lower than larger companies.

A number of the participants raised concerns over their own health and wellbeing, with one commenting 'I'm able to get statutory sick pay for my employees, but what about me? There's nothing!' Another identified that even when they were unwell themselves, they felt they had no choice but to continue working. Stevenson and Farmer (2017, p.24) points out that even with more conservative assumptions {regarding costings} to the calculation of presenteeism, the costs to employers are huge. All participants agreed that they have little, or no resources in terms of time and money to address mental health issues. A number of those interviewed said they

would welcome more government support in terms of both financial assistance and access to support services. This reiterated the lack of awareness amongst the participants of the current support mechanisms available. There are charitable organisations operating in construction and the government has announced funding to train persons in MH first aid training (Ward 2019), however the SMEs were unaware of this. This is supports Iacobucci, (2020) comments on the need for substantial and sustained government funding to ensure that there is a mental health system where no one, is unable to access the care they need.

## CONCLUSIONS

This pilot study provided an overview into the perception of mental health within the Welsh SME construction sector following on from the "Thriving at Work Review" (Stevenson, Farmer: 2017). The findings of this study indicate that despite MH reporting rates rising, there remains a reluctance within the workplace to openly discuss MH. Within most SME's there remains a workplace culture stigmatizing MH and discussions around it.

Within the study awareness of MH was limited. Whilst there have been a number of high-profile MH awareness campaigns most of the participants were unaware of these. The range of work undertaken by the participants mainly covered private domestic construction. There is high visibility of MH campaigns on large commercial sites with Tier 1 contractors leading the way in providing MH support, however, this study found there was no presence on private domestic projects. MH campaigns should actively target this part of the sector and raise their profile to embed effective support where it is lacking and improve access to these initiatives. There is a need to engage quickly and effectively with SMEs through traditional and social media.

SMEs make up a significant percentage of the Welsh construction sector; the findings show they lack knowledge on accessing, as well as implementing mental health support. The SMEs did not have any framework in place to deliver MH training to their workforce, and there is little evidence that the SME owners focus any attention on this important issue. Provision of free training to empower SMEs to manage the MH of their employees will provide the opportunity to reduce the potential impact of MH, both from a business and personal perspective.

The age groups demonstrating the poorest attitudes towards MH within the study were 19-29 and 60-69. This presented as a twofold issue; outdated societal attitudes of the 60- 69 bracket and machoism in the 19-29 group. However, attitudes are evolving around SME's approach to MH; a positive change was identified over the last 3 to 5 years, with half of the respondents noting that the industry is becoming more tolerant and accepting of MH issues. Attitudes and perception are changing, but at a slow pace and there are still barriers to overcome; fear of stigma, embarrassment and a preference for self-reliance from employees, and a lack of awareness from the SMEs.

Reporting rates of MH issues amongst SME's is 22% below the national average, and this was corroborated by the study which found there was a general lack of discussion about MH between employer and employees. This in turn affected the potential awareness of support mechanisms offered. The study highlighted there was minimal awareness of duty of care or legal duties concerning mental health amongst almost all the interviewees.

Current legislation places the emphasis on duty of care towards physical health. MH requires parity with physical health. Enveloping MH under the HASAWA 1974 and

making work-related MH issues reportable under RIDDOR, would bring the importance of MH to the forefront. Legislative change would force an overhaul of the current education curriculum to accommodate the changes. Education is essential to increase MH awareness to both employers and employees. Enabling MH recognition techniques will foster a culture of social acceptance and understanding, supporting the current subculture of acceptance beginning to emerge.

Poor MH issues have a significant economic impact on the construction industry as well as the wider economy. In an SME business, absenteeism and presenteeism pose significant barriers, with an associated reduction in productivity and an increase in the physical risk on site. Programmes and budgets are often so tight that it's too hard to remove anyone to alleviate pressure. Considering the limited workforce in most SMEs, the impact of presentism and absenteeism with the pressure it creates within the business should be a driving force to address MH at a grassroots level.

Further research needs to be commissioned on a macro scale. This should focus on understanding the challenges SMEs face when supporting mental illness which will enable the development of an improved support mechanism.

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# MANAGING CLIMATIC HEAT STRESS IN SINGAPORE: STATE OF THE PRACTICE AND WEARABLES ON SITE

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Climatic heat stress is a prominent risk to safety and productivity of construction projects. In Singapore, the tropical climate pattern made wearables a cost-efficient safety measure to prevent heat injuries on site. A concurrent study was designed to understand the ecology of managing heat stress in Singapore's construction industry. This involved an experimental study to test the effectiveness and usability of a commercial water-cooling headgear with a sample of 30 rebar and carpentry workers amid everyday practice on site. Participants' body temperatures with and without the water-cooling headgear were recorded with a thermal imagery to avoid interfering with the work. In parallel, ethnographic data were collected through observation and six focus groups. Paired-sample t-test between the experimental group and the control group turned a result of significant difference; the ethnographic data analysis confirmed its use is consistent with local coping convention. The research provides a first snapshot of Singapore's state of practice of managing heat stress in the construction industry. It contributes to the knowledge of designing wearables for on-site heat stress mitigation and establishes thermal imagery as a useful non-intrusive approach to heat strain monitoring on site.

Keywords: Singapore; health and safety; climatic heat stress

## INTRODUCTION

Climatic heat stress is a growing health and safety risk with potential life-threatening consequences to the people working on sites (Hesketh *et al.,* 2019). In countries that defined heat related injury as occupational safety incidents, construction industry is among the highest number of workers' compensation cases (Bonauto *et al.,* 2007). This risk is aggravated by the effect of climate change (Hesketh *et al.,* 2019; Gasparrini *et al.,* 2017). In Singapore, a city country located around the equator, the heat hazard is further elevated by the urban heat island effect. Construction workers particularly suffer from exposure to the high uniform temperature and high humidity in the tropical climate in Singapore, as shelter and work-rest regimen cannot make much difference to their thermal condition. Wearables or PPEs in this environment become a more effective and economical choice, contrary to what is normally believed by the Hierarchy of Control. Recent years have seen an increase in the development and test of wearables for heat stress control, focusing on scientific test of

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the product (Yi *et al.,* 2017; Edirisinghe and Jadhav, 2017). However, the systemic and cultural context of construction work, the ecology of which the wearable will become part of, has not yet been given much research attention. In an absence of systems thinking in risk assessment (Goh, 2020), PPEs often end up preventing one hazard but introducing another. For example, Jia *et al. (*2016) reported a temperature of up to 11.5°C higher within worker's safety helmet than the air temperature around. Wearables interact (or interfere) with existing patterns of work activities and impact on the cultural-cognitive institutions espoused by front-line workers, the outcome of which could invalidate the product or introduce new hazards (Rowlinson, 1997). This study aims to bridge these gaps by taking an anthropological approach to in general review the practice of managing heat stress in Singapore's construction industry, and in particular, evaluate the effectiveness of a water-cooling head gear used by workers in mitigating heat risk on site.

## Theoretical Perspective

Climatic heat stress of different climate zones differs in the combination of ambient temperature, humidity, solar radiant heat and wind speed. Human societies and communities accordingly respond with a diversity of institutional infrastructures and local methods to cope with the risk. In Middle Eastern countries such as Qatar and the United Arab Emirates, regulations exist to stop outdoor work between 11:30 and 15:00 during the hottest months of the year. However, driven by many different motives, illegal labouring during the restricted work hours becomes a norm, resulting in high heat-induced fatality rates (Amnesty International, 2013).

The issue of heat stress risk in the construction industry also distinguishes itself from that of the general public by the characteristics of its population base. The population entering and remaining in the construction workforce has been selected over time by its heavy physical work nature, and the remaining workforce share some common lifestyle, work habit, coping styles and career entry/exit pattern. For example, Jia *et al. (*2016) found the most vulnerable age group among construction workers is 26-35, rather than higher, while in the general working population of all industries, vulnerability to heat steadily increases with age (Xiang *et al.,* 2014).

Local traditions and coping conventions are cultural-cognitive institutions as part of the system fabric that work for a specific population in a specific natural and social historical environment (Goh, 2020). Safety regulations configured against local culture are least effective in achieving its goals (Ju and Rowlinson, 2020). Previous studies in Hong Kong identified a vernacular Herbal Teas as a local coping tradition (Jia *et al.,* 2017). The low-cost drink used to be contractor's free provision to workers on site. When it was replaced by vending machines selling bottled drinks, the cost was multiplied and shifted to the workers, which not only restricted their opportunity of heat dissipation, but also introduced a health risk in vending the artificially flavoured, heavily sugared drinks. Studies in southwest China identified employers' provision of a traditional medicine Ageratum Liquid as a local coping convention, recognising its effect of improving human body's immune system and calming down the vomiting digestive system (Jia *et al.,* 2019). Study on acclimatisation in Australia found workers coming from a different climate zone took longer time to adapt to the hot and humid weather on site, mainly due to adjustment of personal life routines (Jia *et al.,* 2020).

These observations and contrasts suggest the necessity of a more delicate study on the ecology of the cultural-cognitive institutions espoused by the target population which

could offset, counter or enable the top-down regulative or technological initiatives (Rowlinson, 1997). An anthropology approach is needed to parallel scientific experimental test of the new intervention, in this case, wearables, with ethnographic study of the work ecology where the construction workers are embedded.

## The Ecology of Heat Stress Risk in Singapore

*The local climate*

Geographically 1.5 degrees north of the equator, Singapore has a tropical rainforest climate characterised by high and uniform temperatures and high humidity (MSS, 2020). Recent national study on climate change projected a steady increase in ambient temperature in years to come (Marzin *et al.,* 2015). Daily mean temperature is projected to increase approximately 2-4°C for the end century period (2070-2099), warm days and warm nights throughout February to September. Extremely hot weather is predicted to occur with increasing frequency and intensity.

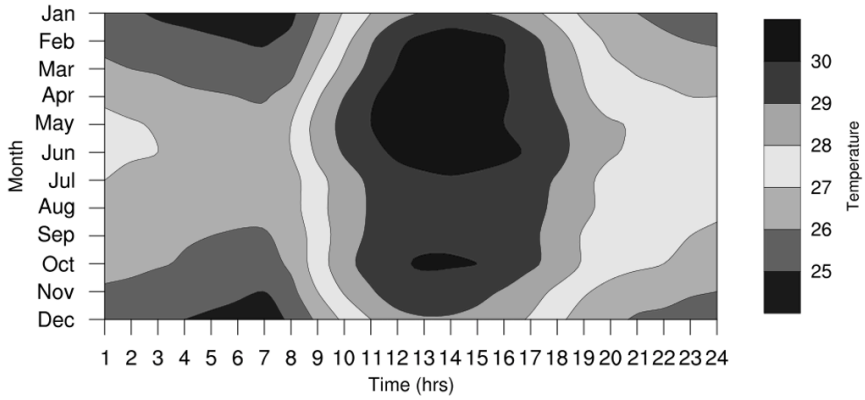


*Fig 1: Hourly variation of temperature in Singapore (1981-2010) (Source: MSS, 2020)*

On top of the natural heat, as a city state, Singapore further suffers from Urban Heat Island (UHI) which can elevate air temperature up to 7°C in the urban commercial area (Chow and Roth, 2006). While there are no distinctive wet or dry seasons, the highest number of warm days occurs during February to May; the highest number of warm nights from June to September. Hourly mapping by Meteorological Service Singapore (MSS) indicates the highest temperature zone is between 11 AM and 4 PM of the day during February to mid-June of the year (Fig 1).

*The institutional context*

Singapore is one of the few countries with an elaborate preventive action plan for heat stress control, employing the use of WBGT and Heat Stress Index as the main indices to alert employees of the hourly weather readings. Heat stress as an occupational hazard is protected by the Workplace Safety and Health Act and further under the Workplace Safety and Health (General Provisions) Regulations, under which the employer has a general responsibility to protect workers from 'excessive temperature and harmful radiation'(MOM, 2012). Under the WSH (Risk Management) Regulations, employers are required to conduct risk assessment to eliminate or reduce the risk of heat stress on workers. In guiding practice, Work Safety and Health Council first published workplace heat stress management guidelines in 2010, updated a first revision in 2012 and a second in 2020 (WSHC, 2020). Employers are required to report heat stroke cases to MOM's online reporting system. Preventive measures include acclimatization, drinking facilities, a balanced work schedule, shaded areas and appropriate work clothing. The current guideline recognises three purposes for

heat stress management: protection against heat injury, accident prevention and sustained productivity. A key development in the 2020 guidelines is it recognises that 'exertional heat stroke' can happen even in cool environment, due to the accumulation of a large amount of metabolic heat from physical activities beyond human body's capacity of dissipation (WSHC, 2020, p. 5). Existing research on heat stress has been focused on the environmental heat but not given enough attention to metabolic heat which in fact accounts for the major amount of the heat load on human body, a potential area for future research. In terms of acclimatisation, MOM recommend a 14-day acclimatisation protocol, during the work-in-heat duration is to be increased from 2 hours per day to routine practice. Re-acclimatisation is required after a prolonged leave, but no exact number of dates is specified. Hydration is specified, where supervised drinking or "water parades" are recommended to ensure workers are properly hydrated. More specifically, WHSC suggests a WBGT-based threshold system for evaluation of risk levels, i.e., less than 31°C, low risk; 31 - 31.9°C, moderate risk; over 32°C, high risk. The thresholds give some certainty in risk assessment, but it is difficult to implement or act on, as accuracies of WBGT metres available in the market range from +/- 0.5°C to +/- 2°C, and the thermal environments on construction site are too diverse to monitor and respond respectively. The regulation provides reference values for protection but cannot practically work for an economy in a tropical climate, practical development in Singapore for managing heat stress are focused on wearables and technological innovation.

*The working population of the construction industry in Singapore*

The working population of Singapore's construction industry is characterised by a large amount of international migrant workers from China and Southeast Asia due to Singapore's skill shortage particularly for unskilled workers (Huang and Yeoh, 2003). Migrant workers are reluctant to see a doctor or notify their supervisors on their latent health conditions, due to their job arrangement which pushes the cost of sick leaves to individuals, uncertainties in their health insurance or fear of losing their job (Lee *et al.,* 2014). They also need to cope with precarity and discrimination in the work environment (Hamid and Tutt, 2019), as well as communication and cultural barriers (Dutta, 2017). Yeoh *et al. (*2017) report that international construction workers in Singapore are required to long work hours without the power of negotiation, constrained by their time-bound work visa which often deprived them certainty and mobility. Their off work living spaces are lack of legal protection, confronting them with personal security issues (Huang and Yeoh, 2003). Thus, at times of conflicting commitments, they are left vulnerable to fatigue, distraction, pressure and mistakes, therefore more vulnerable to accidents. However, not all international workers are having the same extra issues to cope with. Ling *et al. (*2013) examined international workers of different home countries and their patterns of handling conflicts and disputes within the top-down regime of Singapore. They found workers from Thailand had least issues; Chinese workers suffered from poor safety awareness and inability to solve disputes, while worker from India were found lack of initiative (p.25). These extra issues and patterns compound heat stress confronting workers on site.

The official record of Singapore's Ministry of Manpower (MOM) marks six or less heat-related injury cases every year. However, in 2012 alone, Singapore General Hospital reported around 150 heat stroke cases. Such contrast indicates a potential gap of underreporting heat related incidents. A review of practice is needed for

comprehending how frontline staff are coping with heat stress and making sense of relevant regulations or supplementing them with bottom-up self-initiatives.

## RESEARCH METHODS

Based on the contexts reviewed above, wearable personal protective equipment (PPE) was identified as a useful approach to tackling heat stress on site in Singapore. A concurrent study was designed to test the effectiveness of a commercial water-cooling headgear used amid daily on-site practice (Fellows and Liu, 2015). An experimental study was designed to test the effectiveness of a commercial water-cooling headgear applied in daily practice on site. For conducting the experimental study without interfering with the ongoing practice, the research team explored options of non-intrusive technologies for monitoring and measuring relevant parameters. In parallel, ethnographic study was conducted on the participating sites to understand local work context and tradition of coping styles.

*The water-cooling headgear*

The water-cooling headgear under test is a commercially available heat prevention headgears that protect the user's neck from harmful ultraviolet rays of the sun, preventing sunburn while keeping the head cool. Its flap can be detached from the cap and immersed in cool water, or rotated for targeted cooling (Fig 2). The headgear is made of superabsorbent fibre which is light-weighted and soft, effective in absorbing and keeping water. The fibre has anti-static and antibacterial properties which is highly suitable for physically strenuous and sweaty exertions. Innovations of this product include utilisation of water evaporation effect, UV protection and its self-cooling textile. The lifespan of the fibres is limited to 100-120 number of times of wash, which means 3- 4 months of continuous usage.


*Fig 2: Headgear tested in the experimental study*

*Research design*

A total of 35 participants (healthy rebar and carpentry workers) were randomly selected among the outdoor workers on a construction site in Singapore to participate in the experimental study for two weeks in June 2018. Five of the participants dropped out during the study, the data of whom were thus excluded from the analysis. The participants were divided into an experimental group (wearing the water-cooling headgear at work) and a control group (normal work without extra headgear) in Week 1 and switched groups in Week 2 so that each participant had a chance to wear the water-cooling headgear once. Thus, in data analysis, the control and experimental groups were the same people with and without the headgear at different days of the study period. The participants' body temperature (face) was assessed every 30 minutes during 13:00 to 14:30. WBGT on the site was recorded at five-minute interval using a thermal imagery EXTECH HT30.

The most direct measurement for heat strain is body core temperature. Ingestible telemetric pill seemed to be a popular means for measuring body core temperature (Notley *et al.,* 2018), but it is intrusive and associated with health risks on the participants. A non-intrusive technology, thermal imaging, as it has lowered price for lay people usage, was thus adopted in this study. Thermal imagery Fluke Thermal Imager TiR32 was used for measuring heat strain on site (Fig 3). The validity of taking body temperature with thermal imaging was recently recognised by the World Health Organisation.

*Fig 3: Taking participants' body temperature using thermal imagery*

Concurrent to the experimental study, ethnographic data was collected by the first author through on-site observation and six focus group discussions, each involved approximately 5 participants. The sessions were conducted during their tea break time at 3pm. All focus groups were conducted in the local language (Hindi, Chinese, and Tamil) with the help of the bilingual participants and site coordinator. The focus groups explored usability of the headgear, including its comfort, ease of usage, durability, acceptability and effectiveness. General background information of the work team such as workers' socioeconomic status, health protective resources, their perception of exposure to hot environments, experience of heat related disorders, and health measures adopted to cope with hot environment, was also explored through the discussions. On-site observations took notes on local wearables adopted by other workers in coping with heat stress.

*Data analysis*

First, the mean WBGT of the workplace environment in the two study sessions were calculated respectively. An independent sample t-test was conducted to check if the two days can be assumed to be a thermal environment of the same level. Second, body temperature data was treated and compared. Each individual participant in each study session had four measures of body temperature. The mean value of the four readings was calculated as a data point for further analysis. A paired-sample t-test was then conducted to test the statistical significance of the mean body temperature between the experimental group (with the cooling headgear) and the control group (without the cooling headgear). Third, a content analysis on the ethnographic data was conducted to contextualise the quantitative data analysis results. Fourth, a

broader document search was undertaken to ground the findings into Singapore's existing policies, regulations and legislative context.

# RESULTS

## The Sample

The demographic information of the sample is summarised in Table 1. On average, the workers work 8-10 hours per day. 20 (66.6%) participants report that they are fully aware of the heat prevention measures adopted on site, 18 (60%) are very satisfied with the measures.

*Table 1: Demographic information of the participants*

| | Mean (SD) | |
|---|---|---|
| Age | 35.5 +/- 8.5 | |
| Body height (cm) | 167 +/- 8.7 | |
| Body weight (kg) | 64.3 +/- 8.8 | |
| Years of working in construction | 6.7 +/- 7.4 | |
| Smoking/drinking habits | 10 (33.3%) smoking | 7 (23.3%) drinking |
| Trade | 15 (50%) rebar | 15 (50%) carpentry |
| Education | 26 (86.7%) secondary | 4 (13.3%) tertiary |

## Result of the Experimental Study

Mean WBGT of both study days were calculated as 26.4°C in Week 1 and 27.0°C in Week 2. Independent sample t-test comparing between the two weeks' data turned out no significant difference, indicating that heat stress levels of the two weeks can be assumed as the same. This condition ensures the levels of heat strain between the experimental group and the control group are comparable.

Body temperatures with and without the headgear are shown in Fig 4. The drops of temperature were observed in 29 (96.7%) of 30 within the experimental group. Significant differences in body temperature ($p < 0.01$) were found between the experimental group ($M=34.8 \pm 0.712$) and the controlled group ($M=35.2 \pm 0.693$). The results indicate the water-cooling headgear has a significant cooling effect.

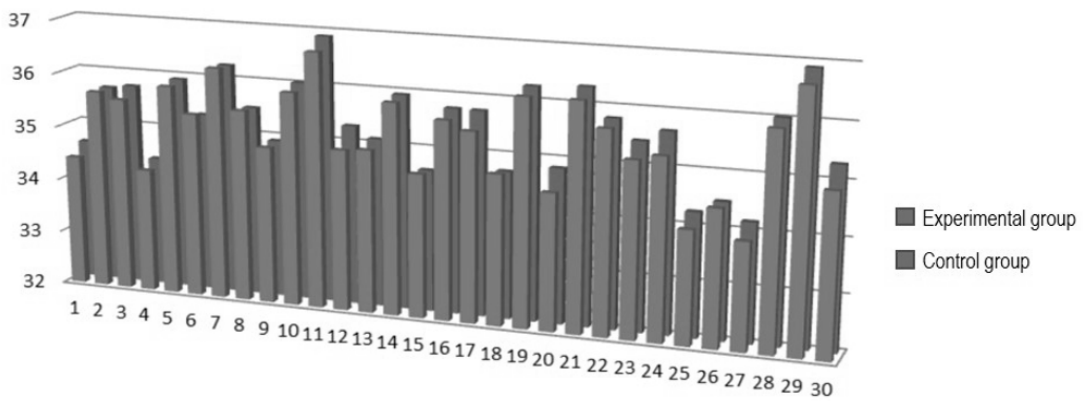

*Fig 4: Comparison of body temperature data between the experimental and control groups*

## Results of the Ethnographic Study on Site

*General issues and practices on site*

Workers perceived a trend of increasing number of hot days in Singapore. They described their jobs as strenuous and physically demanding, with most of their time spent outdoors under direct sunlight or underground in confined spaces. The compulsory personal protective equipment, including hard hats, safety shoes, gloves, harness, safety vests, contributed to the overall heat load on workers; and this is associated with the sensation of hotness and dehydration. A quarter of the participants reported musculoskeletal pain from all the heavy works and early heat stress symptoms from working outdoors over the past few months during work. This number is likely to be higher, as the participants were filling the pre-intervention questionnaire at the presence of their supervisors, a constraint of this on-site study. Reported syndromes included rashes, flushed dry skin, dizziness, weakness/fatigue, nausea, loss of appetite, dark urine, headaches, blurred vision. Some complained of being light headed, irritable and exhausted.

Some of the workers made personal adaptation by wrapping towels and cloths underneath their helmets to protect their eyes against sun exposure or surrounding their necks with wet towels for cooling purpose. A notable observation when walking around on site was the presentation of similar cooling headgears that workers bought on their own accord which functioned similarly to the commercial headgear used for this study, which could be as simple as a towel or piece of cloth soaked with cool water. This pattern indicated that the mechanism of the water-cooling is aligned with local knowledge and work habits. 36.7% of participants found the headgear very effective in combating heat stress. One participant found it uncomfortable to wear.

Eye strain caused by sun exposure is another issue associated with heat stress, on which workers perceived that the provision of sunglasses would have protected their eyesight. However, management decided not to provide on concerns that it might hinder workers view at work. The workers were reluctant to report injuries to their supervisors for three reasons: (1) they perceived injury was part of their job; (2) they feared negative consequences from the employer; (3) taking leave from work meant lost wages and reprimanding in their work environment. Thus workers tend not to report or discuss their heat stress experience with their supervisors for fear of consequences on their employment.

*Perception of the water-cooling headgear*

The water-cooling headgear was perceived as heavy and inconvenient. Its effectiveness is dependent on the frequency of rewetting which is once every 2-3 hours. This could potentially create interference and distraction for the work on a construction site. When wetted, the headgear has a weight of approximately < 0.4 kg was reportedly heavy for the workers. Participants indicated neck strain caused by wearing the headgear. Therefore, the headgear helped mitigate the heat risk but brought in some ergonomic risk which takes more systematic assessment and planning. In spite of this risk, it is notable that 96.7% of participants agreed with permanent implementation of the headgear. Another concern by the workers was the cost of the headgear multiplied by its relatively short lifespan. Workers nominated alternatives of lower cost, such as a towel or those sold at sports retail outlets.

## CONCLUSIONS

This study embedded an experimental test of a cooling headgear in a practice-as-usual site context and paralleled it with an ethnographic study to understand local tradition and vernacular patterns of coping with heat stress in Singapore. The results of the experimental study indicate that workers have significantly lower body temperature when using the water-cooled headgear as compared to a scenario without it. Results of the ethnographic study suggests that the headgear is consistent with local conventions of heat stress mitigation and therefore, as also verified by the quantitative study results, effectively fits for its purpose. The only factor for the adoption of the product would be a competition of price in the market. However, the frequent soaking needed for the headgear, which was found to interfere with the work, suggests such technology needs to be automated. The implication of this study is limited by the accuracy of the measurement instruments and the small sample size. In spite of the limitation, it is the first study to establish a realistic understanding of what's going on in terms of heat stress management on construction sites in Singapore. The study has also tested the usability of thermal imagery for monitoring heat strain in human body. Although the accuracy of such device is to be improved, the study indicates it is a usable, non-intrusive, efficient and effective approach to instant monitoring of body temperature that can help ensure workers' safety in heat. This study serves as a pilot study on the review of heat stress management practice in Singapore's construction industry. Next steps of this series of study will focus on a full-scale review of the industry practice, as well as identifying appropriate technologies for automating the cooling heat gear.

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# EXPLORING THE VALUE IN NEAR MISS REPORTING FOR CONSTRUCTION SAFETY

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Near miss reporting forms part of most contemporary Safety Management Systems across many industries, including construction. It is often seen as a leading indicator that demonstrates attention to safety through the vigilance and commitment of the workforce, the quantity of near misses raised often providing the measure of its value. Its prominence can be attributed to its positioning as the 'foundational layer' in Heinrich's Accident Pyramid, although the causality also often ascribed therein is dubious. However, such reporting also brings problems of system misuse as a tool for blame, increased administrative burdens on safety professionals, and questions have been raised about the contribution such process actually bring to practice. Yet logic dictates that there should be some value in near miss reporting, however the process of reporting, including when and how reports are raised and what information is requested, will inevitably influence such value. A large database of near miss reports (n=3,519) submitted over two years to a UK civil engineering contractor has been analysed to reveal high level patterns within the data. Findings reveal a number of issues with the system and its data suggesting problems for both workers and safety managers, and reflecting problems also identified in other industries, and suggesting areas of focus for the development of a system able to overcome such problems in practice.

Keywords: leading indicators, near miss reporting, safety, value

## INTRODUCTION

A Near Miss (NM) can be defined as: the combination of unsafe conditions and unsafe actions that arise at work in an event that leaves workers defenceless against harm, but which did not actually cause harm, but may or may not cause property damage, damage to the environment and/or loss of time. It is therefore perhaps unsurprising that Near Miss Reporting (NMR) is a common feature of contemporary safety management systems across all industries, including civil engineering and construction (Oswald *et al.,* 2018). Often considered a leading indicator, and thus evidence of a pro-active approach to safety (Lingard *et al.,* 2017), companies across the world have eagerly adopted or developed NMR systems and processes for use within their operations, looking to capture NM knowledge and place mitigations in place to avoid any reoccurrence with potentially more serious consequences.

However, research has shown there can be problems inherent in NMR, and it can be suggested that any impact on practice has yet to be fully realised. For example, a general lack of rigor in many such systems has been noted as problematic (Wirth and Sigurdsson 2008), whilst others such as Gnoni *et al. (*2017:158) debate whether the

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number of reported NMs can ever be '… credibly used as a positive or negative indication of safety'.

Yet there remains sufficient evidence from both within and without the construction industry to not yet 'throw the baby out with the bathwater', and so efforts should perhaps instead be directed at the enhancement and development of NMR systems to the point where they are able to demonstrably add value to safety management on construction sites. This paper presents the first steps in such a project, with the overarching research question that asks, 'where is the value in near miss reporting?', and shares early findings from the analysis of a large body of data produced by a 'typical' NMR system of a large UK civil engineering company. Further research is also proposed to support the overarching project aim: to develop a NMR system able to enhance the value of NM reporting in the construction industry.

## CONTEXT

### The Case for Near Miss Reporting

Underpinning the popularity of NMs within occupational safety management is Heinrich's (1931) Accident Pyramid. NMs form the bottom layer of this pyramid, a set quota of NMs apportioned against relative quantities of minor then major injuries, with one fatality at the top. A variety of ratios have been used in this pyramid over time, for example Phimister *et al.,* (2003) focused on the bottom of the pyramid and asserted that there were 10 minor injuries, 60 incidents resulting in property damage or loss, and 600 incidents without loss or damage for every, one incident of serious injury. However, although the numbers change the overarching approach in the application of this model ascribes a causality within the pyramid that Heinrich himself cautioned against (Oswald *et al.,* 2018). Despite this, the misapplication of this theory still continues, and has resulted in many companies trying to 'capture' as many Near Misses as possible to 'prevent' the fatality at the apex (Choudhry 2014), something Manuele (2011:52) simply describes as a 'myth'.

However, NMR has brought benefits to many industries across the world, from Nuclear (Uth and Wiese, 2004) to Transport (Aldred and Goodman, 2018; Kongsvik *et al.,* 2012) to Aviation (Tinsley *et al.,* 2012) to Petrochemical (Fabiano and Currò, 2012) and so should not be dismissed because of a theoretical hiccup. The desire to capture data on incidents has a long history within organisational safety management practice (van der Schaaf and Kanse 2004), able as it is to support organisational learning and make positive future changes to practice. Indeed, as the factors that cause NMs are the same as those that also cause accidents, once distracting ratios are set aside the process of learning from NMs becomes critical in order to avoid reoccurrence, when different opportunities and contexts could result in a much more serious outcome (Phimister *et al.,* 2003; Tinsley *et al.,* 2010; Cui *et al.,* 2018).

The value of the data obtained from NMs should therefore be considerable. Adams (2005) suggests that the voluntary reporting of incidents provides important information which cannot be obtained by any other means, other than by someone getting hurt of course. Improved safety performance has also been associated with high rates of incident reporting (Storgard *et al.,* 2012) and as such NMR remains a recognised method for improving safety and a well-accepted practice across a wide range of industries (Anderson *et al.,* 2013).

**Problems in Practice**

Like any organisational or management system, NMR processes vary from one firm to another (Marks *et al.,* 2014), with the most common means of documenting NMs being via a secure online database, allowing for anonymous reporting through pre-determined criteria. However, many such systems try to do more than just NMR (as the system that generated the empirical data for this study does) and often also aim to secure other safety-related observations and feedback from the workforce, including successes and good practice, in a way to enhance and develop worker engagement overall. However, despite such laudable intentions, there are fundamental challenges in building a system able to both incorporate NMs and successes coherently (Madsen *et al.,* 2015) and in trying to do too much, additional complications can arise. One of the most obvious limitations of NMR systems is that they can be expensive to set up and maintain. Although there are off-the-shelf solutions available, many companies develop their own in-house systems. However, as Oswald *et al. (*2018) found, implementing a bespoke 'stand-alone' SOR system on a construction project without due consideration of what constitutes best practice can lead to unintended consequences.

For example, the volume of reporting can be problematic in two very different directions. Construction as an industry has a history of under-reporting its accidents, and thus there is the potential for NMs to also be underreported as part of that shared culture. However, underreporting of NMs also happens across all industries, stemming from a complex mix of factors (Prang and Jelsness-Jorgensen, 2014). Overall, this results in a lack of understanding and awareness of actual incident rates and the daily number of errors that occur in the workplace; the NMR process failing to reflect actual events (Kohn *et al.,* 2000; van der Schaaf and Kanse 2004.). Factors of influence range from workers simply having the time to engage with reporting (Kongsvik *et al.,* 2012) to more fundamental confusion as to what a NM actually is, and so when they should be reported. Gnoni *et al. (*2017) found certain NM events that involved unsafe conditions were frequently underreported, which overall create blind spots within the data when more complex scenarios are involved. This is a common problem within NMR, as Hasanspahić *et al.,* (2020) found in their research of NMR in the shipping industry where underreporting is also problematic, with the most significant barrier to NMR at sea being the seafarers' own difficulties in identifying near-miss events.

Paradoxically however, this problem does not mean that NMR systems are under-subscribed. In some cases the volume of data generated by such systems, particularly when they also attempt to capture other safety management aspects and good practice, can be so vast as to be unmanageable (Gnoni *et al.,* 2017). Indeed, the problems of not knowing what to report are often countered by an encouragement to over -report rather than under to ensure everything potentially relevant is captured by the system (Cambraia *et al.,* 2010), exacerbating the issue. For those tasked with processing the data, usually the occupational safety team themselves, this can add considerably to workloads (Oswald *et al.,* 2018) as reviewing, analysing and actioning reports can be very time consuming (Coyle *et al.,* 2005).

An additional complexity worthy of note, that impacts both under and over reporting, is the positioning of blame within this process. A no-blame approach to safety management is also now a common part of the contemporary safety zeitgeist (Sherratt 2016), yet the fear of being blamed for something, even if no accident occurred, can

still hinder reporting (Beasley *et al.,* 2004). Indeed, van der Schaaf and Kanse (2004) found that data may be edited on input to avoid blame or liability in the case of a NM, as workers seek to avoid discipline and any legal consequences. The use of the NMR itself to ascribe blame is a more unexpected consequence of the process, yet Oswald *et al. (*2018) found many examples of reports naming and blaming other workers, organisations and those in positions of authority when any violation of safety rules was witnessed, no matter how small. This perhaps says more about the rules and their status on that case-study project; however, it is recognised that NMR should be undertaken in a way able to support a no-blame culture in practice (Gnoni *et al.,* 2017).

### The Importance of Value

Critical to any NMR system is that its outputs and outcomes are readily able to add value to the organisation's operations, and the resources required to operate that system are proportional to those gains. As with all management, the process must be effective and efficient, and for NMR this means the system must produce data able to enhance understanding and subsequent organisational learning and change. However, as the previous section considered, this is not always straightforward.

In their examination of a NMR system on a UK construction site, Oswald *et al. (*2018) found that instead of providing robust safety knowledge, the bespoke NMR system (which also sought to capture many other safety observations both good and bad) was flooded with 'easy to see' observations around PPE or behaviour violations. However, these were already well known to the safety management team, and were therefore of no real surprise or utility, and '… added little… other than the need for administrative time in managing the vast database it created…[of] volume with little value' (Oswald *et al.,* 2018:44).

Further problems arise when the consequences of reporting are not easily identifiable by those making the reports. For NMR, the action taken to resolve or mitigate a workplace safety issue is the demonstrable outcome of the organisational learning from the system, and thus also a demonstration of its value. Workers will question whether reporting makes a difference, which in turn underpins their motivation to engage (Wu *et al.,* 2008). The perceived competence and mindset of the safety management team also has influence and can deter reporting if workers feel nothing will change (Wagner *et al.,* 2013), whilst Evans *et al. (*2006) also found the 'usual' outcome of an incident influences whether they are reported or not in healthcare settings. The subsequent actions consequentially taken from NMR are therefore critical in the self-validation and continuous development and enhancement of the NMR system. Should a NMR system not add value, i.e. not generate readily utilisable data which can create practical change that enhances safety performance, it could actually be far more detrimental to wider organisational safety culture than having no NMR system or process at all.

## METHOD

Data for this project comes from a large case-study civil engineering company (annual turnover approx. £300m) that undertakes both short and longer-term construction operations in a number of regions across the UK. The company operates an online NMR system with access for all staff and supply chain partners to facilitate health and safety reporting. The process used by this company to collect its data is not unique or uncommon in the industry, and the company itself is accredited to a high standard for

its approach to health and safety and has won national awards for their efforts. The company and the data can therefore be considered representative of current 'best practice' within the industry.

The data analysed here was collected between May 2018 and October 2020 and comprises a total of 3,519 individual reports. Although this data is drawn from just one company, each report is a data point itself making this a considerable sample overall. As the aim of this study is to explore the value in near miss reporting, this sample presents a valid opportunity to undertake that endeavour within the specific context as stated. Generalisation of the findings is not claimed at this stage, but it is suggested that the peripatetic nature of the construction workforce and the commonality of practices across the industry will enable them to likely find fit with comparable companies across the UK.

In order to begin to explore the value within this data, a mixed method approach involving predominantly quantitative and more limited qualitative analysis was undertaken. This included high-level analysis of the data, including consideration of the processes that shaped its collation, and the dominant patterns found within the data ultimately collected. It must be noted that this paper only presents a very high-level initial analysis of this data due, in large part due to constraints of space, and a more detailed qualitative analysis of the data points themselves is planned to develop these initial findings further. The statistical software package SPSS was used to support the quantitative analysis, with Chi-square analysis used to explore relationships as they emerged from the data.

## FINDINGS AND DISCUSSION

### 'Cleaning' the Data

The data for this project is naturally occurring (Lincoln and Guba 1985) and was created by many different authors with an assumed shared goal: to improve and enhance health and safety management within the company. The data has not been subjected to any researcher bias or influence, and thus has considerable ecological validity, however this also brings challenges. In their work exploring unsafe acts and conditions that also drew on a similar body of NMR data from a large civil engineering project, Smith *et al. (*2017) found the classifications originally ascribed within the raw data problematic. Specifically, they found 'muddling' between the use of the labels of 'unsafe conditions' and 'unsafe acts', and in many cases an inappropriate label had been used by the person inputting the data, creating repercussions for its utility. In order to undertake subsequent analysis meaningfully, Smith *et al. (*2017) determined a benchmark for classification to ensure a level of validity and reliability and undertook a re-categorising process, through which a not inconsiderable 90% of records in a sub-sample of n=48 were reclassified.

A similar problem emerged in this study, reinforcing the findings from Smith *et al. (*2017) and further highlighting the complexities in categorisation for all those tasked with generating such data. Although Smith *et al. (*2017) were concerned with the nuances of causality in their conditions/acts evaluation, in this data similar confusion was found in the classifications of Near Misses and Safety/Environmental Concerns. Reporting in the data was constrained to one of three categories by the system: Near Miss, Safety/Environmental Concern, and Safety Suggestion. As noted above, the working definition of a NM for this study is: 'The combination of unsafe conditions and unsafe actions that arise at work in an event that leaves employees defenceless

against harm, but which did not actually cause harm, but may or may not cause property damage, damage to the environment and/or loss of time'. Using this definition as a benchmark, the data was reclassified at this level, and overall n=890 NM reports were reduced to n=682, whilst n=2414 Concerns increased to n=2622. This was a less dramatic shift in the data than Smith *et al. (*2017) experienced, only a 10% overall bi-directional 'swing' to Concerns from Near Misses, but still suggests that a shared understanding of terminology is important among the workforce as similar problems of labelling presented here are also found in previous research (Gnoni *et al.,* 2017; Hasanspahić *et al.,* 2020). This raises considerations for the development of an effective system in which fundamental agreement as to what things are is readily achieved, and how data can be meaningfully labelled for future use. Further analysis of this specific phenomenon, including considerations of how best to mitigate such subjectivity in future, is planned for later in this project, however this finding already raises questions about the value of NMR data in its raw form, and suggests an inherent need for expert re-evaluation and intervention at some point prior to its utilisation which speaks to system resourcing in operation.

**Rating the Risk**

A further categorisation requested by the system when the NM is inputted is a rating of the risk (no-low-moderate-significant). This was a prescribed category within the system, with users asked to 'please select a value' when making their evaluation from the drop-down menu. As shown in Fig 1, across all types of reports the majority of incidents were determined to be low risk, with the fewest considered to be a significant risk to company operations.

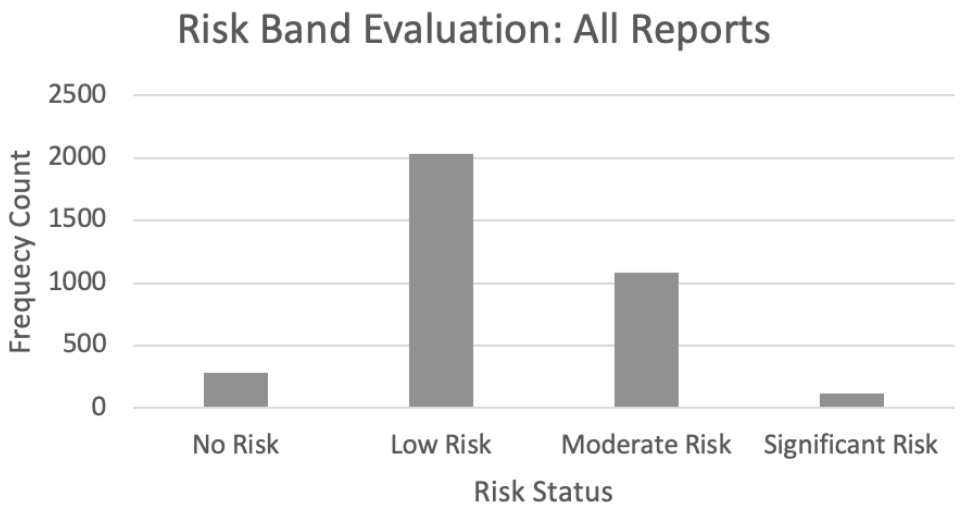


*Fig 1: Risk Band Evaluation, All Reports.*

When NMs are extracted from the data as a whole and their risk profile evaluated, the picture changes to include more reports of incidents with moderate risk, although the profile at either end of the continuum remains relatively similar, with a slight shift from 8% as no risk in all reports to 5.1% in NMs and a corresponding shift from 3.3% as significant risk in all reports to 7.6% in NMs. This can be seen in Fig 2.

Further analysis involving the cross-tabulation results of risk band with the type of report submitted is presented in Table 1. Chi-square analysis was undertaken to explore whether the type of report (Near Miss, Safety/Environmental Concern, Safety

Suggestion) was associated with a certain risk profile within the data thus labelled, testing the null hypothesis that: there is no relationship between the type of report and risk band.

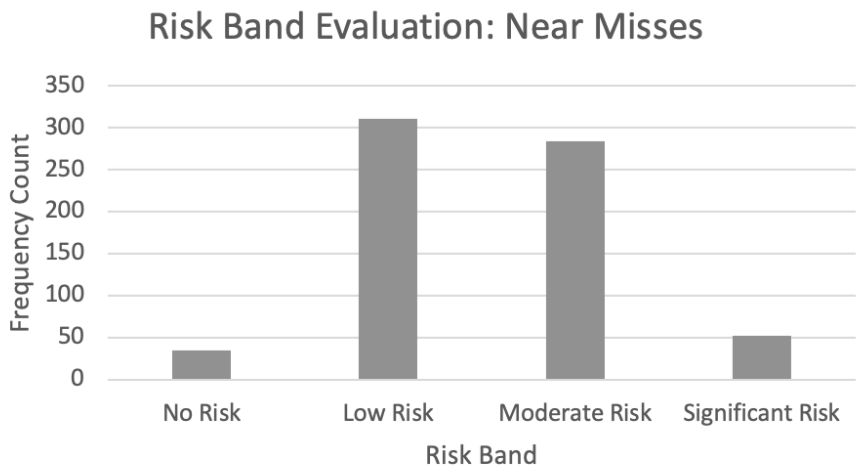


*Fig 2: Risk Band Evaluation: Near Miss Reports*

The Chi-square reveals a significant relationship between the type of report and risk band at a 95% confidence level, indicating that the type of report determines the level of risk associated with it.

*Table 1: Association between type of report and risk band*

| | No Risk | Low Risk | Moderate Risk | Significant Risk | Total |
|---|---|---|---|---|---|
| Near Miss | 35 (5.1%) | 311 (45.6%) | 284 (41.6%) | 52 (7.6%) | 682 (100%) |
| Safety Suggestion | 25 (11.6%) | 134 (62.3%) | 56 (26.0%) | 0 (0.0%) | 215 (100%) |
| Safety/Environmental Concern | 223 (8.5%) | 1591 (60.7%) | 744 (28.4%) | 64 (2.4%) | 2622 (100.0%) |
| Total | 283 (8.0%) | 2036 (57.9%) | 1084 (30.8%) | 116 (3.3%) | 3519 (100.0%) |

These very 'high level' findings are of interest as they again talk to the knowledge and understanding of those inputting the data. It is perhaps rather unrealistic to expect workers to be able to evaluate risk meaningfully (many safety managers will happily debate risk levels between themselves!) and these findings show a clear congregation around the two centre points of low and medium, and a statistically significant lack of variation in the data as to the level of risk ascribed. Although greater numbers of NMRs were ascribed as medium risk than for all-reports, it can be argued that low and medium are 'comfortable' assessments. They are not serious enough to be significant, and so the reporter is to some extent absolved of more serious obligations or involvement from making the NMR itself, which would find fit with the observations of van der Schaaf and Kanse (2004). To note something as significant risk would be a much bolder claim, requiring a certain amount of confidence to not only make it but also to stand by in case of future action. The risk pattern for NMRs could also be explained by the use of reporting targets or the encouragement to over rather than under report (Cambraia *et al.,* 2010) which could also likely result in most NMRs being considered lower risk, either by accident or design.

### Value as Evidenced by Action

Evaluation of how useful the reports were (and thus value in the system as a whole) was initially made through analysis of the subsequent recorded action taken within the system data. Initial action to remedy unsafe situations was often noted in the reports, however a critical part of NMR is the demonstration of management response, without which the motivation to engage drops within the workforce (Wu *et al.,* 2008; Wagner *et al.,* 2013). Table 2 shows the level of reported further action within the data.

*Table 2: Association between type of report and reported further action taken*

| | Yes | No | Total |
|---|---|---|---|
| Near Miss | 47 (6.9%) | 635 (93.1%) | 682 (100.0%) |
| Safety Suggestion | 48 (22.3%) | 167 (77.7%) | 215 (100.0%) |
| Safety/Environmental Concern | 244 (9.3%) | 2378 (90.7%) | 2622 (100.0%) |
| Total | 339 (9.6%) | 2378 (90.7%) | 3519 (100.0%) |

Table 2 reveals that in the majority of all types of report, recorded further action was only taken after a report in 9.6% of all reports to the system, with no recorded action taken for 90.4% of all reports. For NMs this reduces to recorded action taken in response to only 6.9% of NMRs logged in the system, with 93.1% reported as no action being taken. There are two explanations for this: either no action was taken or action was taken and not recorded. The latter is more likely, given the status of the company involved, but this therefore suggests the system is also not supporting the safety managers in the capture and recording of remedial action, perhaps due to the added administration it necessitates (Oswald *et al.,* 2018). It also creates a gap in the organisational learning, but perhaps most detrimentally results in the lack of data to close out the NMR feedback loop, and a lack of information to share with the participating workers. Overall, this raises concerns about the engagement of both workers and the safety managers, and the value this NMR process in its current form is bringing to the organisation.

## CONCLUSIONS

Although undoubtedly limited, this high-level quantitative investigation of a large NMR system dataset from a UK construction firm proud of its approach to safety management has already revealed some potential problems with this bespoke NMR system. Analysis has already revealed issues around labelling and nomenclature, around the questions asked to those reporting, and around the value generated by the system from that data, also evidenced by the lack of 'close out' of any learning generated within it.

These findings resonate with studies from a number of different industries, suggesting that construction is not unique in having these problems, but also that there is scope to develop a NMR system able to enhance the value of NM reporting in the construction industry. This paper presents early findings from a project that aims to do just that. Qualitative analysis of the data will form a more nuanced next step in the process, to explore what value is contained with the reports themselves, analysed through a utility-focused lens. Drawing on best practice and lessons learnt from both construction and the many other industries in which NMR forms a core tenet of safety management, it is hoped a system can be developed that adds value to this process to support the continued improvement of safety in construction. The authors welcome comments and feedback from the ARCOM community on this project as it progresses.

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# Human Resources Management

# WHY DOES ANYONE WANT TO WORK IN THE UK CONSTRUCTION INDUSTRY?

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Construction operatives in the United Kingdom work in conditions which are often dangerous, exposed to poor environmental conditions, and subject to unpredictable employment prospects. Entry to the UK construction workforce is falling. Uptake of construction apprenticeships is low, as young people choose to work in industries that are more secure, better paid and where they can work in more forgiving environmental conditions. This prompts the questions: why does anyone want to go into the construction industry in the first place? What factors influence their choice, and what are the activities that give those in construction most job satisfaction? This research aims to answer these questions. Twenty-five interviews with construction operatives were undertaken, transcribed and analysed using thematic analysis with qualitative analysis software. The findings show that the respondents joined the construction industry through a combination of family ties and personal connections to the industry, an interest in making things and chance. The respondents enjoy the varied nature of their work, the challenge of solving complex programming and coordination problems, and many cite that they enjoy constantly learning on the job. The experience of handing over a completed building and observing the community benefit that a facility can bring was often cited as a source of great satisfaction. Role models are important to encourage the next generation of construction workers to enter the industry. The findings will equip those tasked with recruiting to the construction industry with information to attract new entrants to the workforce.

Keywords: careers advice; recruitment; role models

## INTRODUCTION

It has long been established that the construction industry in the United Kingdom (UK) faces a looming skills shortage, with an ageing workforce, declining numbers of entrants into the industry, and international competition for skilled workers exacerbated by Brexit. 15 years ago, the Leitch report (2006) concluded that a skills shortage existed across all sectors in the UK in the context of an ageing population and increasing global migration. More recently, the Farmer Review (2016) predicted a decline of 20 - 25% in the construction labour force by 2026, and the most recent RICS UK Construction and Infrastructure Market Survey (2020) shows that the UK skills crisis across Quantity Surveyors, all trades, bricklayers, and other professionals persists.

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A 2015 YouGov poll of 18 - 24-year-olds found that only 5% of respondents rated the construction sector as a desirable industry to work in, with only 7% agreeing that this sector offers good career progression (YouGov, 2015). At graduate level, the JISC (2020) report 'What do graduates do,' cites healthcare, education, accounting, local government, computing, social work, law and banking as the top areas for graduate recruitment; construction did not feature in this list. As for school leavers, an Institute for Employment Studies' 2019 report found that 7% of young people under the age of 25 were employed in construction, compared to 10% in manufacturing, 15% in banking and finance and 34% in public administration, education and health. Clearly, young people are choosing to work in sectors other than construction. Is this because these sectors genuinely offer better working conditions and opportunities than construction, or is it because they tell a better 'story'? In 2019, the RICS suggested that construction was losing its appeal, quoting Martyn Evans, project director at M3 Consulting, as saying "There is a real challenge to be overcome in terms of explaining to young people what is attractive about the sector." This paper aims to help address this challenge.

**Factors That Influence Occupational Choice**

Parnell *et al. (*2019) contend that occupational decision making should be an "active, creative process" that should lead to the selection of an occupation that best suits the individual. They suggest that this choice is influenced by internal factors including personal motivation, and external factors which include other people and social expectations. Galvaan concluded from her 2012 ethnographic study that a person's occupational choice can be constrained by their environment and perceived available opportunity. In a subsequent study, Galvaan (2015) suggested that the social capital of the possible entrant and the perceived social position of the role, may promote some choices and hinder access to others. The occupational choices and assumptions made in a particular community link with the social processes that influence job choice, leading to a repeating pattern of job choice in that community. Bentolila *et al. (*2008) suggest that lack of diversity of role models can restrict an individual's range of possible occupations and in turn this can embed disadvantage.

Gibson (2004) examines the influence of the role model on career choice. His career theory explores the attributes of a role model as a person that individuals observe, identify with, and emulate. Identification with a role model is important - with perceived similarities in terms of attitudes or behaviours. Role models have a desirable status that individuals want to replicate for themselves - the subjects tend to model their behaviour on the role model, to increase their similarity. Gibson suggests that 'ideal' selves can be constructed from an amalgam of a number of different role models, helping people envisage their future direction. Gibson does emphasise that the social comparison and identification required for a role model relationship does not require a physical presence, or interaction. Ibarra (1999) suggests that people can 'try out' different selves and test to see if they 'fit', through a relationship with a role model. Role models can illustrate what a future successful professional self could look like (Lockwood and Kunda 1997).

In the construction sector, Faulkner and Day (1986 p247) looked at the perceived social status of industry professions. They suggested that individuals consider multiple facets when assessing the social status of a position in industry, and their possible 'fit' - including "material reward, power/authority, autonomy, knowledge and skills required, education/training, and value to society." More recently, Chileshe and

Haupt (2009) examined the factors that influenced the decision-making process regarding career choice for students in Australia and found that remuneration, training and promotion prospects and working conditions were important elements.

**Construction Industry Characteristics**

*The image of construction*

The Construction 2025 strategy report (BIS, 2013) cited "perceived low image, lack of gender diversity, low pay and job security" as factors that were holding back recruitment to this sector and suggested that 'fundamental change' was required in the way the public see the industry. Chan and Connolly (2006) discuss perceptions of the industry, citing research which variously refers to the disreputable image of builders, and talk of construction as a dirty, low skilled, low status environment. The Farmer review (2016) suggested that the industry conjured images of poor health and safety, in an inhospitable environment that was male dominated, riddled with negative attitudes to those who don't conform to the dominant stereotype, and with poor job security.

*Health and Safety*

Construction has a poor health and safety record; although much improvement has been made in recent years, a career in construction carries more risk than one in other sectors. Alderson (2017) found that construction workers in the UK experience mental ill-health at twice the national average rate. In 2020, the HSE found that construction had more fatal workplace injuries (40) than transport and storage, manufacturing, retail, accommodation and food, admin and support services and waste combined (37) (HSE, 2020). It may not be fair to make comparisons from 2020 where construction sites continued to operate and other sectors shut down in the face of the coronavirus pandemic, but these figures indicate that construction health and safety issues persist.

*Training in construction*

In 2016, the UK Commission for Employment and Skills found that construction had the third lowest percentage of trained members of the workforce (53%) compared to other industries (UKCES, 2016). Construction 2025 suggests that construction investment in training in development is low in comparison to other sectors (BIS, 2013). This report suggests that the lack of investment may be linked to the high proportion of self-employed people, only 17% of whom had attended training in the past year, compared to 41% of directly employed people. The Farmer report (2016) suggested that the large number of self-employed people, low industry margins and adversarial pricing models in construction were contributing to the lack of investment in skills and short-term approaches in construction, compared to other industries.

*Environmental conditions*

Martin (2017) makes the argument that the 'construction sector' covers a huge range of occupations and varieties of construction. Some construction sites may be exposed to the elements, but others are not, and new methods of construction using digital and offsite techniques are growing in prominence. Design (architecture and engineering) tends to be mostly office based and is characterised by Lippa *et al. (*2014) as higher status than site-based occupations. However, to some, the ability to work outdoors, not to be 'stuck in an office all day' may be an attraction.

*Security of employment*

Construction is particularly vulnerable to recession - Lowe and Moroke (2010) found that the failure rate for construction companies during an economic downturn was

double that of other types of company; Tansey *et al. (*2017) confirmed the negative impact of the 'great recession' of 2007 on construction employment, and the greater job precarity in comparison to other sectors of employment. Construction is characterised by high rates of self-employment (Farmer, 2016) - this peripatetic lifestyle which gives a great degree of freedom and control suits many workers, but also exposes them to fluctuating demand for their services. Construction salaries fluctuate hugely, dependent on the prevailing economic climate (Tansey, *et al.,* 2017), although this does mean that salaries can increase significantly during periods of high demand.

Given the questions explored above, anyone working in construction education or recruitment must ask themselves, is it ethical to encourage young people to consider such a career? Can workers be satisfied with, even enjoy a career in construction? What factors might compensate for the environment, the risk and job insecurity? Why does anyone decide to enter construction in the first place? This study uses the analysis of 25 qualitative interviews with people who have been working in the construction industry for at least 5 years to examine the reasons why the interviewees joined the construction industry, and whether they enjoy their jobs. Recommendations are then made that could help halt the decline of young people deciding to enter construction as a career.

## METHOD

To establish a gap in the literature, a search using Google Scholar and Scopus for the term 'benefits of working in construction' for peer reviewed papers published during 2015 - 2021 was undertaken. The first 8 pages of results were reviewed, and no recent peer reviewed academic studies examining the positive effect of working in construction on individual operatives could be found, even as part of a balanced consideration of the drawbacks and benefits, clearly demonstrating a need for research into this area.

This study draws on material gathered as part of a wider research project in which 25 interviews were undertaken with construction operatives. These participants met the selection criteria - they had all worked in construction for a minimum of 5 years and they worked on site or managed site operations. The sample includes 3 directors, 5 contracts managers, 12 site managers and 5 construction quantity surveyors. All interviewees, except for one woman, were white males. To put interview participants at ease at the start of the broader research interview, they were each asked to talk about their background and route into the construction industry, and later in the interview they were asked whether they enjoyed their job, and if so, what aspects of their job they enjoyed the most. The questions were posed during semi-structured interviews, with the freedom to deviate from the written interview outline with unscripted follow up questions. Each interview was audio recorded (with the full, informed consent of the participant) and transcribed verbatim. The transcripts were analysed with the aid of NVIVO software, using thematic analysis where patterns in the data were actively interpreted as described by Braun and Clarke (2006). Care was taken to ensure that the themes generated are coherent (Braun and Clarke 2006). Throughout the presentation of the analysis, the voice of the interviewee has been referenced and extensive use has been made of anonymised direct quotes to connect the analysis and identified themes to the primary data.

## FINDINGS

*Why did the respondents enter the construction industry in the first place?*
The respondents fall into three categories in terms of their response to this question. Many of them had close role models through family ties to construction; some did not want to work in an office and either enjoyed woodworking at school or studied construction at university, and the rest of the respondents fell into construction by accident, or only initially intended to work in construction for a short time. Many respondents reported a mixture of these factors.

*Role Models - family connections to construction*
FS a Project Manager grew up in an environment where most people around him were working in construction, so this felt like a natural route, but he did actively choose the industry for its variety, saying that the main driver was the opportunity to come up with "solutions to different kinds of problems". EN joked when asked why he thought of construction "we're Irish, are we not? That's what we do" …but there is some truth to this, as there are many connections to construction in Ireland that draw young people into the industry.

LH's father was a clerk of works, and when at school he found that "trades was the thing to do." CL's story portrays a picture of an enduring interest in construction from one generation to the next. He tells of following his father onto site, where as a child he would sit on his father's table in the site office and think "I'd love to be running a job like that". Thirty-seven years later and coming close to retirement himself, CL describes with pride how one of the company's key site managers (interviewee XM) initially trained under him, and now his nephew has started training in the same company. ED also followed his father into construction - "it just happened that I was out with him at a young age." QT went from school to a construction apprenticeship for several reasons - he said that he thought he wasn't smart enough for university, his father worked in construction for 47 years, and he actively chose the job based on the variety: "my intention was not to work in an office." His son is now working in construction - he had been intending to go to university after his 'A' levels, but he joined his dad on site, he "didn't like the office environment and went out on the tools so he's been here five years now." EMD "grew up on building sites…I was playing on [concrete] blocks": his father owned a building company, and he had a long-term plan to take over the company when his father retired, but the company went into liquidation once he had qualified. Despite this, he has no regrets and has always been in work himself.

Of the interviewees who didn't have a father in construction, many had a close relative or friend who influenced their decision to join the industry. EF's uncle was a plumber, and his mother was keen that he become a plumber, as she saw this as a good, steady job. He goes on, "it was a family business and I've a pile of cousins are all plumbers." He's never regretted the decision "I wanted to be a plumber…I love it."

*Didn't want an office job, liked working with hands*
The ability to work outdoors, the creative aspects of construction, and the variety of work and work locations, was a big appeal for many of the interviewees. XJ always wanted to be a joiner - "working with me hands, working with wood, to get satisfaction in what you can make". QE relished the idea of the challenge and variety that construction presented - "I liked the fact you were outside, and I liked the fact you could be involved in problem-solving and seeing things constructed and seeing things grow." Similarly, JK knew that he did not want to work in a standard office job, so by

the process of elimination chose to study Civil Engineering at university. XM studied woodwork at school and enjoyed it, going on to become a Master Joiner. DG was also inspired by school woodwork: "I enjoyed it that much and I thought if I'm doing this full-time work won't be laborious; you'll go to your work and you'll enjoy your work and you get paid to do it."

*Accident / chance / regrets*

TY is coming close to retirement as a Quantity Surveyor, with 53 years' experience in construction. He didn't initially want to work in construction - he had applied, and was accepted, as a trainee journalist in Dublin but he "took cold feet" and "wouldn't go to Dublin, because I was only seventeen and didn't want to leave home", so he looked for a local job. By chance, an ex-teacher knew of a job working in the office of a construction company. He started as the "boy in the office" and the job evolved into a Quantity Surveying position. Whilst the interviewee did not say that he regretted working in construction, he "very often" regrets not taking the journalism position but did qualify this saying "I did well enough on what I decided to do."

Some interviewees did not initially start in construction: PJ started working in a clothes shop, although his cousins were working in construction. He hated it, and reported during the interview that when he was asked to work for a joiner, he replied, "I'll do anything to get out of here" and has been happy working in construction since. ME originally studied agriculture, and he admitted that he was "pushed into" construction as this was the family business and given the choice, he'd rather be a farmer. The business group also contains a farm, and he was originally only meant to be working in the construction side of the business 2 days a week, but this has snowballed into a full time, key position with a lot of responsibility.

Several interviewees started working in construction as a 'stop gap' and have never left: ME started working in his brother's business in the summer before going back to school to do 'A' levels and is still there 39 years later. TS started temping for a local council for six weeks in property management and is still working in construction 38 years later. She originally wanted to work with horses and is still wistful for the life that might have been, but is grateful for the steady income that her 'sensible job' can give her family, as her husband is self-employed.

*Do the respondents enjoy their jobs? What do they enjoy most?*

Remarkably, every one of the 25 interviewees responded to this question positively - not one disliked their job. Some, like PJ said "I love me job. I love work," EH said that "I wouldn't do any other job now", and ME said "I probably enjoy my work more than most people enjoy their work." Each interview then probed the reasons why this should be the case.

*Variety*

One factor that came out strongly across the interviews was the variety that comes with a career in construction. FS said that "I absolutely enjoy my job… it's so diverse…you are [always] working with different people. Every job you go to is different; it's got its own set of problems." PA liked the constant variety "you are dealing with different people as jobs vary and jobs go on, there's no two days are the same." NC agrees with this perspective "it's all about the variety, every day you come in, something different, you never know what you are going to be doing, from day to day." QT describes the unique opportunity that a career in construction can offer: "it's a challenge and … it's different every day. I could honestly say - there's not many places you could say where you are going to be thrown a new challenge every day."

Due to the project-based nature of construction, operatives find that their work location, their co-workers, consultants, clients and the physical product changes with each new job - a variety that is unparalleled in any other industry. This changing nature of construction has often been presented in the literature in a negative light.

*Challenge, always keep learning*

One upside that comes with the variety inherent in construction is the idea that workers are never 'done' when it comes to learning new techniques or methods of construction. As FS put it "You always learn in the construction industry, there's new processes, there's new products, there's new ways of doing things." QE described how he enjoyed "challenging the mind, problem solving, planning," and DG said, "Things is always changing within the building game and you are always learning so there's no question about that and the challenges are there every day." EF acted as a mentor in his firm for young trainees and reported that "I always say to the young boys, every day is a school day - always learning" - a statement repeated in a similar format by XJ, CL, ED and TY. Referring to the constant need to learn, NC said of the job "that's why it is interesting, you know. There's different problems arise every day." BD talks of the satisfaction that comes from mastering new challenges: "I feel kind of proud of myself that I was fit to do something that was hard and that I wasn't fit to do before."

*Handover stage*

Many of the interviewees talked about the project handover stage, where the physical evidence of their hard work comes together, as their favourite part of the job. PJ said, "I love to see the end of the project," and FS agrees: "obviously the best part is the handover at the end, when the client gets the building, and they are delighted usually with the end project." XM's words help to expand why he likes this stage: "if you can walk away and leave a good job behind you, that's job satisfaction." He goes on to say, "I get the same buzz out of handover and job satisfaction in every job, regardless of what size." BD talks about the sense of achievement at the end of a project "when you are at the very start there and it's just a hole in the ground, you are just doing foundations and then a year later and you've got something in front of you" and goes on to say "when it is all done and you are able to look back on it, then you look and go, 'that's brilliant looking and I done it.'" The opportunity to build a new facility from scratch, to create a physical asset that is a testament to the skill of the people who designed and built it, is not typically an opportunity available to medics, bankers, politicians, or lawyers.

*Value to society - community recognition*

The respondents clearly experience satisfaction when seeing the project in use; particularly if this project is local to where they live and they can feel validated by the positive feedback in their community. PA said that the reputation of his employer in the community was a big factor influencing his choice to come and work for them: "it's important to have pride in your work, especially being local." FV, a company director, talks of the impact the business can have on his community as one of his main motivations, saying "to complete and hand over a building that you can walk past every day, you can drive past every day and…maybe you look back in five years, ten years, twenty years and in my case some of the buildings over forty years, that is a building…of which we are very proud." DG agrees with this sentiment, saying "it is nice to see a building completely finished and full of people and being used for what it was intended for." When EMD's project won an award, he said that he loved "people associating you with that particular project."

*If the respondents won the lottery and didn't need the money, would they still do their job?*

A number of the respondents laughed when asked this question, but many said that they would like to carry on working in construction in some form if they no longer needed the money. Responses ranged from those who said they would make no change: "If I won the lottery, I don't think it would change my way of going whatsoever" ED; QT "the honest answer is I probably would stay!" to those who would carry on working in construction, but under their own terms. Of the latter group, QE said, "If I won the Lottery, I would love to do the same job but maybe less of it, concentrate maybe - if I could pick my projects that I wanted to be involved with, that would be ideal," and BD said, "if I won the Lottery…I would start my own [construction] company." The respondents' enjoyment of their job in construction corresponds with a 2014 CIC survey, where 83% of those working in the construction industry surveyed said that they were proud to work in the construction industry (CIC, 2014). This number is echoed in a Considerate Constructors survey conducted in 2018, where 85% of those surveyed said that they would recommend construction as a career to young people (CCS, 2018).

## CONCLUSIONS

The difference between the downbeat view of the construction industry from the 2015 YouGov survey of 18 - 24-year-olds quoted in the introduction, and the CIC and Considerate constructors' poll of those working in the construction industry is striking. Only 5% of young people in the YouGov survey rated the construction sector as desirable to work in, but 83% of respondents in the CIC poll were proud to work in the construction industry. This affirmative attitude to the industry is echoed by this study where the interviewees' experiences of working in the construction industry are overwhelmingly (but not exclusively) positive. Key elements of the job that participants enjoy include; working outside, variety, the opportunity to solve problems and learn new skills, and creating a physical object or facility that has an impact on their community. The satisfaction at handover, when they could see the results of their work coming together successfully, and where the value of their work to their community was demonstrated, was a key moment for all of the interviewees. This side of construction is rarely promulgated, as scandal and problems tend to make better headlines. Young people should be made aware of this positive side of a career in construction.

One powerful tool to increase awareness of the industry is through the use of role models. Those already working in construction should be encouraged to talk to their friends and relatives about their experiences in construction - good and bad. It is important that potential recruits in construction get a rounded picture of the industry, as there is little benefit in recruiting people for whom construction would not be a good fit. Moreover, Gibson (2004) found that role models do not need to interact with individuals to be effective. Industry bodies should redouble their efforts to amplify the positive voices and stories of a diverse range of people who are working in the industry, to allow teenagers to imagine themselves in the position of these role models and 'try on' construction as a career as described by Ibarra (1999). Widening access to a variety of role models beyond friendships and family members will avoid the narrowing of choices described by Bentolila *et al. (*2008) and expand the possibilities available to young people in their choice of occupation.

Clearly, there are still a lot of problems that need attention in the construction sector and the academic literature rightly focuses on those; however, more work is needed to examine the benefits of working in this sector, not least to support recruitment efforts. This is only a preliminary study, and the sample may not be representative. Perhaps the participants work in particularly well managed organisations. Certainly, the skewing of the sample towards a white, male demographic means that minority experiences of the industry - precisely those experiences which could illuminate some of the questions raised - are not represented in this study. All participants were working in construction at the time of interview - those who were particularly unhappy in this working environment may have left construction thus will not be captured in this sample. This qualitative study starts to explore some of the positive aspects of working in construction, but does not look at consultancy, make cross industry or cross sector comparisons, and does not attempt to compare job satisfaction across different trades or positions in the construction sector.

The issues with the construction industry in terms of poor health and safety, poor mental health and working environment are well rehearsed; however, there is less literature exploring the positive impact that a career in construction can have on individuals and their communities. Perhaps it is time that construction tells a better story about the opportunities and rewards that are available in careers in this sector.

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# SKILLS TRANSFER AS A MEANS OF ADDRESSING SKILLS SHORTAGE IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

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Measures to manage the effects of skills shortage found in the built environment sector are crucial as the construction industry is a substantial contributor to the country's gross domestic product (GDP) in most developing states. The severity of the challenge of the lack of skills and its impact is felt most severely in the construction industry as the construction industry is driven by equipping labour with the necessary skills to provide finished products such as housing, roads and infrastructure. It is therefore critical that construction companies find ways to retain and sustain skills within their firms if they are to thrive and remain competitive in today's global market. Several strategies have been implemented with the aim of alleviating skills shortage and facilitating skills transfer. The purpose of this paper is to assess the role played by senior workers in the transfer of skills in contracting firms within KwaZulu-Natal. This was a quantitative study, 33 employees in construction firms were randomly selected to complete the questionnaire. The findings indicated that junior workers found that unemployability is the largest contributing factor to skills shortage. The majority of the participants agreed that skills transfer from senior workers is a viable solution to skills transfer. Improvements to the current skills transfer mechanisms were recommended as a means to produce more skilled junior workers. Platforms that facilitate communication between senior workers and junior workers, the identification of goals, workplace shadowing and workshops were recommended.

Keywords: junior workers; skills transfer; senior workers; workplace shadowing

## INTRODUCTION

The construction sector is seen as critical in emerging countries such as South Africa, as these countries attempt to satisfy the requirements of the Sustainable Development Goals (SDGs) through measures to reduce poverty, ensure environmental sustainability and enrich lives (United Nations, 2021).

The construction sector is often the most labour-intensive industry when contrasted to numerous different enterprises as it allows for the employability of unskilled workers (Giang and Pheng, 2011). The construction industry is made up of a combination of participants that are critical to the sustenance of the industry and equips labour with the necessary skills to provide project deliverables (Chan, Chan, Lam, et. al., 2011).

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The lack of skills in the construction industry is a worldwide challenge. But this study focuses on the skills shortage in the South African industry and skills transfer from senior to junior workers as a means to address this. This study was considered important because governments in developing countries such as South Africa often rely on the built environment sector as a mechanism by which infrastructure projects are delivered and in which jobs are created to grow the economy. It is critical that construction companies find ways to retain and sustain skills within their firms if they are to thrive and remain competitive in today's global market.

## LITERATURE REVIEW

*Skills shortage*

In a world with an increasing number of people, a growing economy and growing environmental degradation, the sustainability of skills in the construction industry is required (Dernbach, 2011). A growing population within a country, creates an additional need for construction industry products (Engels and Liu, 2011) such as roads, housing etc. Because contractors are crucial to the success of a project this study looked at the skills transfer in construction firms. Van der Merwe and Barry (2010:1) defines skills shortage as "a situation where employers struggle to fill or experience challenges in filling vacancies in a specific occupation or specialisation owing to an insufficient number of workers with the required qualification and experience".

The lack of skillsets that are critical to the construction industry is a challenge to contractors as they rely on the services rendered by skilled workers such as project managers, technicians, labourers, and construction workers in order to successfully meet their project targets (PWC, 2019). The contractor is an individual or a firm undertaking a contract required to perform a job. Contractors are usually skilled specialists who are entrusted with the task of carrying out the actual construction works and are responsible for the management of a project which includes contract administration, project financial management, material and equipment procurement and the monitoring of project progress (Yoke-Lian, Hassim, Muniandy and Teik-Hua, 2012) and therefore require skills to monitor and maintain their companies and keep them successful.

Skills shortage is regarded as a key risk to project delivery when taking infrastructure development in South Africa into consideration (PWC, 2019) and has a severe negative societal and economic impact. Leibbrandt, Woolard, McEwen and Koep (2010) are of the conviction that problems arising as a result of skills deficiency in South Africa include the significant levels of joblessness and the resultant desperation apparent in local townships. It was manifested in business owners who are struggling to locate suitably skilled people to function within their businesses and in graduates who find that their qualifications render them unemployable. In order to reduce skill shortages in the industry, skills transfer in the workplace is regarded as a possible solution.

*Skills transfer*

A skills transfer is the method in which one teaches an employee how to perform a new task or skill. Skills transfer is regarded as a tool to counteract the skills shortage in the construction industry and there are various types of skills transfer strategies, such as mentorship, for employees (Dorjkhuu, 2013). According to Hoffmeister, Cigularov, Sampson, Rosecrance and Chen (2011) skills transfer between employees has the desired effect of creating a lasting bond between the employees. Secondly,

senior employees train future business leaders and this provides a way for them to give back to the organisation (Hoffmeister, et.al, 2011).

The organisational benefits of skills transfer include the ability to improve and nurture employees and plan channels of progression inside the firm; sharing of basic business information and marketplace trends; nurturing and transfer of scarce skills; increase performance and project delivery and improves worker's commitment to the firm (Marsh, 2012).

Skills transfer leads to the improvement of competitiveness, quality, productivity and the setting out of future ideas to individuals and organisations, which makes it important that the choices of training methods undertaken are properly considered such that its effectiveness is monitored (Iruobe, Ojambati, Akinpade, and Iruobe, 2012).The need for training is dependent on a variety of factors which include but are not limited to; incoming of new employees, increasing morale of workers, response to the changing environment and the improvement of performance (Iruobe, et. al., 2012).

*Government initiatives*

Government has invested in finding solutions to skills shortages (Rasool and Botha, 2011). According to Statistics South Africa, the government had awarded R5 billion in 2016 towards the course of improving higher education. In the 2020 budget speech, R200 million was committed towards improving technical skillsets, universities, colleges and vocational skills improvement (South Africa, Department of Treasury, 2020). Tertiary training is important, but it is not enough to completely tackle the challenge of skills shortages (Rasool and Botha, 2011). Skills transfer strategies are still required to tackle the skills shortage.

The South African government introduced different initiatives to tackle the skills shortage challenge within the construction industry. In 2020, the Construction Industry Development Board (CIDB) established a vehicle for the implementation of the skills development, namely the Standard for Developing Skills through Infrastructure Contracts which seeks to restore the construction industry skills supply pipeline by creating a system of flexible, sustainable, and structured workplace learning opportunities for learners who have completed the theoretical part of their training and require workplace experience (CIDB, 2020).

Forming policies that facilitate skills development is one of the other ways that government has been investing towards skills development for example, forming the Expanded Public Works Programme (EPWP) initiatives as an intervention to skills shortage which was initially positioned as a skills training intervention that provides a stipend salary. The Expanded Public Works Programme is South Africa's largest active labour market intervention.

The Department of Labour has also participated in skills development through the formation of the National Skills Development Strategy (Department of Labour 2005) whose core mandate is skills development. Another form of government intervention has been the passing of the Skill Development Act of 1998 which gave rise to SETA, an acronym for Sector Education and Training Authority (Republic of South Africa, 2020). SETA serves the function of enabling skills development by funding and improving training and learning in the workplace in order to help jobseekers to secure jobs. To date, there are 21 SETAs in South Africa functioning in different sectors (Department of Economic Development, 2020). The Construction Education and Training Authority (CETA) provides support to graduates through offering bursaries,

learnerships, work integrated training opportunities and student placements (CETA, 2020) and implements the values of skills development in the workplace by awarding funds that cover a percentage of the cost of skills development at work to approved employers (CETA, 2020). Park (2012) found that members who attended work programme training were at an advantage to their counterparts and performed better and received a higher income.

The sustainability of skills positively impacts the performance of the built environment sector (Dernbach, 2011). Upskilling junior workers and ensuring that skills are sustained and passed over in due time to reduce the skills deficiency in the building industry is important because the industry is required to be agile, if it is to maintain the same pace and effectively tackle the challenges of this modern era (Aouad, Ozorhon and Abbott, 2010).

## RESEARCH METHOD

For this quantitative study, the population comprised of two hundred and thirty contractors recognised by the KwaZulu-Natal Master Builders Association (MBA) as 'general contractors'. Furthermore, the contractors were subdivided in accordance with their location. Contractors located within the city of Durban were selected, thus yielding a total of 55 contractors. Thirty-three contractors, which was deemed sufficient for this quantitative study (Lewin, 2005), were then randomly selected for the distribution of online questionnaires. The questionnaire focused on questions pertaining to the skills transfer from senior to junior workers as a means to address the skills shortage in the industry. Prior to conducting the questionnaires ethical clearance was obtained. All 33 contractors responded. The data was analysed using Microsoft Excel. The relative agreement index was used to rank the Likert scale items (Burke and Dunlap, 2002). It has an indication of 1 as a perfect match and 0 as no agreement at all. The researchers presented a value more than 0,5 as an indication of a good agreement, a value less than 0,5 as a bad agreement and 1 or as indicating a perfect match. The RAI formula used was:

$$\mathrm{RAI} = \sum \mathrm{w} \div \mathrm{A} \times \mathrm{N}$$

W-weighting given to each statement ranging from 1-5, A = highest weight and N= sample size.

## DISCUSSION

Keeping all workers competent in technology and skills has raised the awareness of multigenerational training. Senior workers refer to those who have worked more than three years and are 26 years and older (Eversole, Venneberg and Crowder, 2012) while junior workers are those who are aged between 18-25 years old and are newly employed with less than 3 years' experience. Junior workers are younger and less experienced and require about a decade before they can be regarded as skilled and experienced (Eversole et.al., 2012). Forty two percent of the participants in this study had more than 3 years' experience indicating that they are senior workers with the remaining participants being classified as junior workers.

Table 1 depicts what the participants regarded as the causes of skills shortage. Eighty two percent of the workers agreed that unemployability of young graduates was a significant contributor towards skills shortage. This concurs with the study by Rasool and Botha (2011) who found that the problem of skills shortage in South Africa can be

attributed to the previous mediocre educational standards offered to the majority of the population and substandard results in core subjects such as math and science. The South African education system weakly addresses the challenge of skills shortage. There is a constant supply of graduates for careers that are no longer experiencing growth adding to skills mismatch and shortages (ibid).

Changes in technology was also seen as an important cause of skills shortage. Sixty seven percent agreed that the lack of training programmes was also a cause of skills shortages. Traditional work training methods such as universities are at times ineffective and progressively fail to meet the expectations of industry because their objectives are centred around the advancement of information and not necessarily the attainment of 'hard" skills (Balynskaya, Sinitsina, Kuznetsova and Koptyakova, 2015). Employers expect graduates to be well-versed on matters pertaining to the area of work, keep abreast of new work trends and be practically competent (ibid). This is especially shown by employers advertising jobs that require 3-5 years of experience for an entry level job. The expectations of employers clearly demonstrate a need for skills transfer and workplace training (Balynskaya, et.al, 2015).

Emigration and resettlement otherwise known as the 'brain drain' is another stressing component of the skills challenge in many African countries (Dumitru, 2014). Brain drain describes the international migration of the valuable and experienced workforce thereby taking away human capital from the poorer countries. The movement of highly trained people from the native nations to first world countries adversely affects poorer countries since the number of knowledgeable people within its talent pool decreases. The brain drain was ranked 4th as a cause of skills shortage.

*Table 1: Causes of skills shortage*

| Causes of skills shortage | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| Unemployability of young graduates | 4,03 | 1,08 | 0,81 | 1 |
| Changes in technology | 3,52 | 1,10 | 0,81 | 1 |
| Lack of training programmes | 3,94 | 1,22 | 0,76 | 2 |
| Inadequate understanding of types of skills | 3,70 | 0,95 | 0,74 | 3 |
| Brain drain | 3,64 | 1,14 | 0,70 | 4 |
| Lack of academic training | 3,33 | 1,19 | 0,67 | 5 |
| Skills mismatches | 3,00 | 1,03 | 0,60 | 6 |
| Retirement of staff | 2,94 | 1,11 | 0,57 | 7 |

Table 2 represents challenges that affects junior workers in the construction industry. The main challenge that junior workers experienced was underqualification. Fifty eight percent of the participants felt that they lacked experience (ranked 2nd). The 3rd challenge experienced by junior workers was the fact that they were unfamiliar with the people they worked with. Of interest was that fact that the complexity of the work that needed to be conducted was not considered as a major challenge.

The South African construction industry also faces is a high dropout rate in skills development programmes. Government initiated skills development programmes experience dropout rates ranging between 45% and 65% in most skills development programmes.

*Table 2: Challenges experienced by junior workers*

| Challenges faced by junior workers | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| Underqualification | 2,94 | 1,190 | 0,782 | 1 |
| Lack of experience | 3,45 | 1,252 | 0,691 | 2 |
| Unfamiliar with people I worked with | 3,27 | 1,232 | 0,682 | 3 |
| Not used to the working environment | 3,24 | 1,001 | 0,648 | 4 |
| Unfamiliar with the office | 3,12 | 0,111 | 0,624 | 5 |
| Complexity of work | 3,06 | 1,116 | 0,612 | 6 |
| Lack of skills needed for my job | 2,73 | 1,257 | 0,545 | 7 |

Training for a newly employed graduate is critical as graduates leave the educational institution learned in the theoretical sense but lacking practical experience. Table 3 indicates that 67% of the junior workers leave skills development programmes because they receive better jobs opportunities. They also feel that they do not get enough help (ranked 2nd). The least likely reason for junior workers to leave skills development programmes was the lack of commitment.

*Table 3: Reasons why junior workers leave skills development programmes*

| Why Juniors leave skill development programmes | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| Leave for better jobs | 4 | 0,95 | 0,776 | 1 |
| Do not get enough help | 3,38 | 0,976 | 0,655 | 2 |
| Lack of adequate support from seniors | 3,18 | 1,211 | 0,636 | 3 |
| Workplace is mundane | 3,06 | 0,998 | 0,612 | 4 |
| Junior workers are uninspired | 3,03 | 1,075 | 0,606 | 5 |
| Lack of commitment | 2,18 | 1,103 | 0,436 | 6 |

The transfer of skills has received increased attention because of its significance and the role it plays in the construction industry. The transfer of both hard and soft skills is important in the wellbeing and success of the construction company. Table 4 shows different skills transfer strategies from senior workers to junior workers that can be used. Mentoring which is defined as "human resource development mechanism that aids in the learning and the transfer of knowledge and skill" (Hamburg, 2013: 219) is generally regarded as the more popular method of transferring skills.

But for this study, surprising seventy three percent (73%) of the respondents agreed that working in projects with diverse teams was the first method that was selected as a skill transfer method. This was followed by mentoring and meetings between senior and junior workers. This is similar to the findings by Dorjkhuu (2013) who found that periodic training, every morning training (or quick training) and team-based learning were useful strategies for skills shortage interventions in the workplace. Successful workplace training is centred around the core purpose of producing an expert technician who is able to think critically and apply themselves professionally in a manner that promotes individuality (Balynskaya, et. al., 2015).

*Table 4: Skills transfer methods*

| Skills transfer from senior workers to junior workers | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| Project tasks in teams | 3,79 | 1,023 | 0,694 | 1 |
| Mentoring | 3,36 | 1,319 | 0,673 | 2 |
| Meetings between senior and junior workers | 3,06 | 1,368 | 0,612 | 3 |
| Weekly and monthly training sessions | 2,73 | 1,442 | 0,545 | 4 |

Table 5 represents how the transference of skills in the workplace have helped the participants. Ninety one percent of the participants agreed that skills transfer helped them grow professionally. This was followed by communicating with senior workers which helps junior workers perform better. Communicating with senior workers was also seen as important for the transfer of skills.

*Table 5: Success of skills transfer*

| Success of skills transfer | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| Skills transfer help me grow professionally | 4,58 | 0,751 | 0,915 | 1 |
| Communicating with senior workers helps me perform better | 4,39 | 0,747 | 0,879 | 2 |
| Communicating with senior workers is important for skills transfer | 4,36 | 0,783 | 0,873 | 3 |
| Communicating with senior workers motivate me | 4,21 | 0,992 | 0,842 | 4 |
| I find that I am now more skilled | 4,06 | 1,059 | 0,812 | 5 |

Table 6 represents the results of skills transfer measures. Eighty two percent of the participants agreed that students could benefit from skills transfer. Seventy three percent of the participants agreed that skills transfer increases learning when discussing work with their peers. The participants also agreed that skills transfer allowed then to communicate better.

*Table 6: Assessment of skills transfer*

| Assessment of skills transfer | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| I think the students could benefit from skills transfer | 4,06 | 1,014 | 0,800 | 1 |
| I learnt through interactions with others | 3,97 | 0,933 | 0,770 | 2 |
| Skills transfer allows me to communicate | 3,81 | 0,896 | 0,745 | 3 |
| I understand the importance of skills transfer | 3,94 | 1,153 | 0,739 | 4 |
| Skills transfer helps me do my job better | 3,94 | 1,124 | 0,739 | 4 |
| Increases my learning | 4,00 | 1,114 | 0,727 | 5 |
| The environment at work is conducive to skills transfer | 3,58 | 1,025 | 0,673 | 6 |
| I have not benefitted from skills transfer | 2,31 | 1,281 | 0,448 | 7 |
| I find interactions difficult | 2,32 | 1,077 | 0,436 | 8 |

Table 7 shows structures that can be put in place for skills transfer. Seventy three percent of the participants agreed that senior workers should help junior workers

identify skills transfer goals. Senior workers taking junior workers alongside them was ranked second. Workshops were also identified by 63% of the participants as a method to transfer skills. The participants did not believe that recognition and reward of senior workers enhanced skills transfer.

*Table 7: Structures put in place for skills transfer*

| Structures put in place for skills transfer | Mean | Std Dev | RAI | Rank |
|---|---|---|---|---|
| Seniors help junior workers identify skills transfer goals | 4,06 | 0,914 | 0,788 | 1 |
| Senior workers take junior workers alongside them | 3,91 | 1,058 | 0,758 | 2 |
| Workshops | 3,91 | 0,928 | 0,758 | 3 |
| Platforms of engagement | 4,00 | 1,033 | 0,752 | 4 |
| Motivate diverse teams | 3,84 | 1,221 | 0,745 | 5 |
| Give incentives to junior workers | 3,72 | 1,198 | 0,721 | 6 |
| Employment opportunities | 3,74 | 1,094 | 0,703 | 7 |
| Appoint a supervisor | 3,74 | 1,316 | 0,703 | 8 |
| Recognise and reward senior workers | 3,52 | 1,338 | 0,661 | 9 |

# CONCLUSIONS

Construction projects are characterised by a high level of design knowledge, technical skills, competent human resources and managerial capabilities. The severity of the challenge of the lack of skills and its impact is felt most severely in the construction industry as the construction industry is driven by equipping labour with the necessary skills to provide finished products such as housing, roads and infrastructure. As an industrial sector, the construction industry is reliant on the conservation of skills in the industry.

Unemployment, changes in technology and lack of training programmes were considered as some of the important causes for skills shortages experienced in the industry. Skills transfer is important to overcome the challenges that junior workers in the construction industry experience, such as underqualification, lack of experience and the fact that they were unfamiliar with the people they worked with. Skills transfer helps junior workers grow professionally, improve their communication and their performance. The respondents in this study agreed that working in projects with diverse teams was the best method for the transference of skills.

In terms of structures that can be put in place for skills transfer, it was suggested that senior workers should help junior workers identify skills transfer goals, junior workers should shadow senior workers and workshops should be used as a method to transfer skills. The research contains information regarding the transference of skills in the construction industry and analyses the importance of these skills being transferred amongst employees within the construction industry thereby creating an environment with increased level of skill while trying to reduce the skill shortage predicament.

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# PROFILE OF PROJECT MANAGERS' COMPETENCIES FOR COLLABORATIVE CONSTRUCTION PROJECTS

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Several studies have indicated that project managers' competencies contribute to construction project success in a considerable manner. However, these studies have mainly addressed subject of the interest in the context of traditional construction projects. The choice of construction project delivery models is increasingly turning from traditional ones towards the integrated ones (also called collaborative delivery models). Thus, it is imperative to understand how the competency profile for the project managers needs to be developed to support their successful performance in construction projects with collaborative delivery models. To that end, the survey strategy was employed. Then, a self-evaluation questionnaire comprising 60 linguistic statements, representing 30 behavioural competencies, was utilized for analysing the type and frequency of project managers' different behaviours in their everyday work in their current and target states (as is, and as the informant wants it to be in the future). This questionnaire was sent to 33 project managers of relevance in Norway and Finland with a response rate of 73%. The findings present the competency profile of project managers for collaborative construction projects. This competency profile comprises two groups of (i) competencies contributing to the individual performance of the project managers, e.g., trustworthiness, stress tolerance, initiative, optimism, and (ii) competencies contributing to the team performance and dynamics, e.g., conflict management, group capabilities, understanding others. The findings of this study can be insightful for project managers in collaborative construction projects to benchmark their competencies and improve their performance, and for their employers to hire the right project manager.

Keywords: competency; collaborative project; integrated project delivery

## INTRODUCTION

The differentiators between successful performers and average ones have come to be called competencies (Zwell 2000). Moradi *et al.,* (2021: 3) stated that "competencies are underlying characteristics (motives, traits, self-concept, skills and knowledge) which cause different kinds of actions while being combined with an intent, which is situation-oriented. The resultant action in a given situation is called competency." In terms of improvability, competencies related to skill and knowledge are relatively easy to develop, competencies related to motive and trait are hard to develop, and

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finally the competencies related to self-concept lie somewhere between and are somewhat hard to develop (Spencer and Spencer 1993; Zwell 2000). Competency, due to its behavioural nature, can predict and contribute to successful performance in a consistent manner. Consequently, project managers need to possess certain competencies because competency is an important predictor and facilitator of their successful performance, which in turn, has considerable effect on project success (Müller and Tuner 2007; Spencer and Spencer 1993; Zhang *et al.,* 2013; Moradi *et al.,* 2020a).

In the field of construction projects, the importance of project managers' competencies is considerably high as they are greatly responsible for the successful completion of the projects. Consequently, there exists substantial interest from the research community towards project managers' competencies in construction projects (for instance, Ahadzie *et al.,* 2008 and 2009; Dogbegah *et al.,* 2011; de los Ríos-Carmenado *et al.,* 2014; Klendauer *et al.,* 2012; Tabassi *et al.,* 2016). These efforts, in a holistic view, can be divided into two parts: studies addressing project managers' competencies in construction projects with traditional delivery models, and in construction projects with collaborative delivery models and/or working practices.

Traditional delivery models of construction projects (e.g., design-bid-build, design-build) usually separate design and construction phases, which in turn hinders early involvement of the contractor and other key parties in the project and its design phase. Moreover, the lowest construction price is usually the main criteria for selecting the contractor (Forbes and Ahmed 2011). On the other hand, collaborative delivery models (e.g., alliancing, partnering, integrated project delivery) have some elements and characteristics such as early involvement of the key participants of the project, shared risk-reward based on project outcome, joint project control and trust-based relationships. These elements enable the key parties, with aligned interests, to work together (collaboration) and exchange information (cooperation) for the good of the project (Engebø *et al.,* 2020; Lloyd-Walker and Walker 2015; Fischer *et al.,* 2017, Oakland and Marosszeky 2017). In this study, "traditional construction projects" and "collaborative construction projects," represent the terms "construction projects with traditional delivery models," and "construction projects with collaborative delivery models and/or working practices" respectively.

According to (Moradi *et al.,* 2021), the undertaken studies addressing project managers' competencies in construction projects have mainly focused on traditional construction projects (for instance, Ahadzie *et al.,* 2014; Abdullah *et al.,* 2018; Dziekoński 2017; Mutijwaa and Rwelamila 2007; Shah and Prakash 2018). Fig 1 shows those competencies for project managers of traditional construction projects which have been mentioned in the literature more than five times. Project managers' competencies in collaborative construction projects have been studied in a limited manner by the research community (e.g., Walker and Lloyd Walker 2011; Moradi *et al.,* 2020b). This study aims to find out how the competency profile for the project managers needs to be developed to support their successful performance in collaborative construction projects.

## METHODOLOGY

The survey strategy was employed for conducting this study where a web-based questionnaire, in a self-evaluation manner, was utilized to identify the most appropriate competencies of project managers in collaborative construction projects. Self-evaluation of behavioural competencies is an efficient and effective way for

studying project managers' competencies in a certain context (Liikamaa 2015; Chang *et al.,* 2009).

| Competency/Reference | Edum-Fotwe and McCaffer, 2000 | Dainty et al., 2004 | Cheng et al., 2005 | Mutijvaa and Ryelamila, 2007 | Ahadzie et al., 2008 | Chen et al., 2008 | Ahadzie et al., 2009 | Lee et al., 2011 | Dogbegah et al., 2011 | Hwang and Ng, 2013 | Zhang et al., 2013 | Iaili Jabar et al., 2013 | Liyana Othman and Jaafar, 2013 | Panas et al., 2014 | Omar and Fayek, 2016 | Tabassi et al., 2016 | Dziekonski, 2017 | Abdullah et al., 2018 | Shah and Prakash, 2018 | Moradi et al., 2018 | Frequency of appearance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Teamwork and cooperation | | ✓ | ✓ | | ✓ | | ✓ | ✓ | | | ✓ | | | | ✓ | | ✓ | | ✓ | | 9 |
| Cost management | | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | | ✓ | |
| Communication | | | ✓ | | | ✓ | | | ✓ | ✓ | | | | | ✓ | | ✓ | | ✓ | | 7 |
| Leadership | | ✓ | ✓ | | | | | | | | ✓ | | | | ✓ | ✓ | | | | ✓ | |
| Time management | | | | | ✓ | | ✓ | | | ✓ | | | | | ✓ | | ✓ | | ✓ | | 6 |
| Quality management | | | ✓ | | | | | ✓ | ✓ | | | | | | ✓ | | | ✓ | ✓ | | |
| Flexibility and adaptability | | ✓ | ✓ | | | | | | | | | | | | ✓ | | ✓ | | ✓ | | |
| Resource management | | | | ✓ | | | | | ✓ | ✓ | | | | | ✓ | | | ✓ | | | |
| Knowledge of construction | | | | | ✓ | ✓ | ✓ | | | | | ✓ | | | | | | | ✓ | | |
| HSE (Health, Safety, Environment) | | | ✓ | | | | | ✓ | | | | | | | ✓ | | | ✓ | ✓ | | |
| Experience | ✓ | | | | | | | ✓ | | | | | ✓ | | | ✓ | ✓ | | | | 5 |
| Ethics | | | | | | | | | ✓ | | | | ✓ | | ✓ | | ✓ | | ✓ | | |
| Problem solving | | | | | | | | | | | | ✓ | | ✓ | ✓ | | ✓ | | ✓ | | |
| Impact and influence | | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ | | | | | | |
| Team management | | | ✓ | | | ✓ | | ✓ | | | | | | | ✓ | | | ✓ | | | |

*Fig 1: Appearances of different project managers' competencies in the literature for traditional construction projects*

The questionnaire was sent to 33 project managers of collaborative construction projects. Data collection was undertaken through non-probability volunteer sampling. These project managers were selected among the ongoing or recently completed alliance and/or partnering construction projects in Finland and Norway. These two countries were selected for data collection because of their representativeness in terms of collaborative construction projects (Hosseini *et al.,* 2016; Moradi *et al.,* 2020b). The categories of the studied construction projects in this study comprise housing construction (residential building), institutional construction (hospital and school), and infrastructure (road and railway construction). In total, 24 questionnaires were completed by 12 Norwegian project managers and 12 Finnish project managers (February-April 2020), and a response rate of 73% was achieved. Among respondents, 35% of them are/were working as the client's project manager and 65% of them as the contractor's project manager. Fig 2 presents the demographic information of the survey respondents.

The utilized web-based questionnaire "Cycloid", by Evolute Technology, focuses on the evaluation of key behavioural competencies of project managers based on their current state (reality), target state (vision), and creative tension. Creative tension is the gap between personal vision (target state) and current reality (current state) (Chang *et al.,* 2009; Liikamaa, 2015). In other words, creative tension is the willingness of an individual (here the project manager) to improve his/her competencies further.

Accordingly, 30 behavioural competencies of project managers were evaluated through 60 linguistic statements, two statements per competency. In this study, respondents were asked to choose and determine the frequency of their behaviours in the situations presented by each linguistic statement on a scale: never/seldom/often/always in their current and target state.

How often these behaviours occur in the statements representing each competency were evaluated both in the current and target states through analysing the numeric values of the current and target states of the self-evaluation results. Liikamaa (2015) has categorized these 30 competencies into two main groups and five subgroups (see Table 1).

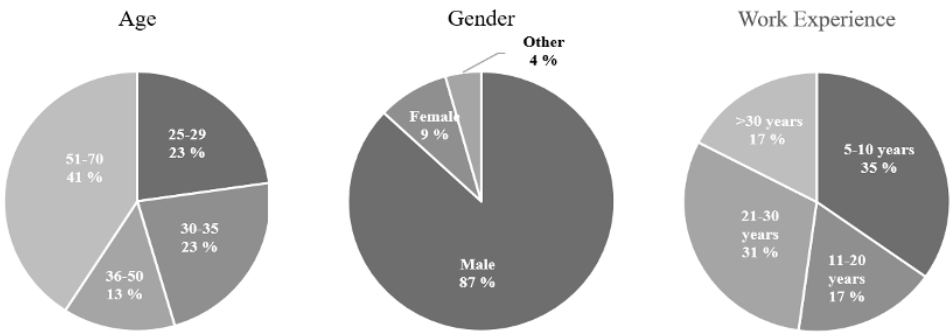


*Fig 2: Demographic information of the survey respondents*

After its first development, Cycloid has been utilized in several studies for evaluating project manager's competencies in different contexts (for instance Liikamaa 2015; Chang *et al.,* 2009; Moradi *et al.,* 2020).

*Table 1: Project managers' competencies in Cycloid*

| Group | Subgroup | Competency |
|---|---|---|
| Personal competencies | Self-awareness | Emotional awareness, Self-assessment, Self-confidence |
| | Self-control | Trustworthiness, Maintaining order, Flexibility, Innovation, Responsibility, Seeking information, Production efficiency, Decision quality, Stress tolerance |
| | Cognitive ability | Analytical thinking, Conceptual thinking, Language proficiency |
| | Motivation | Achievement orientation, Commitment, Initiative, Optimism |
| Social competencies | Empathy | Understanding others, Developing others, Leveraging diversity, Organizational savvy |
| | Social skills | Communication, Conflict management, Management, Leadership, Relationship building, Collaboration, Group capabilities |

Analysing the obtained research data from the field surveys revealed the significance of project managers' different competencies in the current state, target state and creative tension. Top 10 competencies of each respondent group in their current state, target state and creative tension were chosen and compared with each other for identifying the similarities and differences. Those top 10 competencies are seen as the most important ones contributing to the successful performance of the project managers. The ranking of the competencies listed in Fig 3 and 4 have been developed based on the median of the ranking in the current state, target state and creative tension of the two respondent groups. Those competencies with the same rank in both respondent groups, have been listed alphabetically.

# RESULTS

## Significance of Competencies in the Current and Target State

The following Fig 3 presents the results of comparing the 10 most significant competencies of the respondent groups in the current state and in the target state. Concerning the current state, it became clear that 7 out of 10 most significant competencies of both respondent groups were the same. These identified common competencies have been listed in Fig 3 and labelled as "common" under the category of "Current state." Conversely, 3 out of 10 most significant competencies in the current state of each respondent group were different, and therefore, those six competencies, in total, have been labelled as "specific" under the category of "Current state," as can be seen in Fig 3. Regarding the target state, similar results were obtained in terms of the number of commonalities and specificities (see Fig 3).

Among the identified common competencies in the current state, trustworthiness was the most significant one, with the statements concerning acting honestly and in an ethical manner and admitting mistakes. Among the specific competencies in the current state (Fig 3), responsibility was the most significant one. This competency is related to the quality of being responsible for the progress of one's own work and the feeling of responsibility over common goals. Fig 3 presents the complete list of the specific competencies in the current state. Regarding the target state, as listed in Fig 3, trustworthiness and responsibility, again, were the most significant competencies in the categories of "common" and "specific", respectively.

| Current state | | | Target state | | |
|---|---|---|---|---|---|
| R | Competency | Common or specific | R | Competency | Common or specific |
| 1 | Trustworthiness | Common | 1 | Trustworthiness | Common |
| 2 | Group capabilities | | 2 | Stress tolerance | |
| 3 | Initiative | | 3 | Conflict management | |
| | Optimism | | | Group capabilities | |
| | Stress tolerance | | | Self-assessment | |
| 4 | Flexibility | | 4 | Initiative | |
| 5 | Leadership | | 5 | Optimism | |
| 1 | Responsibility | Specific | 1 | Responsibility | Specific |
| 2 | Achievement orientation | | 2 | Collaboration | |
| | Collaboration | | | Leveraging diversity | |
| 3 | Leveraging diversity | | 3 | Decision quality | |
| 4 | Self-assessment | | | Maintaining order | |
| 5 | Analytical thinking | | 4 | Leadership | |

*Fig 3: Project managers' competencies in their current state and target state*

## Creative Tension

The 10 most significant competencies of both respondent groups in terms of creative tension were compared. As can be seen in the following Fig 4, production efficiency, decision quality and understanding others are three competencies which were common between both the respondent groups. Production efficiency is the capability of project managers in performing tasks quickly and according to high standards. Decision quality is about making decisions based on principles, purposes, and values. Understanding others points out to project managers' ability to sense the feelings and perspectives of other people.

The number of identified common competencies between creative tension of the respondent groups (listed in Fig 4) represents a weak overlap, unlike the current state and the target state. The most significant competency among the identified specific ones in creative tension is relationship building, which is related to the ability of project managers in building or maintaining friendly relationships or networks of contacts with people who are or might be useful in achieving work-related goals. The second one is communication representing the ability to listen to others, to openly express one's feelings, ideas and opinions and to read non-verbal cues. The third one is management for controlling people and things in a systematic way.

Stress tolerance, collaboration, and conflict management are three competencies here, which were also among the 10 most significant ones in the current and the target state. This amount of emphasis on these competencies means that stress and conflict amount can be very high in some collaborative contexts. The competencies (labelled "specific" in Fig 4) are seen, here, as the context-oriented ones which their contribution to the successful performance of project managers can be different based upon the specific characteristics of the collaborative construction projects, e.g., culture, contracting parties.

| Rank | Competency | Common or specific |
|---|---|---|
| 1 | Production efficiency | Common |
| 2 | Decision quality | |
| 3 | Understanding others | |
| | | |
| 1 | Relationship building | Specfic |
| 2 | Communication | |
| 3 | Management | |
| | Stress tolerance | |
| 4 | Collaboration | |
| | Conflict management | |
| 5 | Emotional awareness | |
| | Maintaining order | |
| 6 | Language proficiency | |
| 7 | Analytical thinking | |
| | Commitment | |
| 8 | Organizational savvy | |
| | Seeking information | |
| 9 | Achievement orientation | |

*Fig 4: Project managers' creative tension competencies*

## Profile of Project Managers' Competencies for Collaborative Construction Projects

A profile of project managers' competencies was developed for collaborative construction projects (see Fig 5). This was undertaken through analysing the 10 most significant competencies of both respondent groups in their target state and creative tension and identifying the common ones. This profile is comprised of two main parts: (i) competencies contributing to the individual performance of the project managers, and (ii) competencies contributing to their team performance and dynamics.

Competencies contributing to the individual performance
The obtained research results suggest that the identified competencies in this category mainly contribute to the project managers' individual performance (Fig 5). Accordingly, these competencies enable project managers to be successful in the tasks, which they need to handle by themselves. In terms of the improvability, these competencies are mainly hard or somewhat hard to improve (except production efficiency), and therefore it is the most cost-effective way for employers to hire those project managers which already have these competencies. Production efficiency is the only competency in this group, which is easy to improve, and a cost-effective way for improvement is training.

Competencies contributing to the team performance and dynamics
The competencies of this category, as can be understood from their definition, seem to mainly contribute towards team performance (Fig 5). Accordingly, these competencies (group capabilities, conflict management) enable the project managers to succeed in those tasks, which need to be accomplished in cooperation with other team members. It also means that these competencies, (understanding others, decision quality) positively affect the project managers' leadership, as a whole, which subsequently can improve team performance and dynamics.

Training provides a possibility for improving the competencies contributing to the team performance. These competencies that are improvable can be considered by employers for the recruitment of project managers and improving the performance of the present ones.

| Profile of Project Managers' Competencies for Collaborative Construction Projects | | | | |
|---|---|---|---|---|
| Category | Competency | Definition | Improvability | Key function(s) for employers |
| Competencies contributing to the individual performance | Trustworthiness | To deliver on promises, keep schedules, arrive on time on meetings and complete work as agreed and maintain trust between people. | Hard to improve | - Selecting those project managers that already possess these competencies |
| | Stress tolerance | To maintain performance when facing workload pressures and or organizational impediments. | | |
| | Initiative | The ability to see new possibilities and to seize opportunities. To do more than what is expected. | | |
| | Optimism | Pursuing goals regardless of obstacles and setbacks. | | |
| | Self-assessment | The comprehension of one's own limits and strengths. | Somewhat hard to improve | - Improving performance of the existing project managers by training<br>- Selecting the project managers |
| | Production efficiency | Performing tasks quickly and according to high standards. | Easy to improve | - Improving performance of the existing project managers by training |
| | | | | |
| Competencies contributing to the team performance and dynamics | Conflict management | The ability to negotiate and resolve disagreements between people. To reach out for win-win situations. | Somewhat hard to improve | - Improving performance of the existing project managers by training<br>- Selecting the project managers |
| | Group capabilities | The capability of working cooperatively with others, to be part of a team, to work together. | Easy to improve | - Improving performance of the existing project managers by training |
| | Decision quality | Making decisions based on principles, purposes, and values. | Somewhat hard to improve | - Improving performance of the existing project managers by training<br>- Selecting the project managers |
| | Understanding others | The ability to sense the feelings and perspectives of other people. | | |

*Fig 5: Project managers' competencies for collaborative construction projects*

# DISCUSSION

The findings of this study imply that successful project managers of collaborative construction projects need to possess two sets of competencies which are related to individual performance and team dynamics. Competencies related to individual performance are mainly related to the enduring characteristics and traits of the personality and therefore hard to improve. Conversely, the competencies related to team performance and dynamics can be easily improved through training, as they are related to skill and knowledge. Therefore, it can be argued that motive, trait and self-image-oriented competencies of project managers in collaborative construction projects can mainly contribute towards individual efficiency and effectiveness, whereas skill and knowledge competencies can contribute towards better team dynamics and performance. Those competencies of project managers contributing towards team performance can be improved by training. A slight improvement in these competencies (skills and knowledge) will result in considerable development in the performance of the whole project team (Spencer and Spencer 1993; Zwell 2000).

The presented competencies in Fig 5 seem to be in line with the prior research and aligned with the key characteristics and elements of collaborative construction projects. As it has been stated by different scholars (e.g., Oakland and Marosszeky 2017; Fischer *et al.,* 2017), collaborative construction projects represent a working environment in which the project manager, as the leader, collaborates and cooperates with the key participants based on trust-based relationships to form a single integrated team with aligned commercial interests solely for the best of the project. The developed profile in this study (Fig 5) presents those competencies which enable project managers to build reliable relationships with all team members (through trustworthiness, group capabilities, understanding others), and to reach out win-win situations (through conflict management and stress tolerance) when there is conflict within the project team. The project managers also need to be individually productive as the project leaders, where they need initiative, optimism, self-assessment and production efficiency competencies to succeed. The competencies presented in Fig 5 are also in line with the recent relevant studies (Moradi *et al.,* 2021).

The developed profile of project managers' competencies provides a novel research-based contribution. It includes practical insights for the project managers and their employers to be aware of the value-adding competencies in the collaborative

construction projects, which can be used in hiring the project managers and improving the performance of the existing ones. The presented results, for instance, in Finland with over 5 billion EUR launched collaborative construction projects (since 2013) can mean significant savings when selecting project managers with fitting competencies and also improving performance of the currently employed ones.

The presented competency profile and its details can be important and value-adding also for the other project professionals (e.g., project coordinators, site engineers, project controllers). These competencies, in the big picture, represent the individual efficiency and effectiveness, teamwork, mutual understanding and trust, collaborative cooperation, and no-blame related behaviour, which indicate the key elements and characteristics of collaborative construction projects (Moradi 2021).

## CONCLUSIONS

This study aimed at understanding the spectrum of required competencies for being a successful project manager in collaborative construction projects. The results provide the basis for the following conclusions concerning project managers' competencies in collaborative construction projects:

- The competencies contributing to the individual performance include trustworthiness, stress tolerance, initiative, optimism, self-assessment, and production efficiency.
- The competencies contributing to the team performance include conflict management, group capabilities, understanding others and decision quality.
- The developed profile of project managers' competencies, in the big picture, represents blame-free behaviours with a focus on individual productivity as well as supporting and developing others, and joint planning, control and management of the project.

These findings provide novel understanding over project managers' competencies in collaborative construction projects. The developed profile of competencies needs validation in other contexts as well. Therefore, complementary studies in various regions and business conditions are a potential area for further research.

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# IMPACT OF REGULATORY FOCUS ON OPPORTUNISTIC BEHAVIOUR IN CONSTRUCTION PROJECTS

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Opportunistic behaviour, an obstacle to close collaboration, is common in construction projects. But little is known about how the parties' characteristics impact their tendency to commit opportunistic acts. This study applies regulatory focus theory (RFT) to describe clients' inherent motivation orientation and examines the effects of regulatory focus on their opportunism. The questionnaire data from clients in construction projects were analysed with Partial-Least Squares Structural Equation Modelling (PLS-SEM) to verify the theoretical hypotheses. The results show the promotion focus of clients can increase their tendency to conduct opportunistic behaviour, but their prevention focus has no significant effect on it. This study contributes to the body of knowledge by empirically confirming that parties' inherent characteristics play a significant role in predicting their opportunistic behaviour. The findings can help parties to understand and predict other parties' decision behaviour by figuring out their motivation orientations, so as to wisely and rationally employ project management approaches under various circumstances.

Keywords: projects; transaction cost; economics; organisation; client

## INTRODUCTION

Opportunistic behaviour, resulting from temporary relationships and information asymmetry, is tempting and rampant in construction projects (Chen *et al.,* 2012; Lau and Rowlinson 2009). These behaviours, like taking advantage of contractual loopholes, shirking obligations, and hold-up problems, are common on the side of contractors and clients (Lu *et al.,* 2015). Opportunism, defined as a behaviour by a party that pursues self-interests with deceit at the expense of other parties, is a significant barrier to project success. Opportunism may increase transaction costs and inhibit the development of collaborative relationships (Wang and Yan 2013). Therefore, previous research has paid some attention to the drivers and factors impacting it, which are mostly based on agency theory, transaction cost theory, resource dependence theory, and relational contract theory (Zeng *et al.,* 2015; Shi *et*

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*al.,* 2018; Zhang and Qian 2017). But little attention is paid to the factors that stem from parties' characteristics. It is recognized that under a similar situation, parties may behave in different ways. The traits inherent to the parties, such as internal motivation, may have important implications for the emergency of opportunism in the exchange relationships (Das and Kumar 2011). Moreover, most of the previous related literature focuses on contractors' opportunistic behaviour, but some researchers have empirically proved that clients also conduct opportunistic acts in business relationships with contractors in construction projects (Lu *et al.,* 2015). This study intends to further investigate the impact of clients' internal motivation on their opportunistic behaviour, which gets little attention from researchers.

In cases where scholars have begun to examine the issue of motivation, the discussion has been confined mostly to the individual level, with very little attention to the interfirm level (Johnson *et al.,* 2015). However, understanding the genesis of construction project parties' behaviour would be helpful to manage their relationships (Das and Kumar 2011). Motivational orientation refers to the perspective that some parties are risky, open, and eager to maximize gain; other parties may be conservative and try to avoid loss (Das and Kumar 2011). For example, the state-owned construction companies in Vietnam are more likely to take conservative strategies and conform to regulations as this kind of client is more restricted by the government policies and government strategic goals. They are also less eager to explore new business and inclined to maintain the status quo (Ling *et al.,* 2009). Differences in motivational orientation may influence parties' choices between cooperative and competitive strategies (Johnson *et al.,* 2015). Therefore, it is worth raising the issue of whether a parties' motivational orientation also plays a role in determining its intention to opportunistic behaviour, which has not yet been empirically studied in the literature.

Regulatory focus is a concept of motivational orientation and refers to an organization's tendency to either pursue success (promotion focus) or avoid failure (prevention focus) (Das and Kumar 2011). A party with high promotion focus may be risk-seeking, more likely to break rules, and has a more open culture. Parties high in prevention focus will opt for maintaining the status quo and more contractual rigidity compared with the party with a promotion focus (Johnson *et al.,* 2015; Das and Kumar 2011). Parties high in different focus may be varied in the attitudes toward opportunistic behaviour (Das and Kumar 2011). Therefore, we believe that regulatory focus plays a key role in shaping the willingness to commit opportunistic acts. Overall, this study aims to examine the effects of clients' regulatory focus on their opportunistic behaviour in construction projects.

## THEORETICAL BACKGROUND AND HYPOTHESIS

### Opportunism

Opportunism is defined as "a lack of candour or honesty in transactions, include self-interest seeking with guile" (Williamson 1975: 9). Opportunistic behaviour of the parties in construction projects can be defined as a behaviour by a party that is motivated to pursue self-interests with deceit at the expense of another party (Luo *et al.,* 2006). Some typical manifestations of opportunism are common in practice, such as taking advantage of holes in contracts, withdrawing commitments or promises, illegal subcontracting, shirking obligations, colluding, and so on (Lau and Rowlinson 2009).

Opportunism has obtained some attention in the literature of construction project management in recent years. The principal-agency theory attributes the opportunistic behaviour of agencies to information asymmetry (Forsythe *et al.,* 2015). Lu *et al. (*2016) considered external uncertainties and complexity of construction projects as the antecedents of opportunism. Zhang and Qian (2017) explored the drivers of opportunistic behaviour of parties in construction projects from the power asymmetry perspective, which borrowed from resource dependence theory. Based on transaction cost theory, Shi *et al. (*2018) confirmed that asset specificity has positive effects on contractors' opportunistic behaviour, contract and trust can moderate the effect. While some research has examined opportunism in construction projects, less attention has been paid to the impact of the characteristics (e.g., motivation) of the parties on their opportunism.

**Regulatory Focus**

Regulatory focus is a psychological term primitively to describe motivation orientation of individuals, explaining the difference of individuals' tendency to either pursue success (promotion focus) or avoid failure (prevention focus) (Tuncdogan *et al.,* 2015). However, regulatory focus can also describe the macro-level motivation of organizations (Johnson *et al.,* 2015; Florack and Hartmann 2007). First, managers in construction projects as well as boundary spanners who interact with other parties on behave of a party, have personally preferred orientations, which would influence the party's decisions. Second, the institution and culture of the party may explicitly or implicitly shape a prevailing orientation (Das and Kumar 2011). Therefore, these elements of a party (institution, culture, and managers' traits) may shape the party's distinctive strategic orientation and posture, which can be embodied as regulatory focus (Das and Kumar 2011). For example, the state-owned companies in Vietnam are more likely to take conservative strategies and conform to the regulations as this kind of client is more restricted by the government policies and government strategic goals. They are also less eager to explore new business and inclined to maintain the status quo (Ling *et al.,* 2009). Therefore, the regulatory focus is appropriate to depict the firm-level motivation of clients in construction projects.

Promotion focus is concerned with the desire to maximize success, while prevention focus describes the desire to minimize loss (Das and Kumar 2011). A party with a promotion focus may be risk-seeking, more likely to break rules, more adaptable to changing environments, and has a more open culture. On the contrary, a party with a prevention focus will have a stronger sense of duty or responsibility, chose to maintain the status quo, and more contractual rigidity. When cooperating with a partner, the prevention focus party may more care about if the behaviour is the right thing with regards to the contract and cooperative relationship (Das and Kumar 2011). While the two kinds of focus appear to be juxtaposed, (Stam *et al.,* 2010; Lanaj *et al.,* 2012), they are not two ends of a continuum but orthogonal (Higgins *et al.,* 2001). Firms can have different combinations of high or low levels of promotion and prevention focus, like individuals (Idson *et al.,* 2000). For instance, some firms might exhibit high levels of promotion and prevention focus because they have had positive experiences with both motivational orientations in the past (Lanaj *et al.,* 2012). Higgins *et al. (*2001) also revealed that there is only a low correlation between the two types of regulatory focus which indicates the independence between them.

### Effects of Regulatory Focus on Opportunism

Motivational orientations of parties determine the interpretations of parties' intentions, actions, and behaviours (Das and Kumar 2011). Parties in construction projects are varied in their willingness of conducting opportunistic behaviour. One of the reasons may be that they have disparate motivation orientations. As promotion focus is associated with goal maximization (Idson *et al.,* 2000), a client with high (as compared to low) promotion focus may try numerous methods, even breaching a contractual or relational contract under the table, as long as its goals are achieved. Moreover, at the formation stage of a cooperative relationship, a party with high promotion focus may be more likely to overstate its capabilities or giving adequate or misleading information to trap the unwary party into the relationship (Das and Kumar 2011). Besides, a project manager with high promotion focus is more likely to take risks to realize its goals (Gino and Margolis 2011). Opportunistic behaviour is also a kind of risk behaviour. As Caniels and Gelderman (2010) suggested, exerting opportunism might trigger a tit-for-tat strategy from the other party; more than this, the victim of opportunism may even exit the contractual relationship or apply punishment; then, the cooperative relationship will be at the risk of cutting short. But even so, a client with high promotion focus may take the risk of committing an opportunistic act if this act can realize its aim. Therefore, this study develops the following hypothesis:

H1: The promotion focus of the client is positively associated with its opportunistic behaviour.

Prevention focus is associated with seeking to avoid failure (Idson *et al.,* 2000). A firm with high prevention focus has a strong sense of complying with the contract and fulfilling responsibility (Das and Kumar 2011). To make sure the success of projects, parties may make a rigid and complete contract to avoid conflicts in the future, meanwhile, it hopes partners' behaviours are predictable and conform to contract clauses. Opportunistic behaviour aims to seek self-interests at the cost of others' interests which may cause the failure of projects. Hence, opportunistic behaviour by other parties is a big concern for the party that particularly keeps a watchful eye on things that may bring negative outcomes. Moreover, opportunistic behaviour may breach contractual terms or relational norms (Zhang and Qian 2017), which would be against the value of a party with a prevention focus that emphasizes responsibility and rule conformation (Pennington and Roese 2003). Therefore, due to a low tolerance of risk of failure, a client with high prevention focus may also have a low threshold of tolerating partners' opportunism and less propensity to commit an opportunistic act.

H2: The prevention focus of the client is negatively associated with its opportunistic behaviour.

## RESEARCH DESIGN

The research question of this study is that whether the client's motivation orientations (regulatory focus) can influence their opportunism. According to post-positivism, this research can apply a deductive research strategy to explore this problem as the extant theories are substantial for hypothesis development (Grix 2010). Therefore, the quantitative survey method was employed to test the hypotheses.

### Sample and Data Collection

This study chooses the practitioners of clients in construction projects as the potential respondents. The unit of analysis focuses on one party. This can control the effects of

different parties on the theoretical model. The practitioners of clients we sent the questionnaires are those who coordinate with the contractors on a daily basis and have a good understanding of the relationship between them, like project managers, department managers, project representatives.

To distribute the questionnaires, first, the authors attended three seminars in Tianjin, which aimed to improve the capabilities of practitioners in project management and EPC contract management. The attendees are from these companies that are mostly government-owned, which represent the government to be responsible for infrastructure construction such as expressway construction, urban railway construction, and so on. 93 paper questionnaires were distributed to the attendees. Second, 65 questionnaires were distributed with the help of the practitioners in the construction industry who have cooperated with or are acquainted with the authors. Third, to improve the response rate, the "snowball" method was also applied (88 surveys were distributed by this means), which is that the respondents, or practitioners from contractors available, were requested to provide the contacts (e.g. email or social software Wechat name) of other potential respondents. Through the above approaches, 246 questionnaires were sent out, 140 were received, after removing 17 invalid surveys, 123 were obtained; the response rate was 56.91%. The majority of participants are male (85.37%), which is characteristic of the industry. A total of 18.7% of participants are in the position of project manager, 36.59% are owner representatives, 27.64% are department managers, the rest are in the other positions. Most respondents are in their current position for less than 8 years (71.55%); those more than 20 years occupy 3.25%. The types of projects they were involving in while responding to the questionnaires are diverse; 25.2% of them were participating in residential projects, 21.14% were infrastructural construction projects, 18.7% were office projects, the remaining respondents were taking part in public and industry projects.

**Measures**

The questionnaire was developed in English. According to the standard translation-back-translation procedure (Brislin 1980), it was then translated into Chinese by three engineering construction doctoral students and then translated back into English by the other three engineering construction doctoral students to ensure uniformity with the original. A Likert scale was used with questions scored from 1 (= strongly disagree) to 7 (= strongly agree). The regulatory focus was operationalized using a ten-item scale which was developed based on the work of Das and Kumar (2011). Five items are using to measure promotion focus (For example, we make decisions based on the principle of "maximizing success"; To achieve our aims, we can break conventional rules). Another five items were for measuring prevention focus (such as, we view "avoiding loss (failure)" as our guide to action; We strictly implement our corporate internal regulations and rules). A seven-item measure was adopted for measuring opportunism (Like, on occasion we lie about certain things to protect our interests; We sometimes promise to do things without actually doing them later) Luo *et al.,* 2006). Finally, the structural model included two control variables of prior cooperation with the partner (Whether the client had an exchange relationship with the partner before), and prior cooperation satisfaction (if having prior cooperation experience, the satisfaction level of the client with the prior cooperation experience).

# RESULTS AND DISCUSSION

In general, PLS-SEM (Partial-Least Squares Structural Equation Modelling) is one of the main approaches to analyse data from questionnaire surveys with Likert scales, especially suitable for small sample sizes and skewed distribution (Reinartz *et al.,* 2009). As the sample size is 123, relatively small; this study applied PLS-SEM to statistically analyse the data. Following the guidelines for PLS-SEM given by Hair *et al. (*2013), the structural model representing the structural paths between the variables, and the measurement model representing the relationships between each variable and its associated indicators were evaluated with the SmartPLS, version 3.2.8.

## Measurement Model

The assessment of the measurement model was based on reliability and validity (Hair *et al.,* 2013). Standardized indicator loadings for all the items were above the threshold of 0.5 recommended by Hair *et al. (*2013) (Table 1).

*Table 1: Evidence of reliability and convergent validity*

| Constructs and Items | AVE | CR | Cronbach's α | Loadings |
|---|---|---|---|---|
| Promotion Focus (ProF) | 0.547 | 0.855 | 0.803 | |
| ProF 1 | | | | 0.591 |
| ProF 2 | | | | 0.629 |
| ProF 3 | | | | 0.78 |
| ProF 4 | | | | 0.809 |
| ProF 5 | | | | 0.852 |
| Prevention Focus (PreF) | 0.549 | 0.855 | 0.832 | |
| PreF1 | | | | 0.783 |
| PreF2 | | | | 0.814 |
| PreF3 | | | | 0.888 |
| PreF4 | | | | 0.507 |
| PreF5 | | | | 0.651 |
| Opportunistic behavior (OB) | 0.490 | 0.869 | 0.836 | |
| OB1 | | | | 0.795 |
| OB2 | | | | 0.691 |
| OB3 | | | | 0.633 |
| OB4 | | | | 0.638 |
| OB5 | | | | 0.575 |
| OB6 | | | | 0.794 |
| OB7 | | | | 0.742 |

All the Cronbach's α of the constructs are above 0.7, and CR values are more than 0.8, which reveals the acceptance of the construct reliability (Table 1). Consequently, the measurement model reaches a satisfactory level of reliability. The average variable extracted (AVEs) for all the constructs is more than 0.5 (Table 1), except opportunistic behaviour, but its AVE is also closed to 0.5, indicating an accepted convergent validity. For satisfied discriminate validity, according to the Fornell-Larker criterion, it's requested that the square roots of all AVEs in diagonals are more than the off-diagonal elements in the corresponding rows and columns. Table 2 shows the satisfactory results of the measurement model. Therefore, the validity is acceptable.

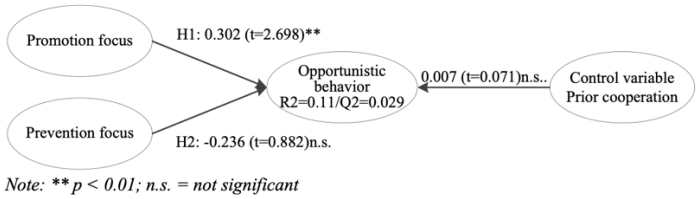
## Structural Model

To test the hypotheses, the full PLS-SEM structural model was performed (hypotheses H1-H2, see Fig 1). The coefficients of determination R^2 for all endogenous constructs were computed (see Fig 1). The construct cross-validated redundancy index (Q2) for endogenous constructs that were used to assess the predictive relevance of the structural model is above 0 (Chin 2010) (see Fig 1), Therefore, the predictive relevance of the model is accepted.

*Table 2: Discriminate validity (Fornell-Larcker Criterion)*

| | ProF | PreF | OB |
|---|---|---|---|
| ProF | 0.739 | | |
| PreF | 0.267 | 0.741 | |
| OB | 0.238 | -0.157 | 0.7 |

*Note: ProF: Promotion focus; PreF: Prevention focus; OB: opportunistic behaviour*

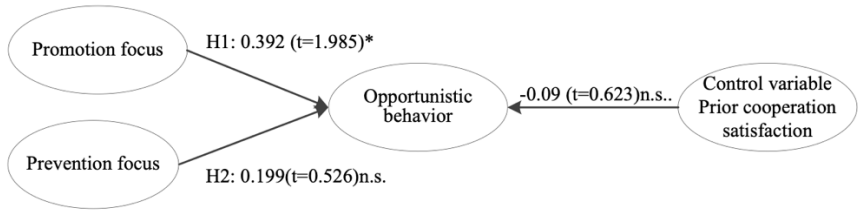



*Note: ** p < 0.01; n.s. = not significant*

*Fig 1: Results of the structural model with control variable of prior cooperation*

The path coefficients between the independent variables and dependent variable in the structural model were assessed through bootstrapping with 123 cases, 5000 subsamples (Hair *et al.,* 2013). First, the authors controlled the effects of prior cooperation on the dependent variables. Fig 1 shows that the path coefficient between promotion focus and opportunistic behaviour is significant (H1: b=0.302, p<0.01), but that between prevention focus and opportunistic behaviour is insignificant (H2: b=-0.236, n.s.). Second, the structural model was assessed under the control of the effects of prior cooperation satisfaction on the dependent variables with the sample having prior cooperation. The results also demonstrate a positive effect of promotion focus on opportunistic behaviour (In Fig 2, H1: b=0.392, p<0.05); but the insignificant effect of prevention focuses on opportunistic behaviour (In Fig 2, H2: b=0.199, n.s.). Therefore, both of the two models' results show that H1 is supported, and H2 is rejected. These imply that even with the influence of control variables (prior cooperation experience and prior cooperation satisfaction), the promotion focus of clients has a positive effect on their opportunistic behaviour, but their prevention focus does not.

From the supported hypothesis 1 and the unsupported hypothesis 2, this study finds that a promotion-oriented client is more likely to take opportunistic strategies to achieve its aim, compared with a prevention-oriented client. It supports the proposition of Das and Kumar (2011) that firms with different regulatory orientations will be varied in the inclination to commit opportunistic acts.




*Note: * p < 0.05; n.s. = not significant*

*Fig 2: Results of the structural model with control variable of prior cooperation satisfaction*

Hypothesis 2 is unsupported; the reason may be that opportunistic behaviour means to breach the rule of morality and a significant character of prevention focus is rule compliance. The moral code is commonly accepted and constrains the behaviour of most people in society. Thus, it is promotion focus rather than prevention focus that greatly determines the tendency of a client to conduct opportunistic behaviour.

Moreover, there are two different forms of opportunism: active form and passive form (Wathne and Heide 2000). Active opportunism involves that actors engaging in a behaviour that is expressly forbidden, whereas passive opportunism implies that actors fail to fulfil their expected obligations. The influence of prevention focus on opportunism may be varied in the two forms (Das and Kumer 2011), but this study didn't specifically distinct the two forms, which may contribute to the unsupported H2.

## CONCLUSIONS

Overall, with the data from clients in construction projects, this research confirms that promotion focus positively affects the inclination to conduct opportunistic behaviour, but prevention focus does not. This study has important theoretical implications for stakeholders' relationship management in project management. First, it incorporates RFT to explore the inducing mechanism of opportunism. The drivers of opportunism have received some attention in recent years, but previous literature are mostly based on agency theory, transaction cost theory, resource dependence theory, and relational contract theory (Crosno and Dahlstrom 2008; Zeng *et al.,* 2015; Shi *et al.,* 2018; Zhang and Qian 2017), the question of how the characteristics of parties influence their opportunism have been ignored, even some researchers have put forward that motivation orientations of a firm or an organization play a critical role in its decision behaviours (Das and Kumar 2011; Johnson *et al.,* 2015). This study fills this gap to extend the boundary of antecedents of opportunism for project management research by incorporating RFT.

Second, this study shed new light on parties' inherent characteristics by borrowing RFT to describe the motivation orientations of parties. Regulatory focus, which is primitively used at the individual level, was confirmed empirically that can be used at the interfirm level. It responds to the proposition of Das and Kumar (2011) and Johnson *et al. (*2015) that regulatory focus has the potentiality to shape organization characteristics. The demonstration of this theory lays a foundation for future research on the characteristics and behaviour of project parties.

This paper also provides several implications for construction project practitioners who intend to manage stakeholder relationships, by confirming that the parties indeed exhibit different kinds of regulatory focus and their promotion focus positively affects their inclination to conduct opportunistic behaviour. This is an important observation because it can partly answer the question that where the parties' motivation to opportunistic behaviour comes from. With these findings, it is easier for the parties to predict others' opportunistic behaviour, consequently choosing a more effective way for controlling this behaviour and relationship management. When cooperating with a promotion-oriented party, more rigid supervision may be needed to curtail its opportunistic behaviour. In addition, parties can figure out their types of motivation orientation as well as other parties' through RFT, which helps to understand the characteristics of other parties. With better mutual understanding, the parties can be easier to understand the motivations of others' decision-making and choose more effective project management approaches. Moreover, parties with the two different motivation orientations will behave differently and prefer different cooperating ways, therefore, sometimes, parties may need to get rid of the limits from their constant motivation orientations to coordinate with each other in various conditions.

There are some limitations in this research that open up avenues for future research. The way to do business may be varied in different sizes of the clients, private or

public owned, or culture of the country. The tendency to become opportunistic may also depend on these factors. Future research could broaden the survey by incorporating these factors into the conceptual model. Moreover, RFT was built up initiatively to describe motivation orientation at the individual level. However, this study employed it to examine the motivation of firms. Although previous research has generalized it from psychological orientation to organization motivation. More research is still needed to explore how RFT engages (or not ...) with structural explanations of behaviour (for instance, institutional theory).

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# Information Management

# BARRIERS IN BLOCKCHAIN TECHNOLOGY ADOPTION FOR FACILITIES MANAGEMENT PROCUREMENT PROCESS IN SRI LANKA

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Procurement has become an essential facilities management business operation. With the increase of complexity and transparency issues in existing procurement processes, the adoption of an advanced digital technology is required. As a solution, this study investigates the existing barriers in adopting blockchain technology for facilities management procurement process in the Sri Lankan context and presents the potential solutions to overcome them. A qualitative approach was adopted for this study and blockchain technology experts in information technology field and research field were interviewed using semi-structured interviews until the data saturation was achieved. Findings revealed, main adoption barriers related to socio-cultural, legal, economical, technical, political and administrative categories. Resistance to change, absence of laws and regulations, financial incapability, absence of a customised solution for the use case and less autonomy are some of the identified barriers. Conduct training and awareness on blockchain technology, identify system requirements and the system design properly, and develop laws and regulations for blockchain technology adoption are some of the proposed solutions. The research concludes by guiding facilities management and information technology professionals to overcome the identified barriers.

Keywords: blockchain technology; facilities management; procurement; Sri Lanka

## INTRODUCTION

According to Shi and Tay (2019), adoption of advanced technologies can result in efficient Facilities Management (FM) operations while increasing productivity and reducing costs. Authors further stated, Blockchain Technology (BCT) can have a significant impact on FM practices in operations and maintenance of buildings which enables real time data monitoring, analytical services, fault detection of equipment through the integration of artificial intelligence and especially transparent record keeping, reduction of manual errors and issues in data verification by the use of smart contracts. BCT is advantageous for FM under different perspectives such as data security, easy access, cost reduction and replacement of manual processes (Conley and Richards 2018). When considering the FM industry, procurement process is essential for managing service providers, obtaining the required building facilities, and continuing reliable and effective business operations (Pun, Choy and Lam 2018). Due to the rapid changes in the highly competitive market, procurement has become a

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complex and challenging process which needs to adopt innovative processes to be more effective (Hong and Kwon 2012). The requirement of transforming to an advanced digitalised procurement system is identified by the FM industry and BCT can be considered as a significant innovation for this purpose (Gunasekara, Sridarran and Rajaratnam 2021). According to Nicoletti (2017), by applying BCT throughout the procurement process, the security of the procurement process can be improved. However, Adama and Michel (2017) argued, it is required to investigate the challenges in the adoption of new technologies while evaluating their applicability for the FM industry.

In the Sri Lankan context, BCT has applied in the private bank sector, and it is expected that BCT will change the Sri Lankan banking sector (Perera 2018). However, BCT is still new to Sri Lanka, and thus the BCT adoption for FM procurement process is a major challenge and it is required to identify and solve the existing barriers before its implementation. Therefore, it is required to analyse this gap and this research aims to identify the related barriers and solutions to overcome them. Recently, researchers have identified common barriers on the applications of BCT, and some have researched on barriers specifically for supply chain management (SCM). This is the first research to analyse the gap in identifying barriers in BCT adoption which will be beneficial for FM industry for the future development of the procurement process. The research scope was limited to identifying barriers in the Sri Lankan context.

## LITERATURE REVIEW

### Role of Facilities Management in Procurement

Pun, Choy and Lam (2018) stated that procurement is a crucial and a complex process in FM for managing services and for interacting with different stakeholders to support the core business function of any organisation. Authors further mentioned, Facilities Managers have to consider the quality and cost of the procured services because of the prevailing dynamic and complex business processes in the organisations. However, FM procurement strategy should be properly planned to make a correct procurement decision on behalf of the organisation (Atkin and Brooks 2015). Authors further mentioned that this FM procurement strategy should adhere to the existing business processes to fulfil the corporate objectives through the procurement process. The procurement process is aimed at selecting the best bidder who provides the required service of clients within the specified time limit at an acceptable price while accepting the optimal commercial and legal terms (International Facility Management Association and Royal Institution of Chartered Surveyors 2018).

### Issues in Current Facilities Management Procurement Process

According to Tavares (2018), procurement process is more complex because large number of transactions are involved, and it should be based on trust among the parties involved in the process. Currently existing transaction systems are designed to be centralised and a third party is monitoring and managing transaction instead of the parties who are involved in the transaction (Yli-Huumo *et al.,* 2016). Facilities Managers have found that existing systems are consisting of inefficient and time-consuming search interfaces, lack of unified interfaces for information exchange, and unable to process and store large amounts of data (Koch, Hansen and Jacobsen 2017). Application of BCT for pre tendering, tendering and post awarding phase of FM procurement process can solve the current issues in FM industry in terms of

transparency, security, efficiency, integration and third-party intervention for transactions (Gunasekara, Sridarran and Rajaratnam 2021).

**Adoption of Blockchain Technology**

In the past few years, BCT or distributed ledgers have become an important future technology (Barenji *et al.,* 2018). BCT was introduced by Satoshi Nakamoto, as the first Distributed Ledger Technology (DLT) which could be applied in cryptocurrency associated functions (Li, Greenwood and Kassem 2018). However, Yli-Huumo *et al.,* (2016) argued, BCT has a broader application beyond the cryptocurrencies, and it can be applied to any environment where transactions are carried out. The presence of a secured distributed database of blockchain, makes it a very attractive technology to solve the current financial as well as non-financial industrial problems (Crosby *et al.,* 2016). Distributed databases can assist various stakeholders in the organisation's procurement process when required and they can enable a procurement process which is reliable and uninterrupted (Nicoletti 2017). Smart contracts are currently the most revolutionary blockchain applications which automatically generate payments and transfer money or other assets when negotiations are fulfilled (Iansiti and Lakhani 2017). BCT developers have stated, currently most of the companies in the world are focussed on blockchain-related innovations, but only a few of these companies are working on actual BCT development due to poor knowledge and poor understanding of this technology (Mattila 2016). However, Hileman and Rauchs (2017) argued, although the use of blockchain may have a revolutionary advantage over other technologies, they are not a perfect solution in some cases, and they cannot magically solve every problem.

Though infrastructure is identified as a major challenge on the adoption of blockchain in SCM, organisational capabilities, such as internet, cloud services, integration with SCM, training and awareness are also important (Queiroz *et al.,* 2020). Authors further stated, effect of trust is another challenge for the adoption of BCT, and thus it is required to monitor and identify the behaviours that affect the trust in BCT by enabling the confidence in the information that is shared among the parties who are involved in operations of SCM. The adoption of blockchain for procurement must overcome obstacles such as, resistance to adapt new technologies, integration with legacy systems, adoption costs, and obtaining stakeholder support (Williams-Elegbe 2018). Nawi *et al.,* (2016) argued, although the organisations cannot control the external obstacles arising from industry, market, government and technological change, these obstacles can be minimised or even eliminated entirely through careful planning and research. However, Hackius and Petersen (2017) argued, organisations are reluctant to invest their resources to develop BCT based applications despite realising that blockchain may have a favourable impact on them. Accenture Operations (2017) stated, to take full advantage of new technologies, companies must review their policies and procedures and ensure that everyone understands their roles and responsibilities clearly relevant to the new procurement process.

## RESEARCH METHODOLOGY

According to Kothari (2004), research approaches can be categorised as quantitative approach and the qualitative approach. Author further mentioned, in quantitative approach, data is generated in a quantitative form and data is subjected to quantitative analysis rigorously in a formal and rigid manner wherein qualitative approach is concerned in the assessing of attitudes, opinions and behaviours subjectively. Antwi and Hamza (2015) stated, quantitative approach is concerned in quantifying social

phenomena by collecting and analysing data while qualitative approach is focused in understanding social phenomena. This research is focused on presenting barriers and solutions to overcome those barriers when adopting BCT for FM procurement. Therefore, in order to do it successfully understanding the current phenomena is required by assessing of attitudes, opinions and behaviours subjectively. Therefore, qualitative approach was selected.

According to Yin (2018), case studies, surveys, experiments, archival analysis and histories are the main social science research strategies. Thus, barriers in adopting BCT for FM procurement and solutions to overcome them were identified using an expert survey.

When designing a high-quality research, establishing inclusion and exclusion criteria for research participants is a standard and necessary approach (Patino and Ferreira 2018). Inclusion criteria characteristics are predefined to identify subjects who will be included in a research study (Salkind 2010). In contrast, the exclusion criteria characteristics are defined as potential research participants meeting the inclusion criteria including additional features that may affect research success or increase the risk of adverse results (Patino and Ferreira 2018). Inclusion criteria considered in this research are, selection of normative experts from Sri Lanka in the Information Technology (IT) field who actively contribute to the development of blockchain-based solutions and who conduct research on blockchain adoption, and with at least seven-year experience in the field of expertise. Experts which do not meet the minimum outcomes were excluded.

All of the experts were given an introduction on how the FM procurement process is performed before the interviews. Profiles of experts are presented in Table 1.

*Table 1: Profiles of Experts*

| Expert | Designation | Years of Experience | Field of Expertise |
|---|---|---|---|
| E1 | Senior Software Engineer | 8 | IT field with experience on developing blockchain based solutions |
| E2 | Lead Consultant -Technology | 7 | |
| E3 | Senior Technical Lead | 8 | |
| E4 | Technical Lead - Blockchain Development | 10 | |
| E5 | Senior Software Engineer | 7 | IT field with experience on conducting research on blockchain adoption |
| E6 | Director of Software Engineering | 10 | |
| E7 | Senior Software Engineer | 6 | |
| E8 | Head of Engineering | 15 | |

Semi-structured interviews were selected as the data collection technique to investigate the barriers. Dawson (2002) stated, in qualitative social research, the most commonly used interviews are semi-structured interviews. In semi-structured interviews, interviewees can explain their thoughts freely and they can highlight their areas of special interest and expertise and able to question certain responses especially to reveal and resolve obvious contradictions (Horton, Macve and Struyven 2004). Eight semi-structured interviews each lasting 1.5 hours were conducted. These interviews were audio recorded and transcribed.

Commonly identified qualitative data analysis techniques are content analysis, thematic analysis, grounded theory, interpretative phenomenological analysis, and some other narrative analysis techniques (Robinson 2013). Content analysis and thematic analysis seem to have the same goal of analysing and examining the

narrative material by dividing the text into relatively small content units and submitting them to descriptive processing (Sparker 2005). By using content analysis, the data can be qualitatively analysed and the data can be quantified at the same time (Gbrich 2007). On the contrary, thematic analysis provides a purely qualitative, detailed and nuanced description of the data. (Braun and Clarke 2006). In this regard, qualitative researchers should be more familiar with thematic analysis as an independent and reliable qualitative analysis method. (Vaismoradi 2016). The thematic analysis process may be based on previous categories, or categories that become clear to the researcher only while the analysis is in progress and once the interview data is collected from the interviewee, these categories will become the "themes" that researchers use to analyse the collected data (Fox 2004). Therefore, thematic analysis was selected as the data analysis technique because five main themes were identified as the types of barriers in BCT adoption, and the data analysis was performed using NVivo software.

## FINDINGS AND ANALYSIS

### Barriers in Blockchain Technology Adoption for Facilities Management Procurement Process and Solutions to Overcome Them

According to the responses provided by the experts, barriers in adopting blockchain for FM procurement process can be categorised as socio-cultural, legal, economical, technical, political and administrative barriers as follows.

Socio - Cultural Barriers and Solutions to Overcome Them
E1 stated, resistance from industry is the main socio-cultural barrier in Sri Lankan FM industry and explained that people have still not understand the strength of BCT applications for the FM procurement use case. Further E1 stated, while foreign banks are currently using blockchain based cryptocurrencies for payments, Sri Lankan banks have a low level of trust on the execution of payments through this technology. E4 mentioned, in addition to attitude problems, lack of knowledge and skilled resources is another main issue for the blockchain implementation in Sri Lankan FM procurement process. E8 mentioned, it is difficult to integrate different suppliers and FM service provider organisations related to FM procurement process because they will be reluctant to feed data from their current databases or systems by considering a blockchain based system as an overhead. E5 stated, confidence must be there to disclose all the procurement-based information because normally data within the blockchain is public and it is more transparent, unlike a deposit done in a bank where normally information is stored in a private ledger. Further E5 mentioned, the mentality of organisational management should be fit to this type of situation and there is a lack of confidence in using blockchain which facilitates a transparent procurement process. E4 added, blockchain will be inconvenient for FM users, suppliers and other stakeholders because it is a new technology, and they are not used to it. According to most of the experts, there are barriers of how people can be brought into a blockchain based platform to do procurement activities. It is required to identify whether suppliers are ready to feed procurement related data and the basic idea on blockchain should be there. Thus, it is important to make people confident enough to use blockchain by conducting awareness and training programmes on blockchain implementation for FM procurement.

Legal Barriers and Solutions to Overcome Them
Most of the experts stated, it is important to identify whether the contracts are legally binding and what is the relevant law when using smart contracts between suppliers

and FM organisations in terms of payments and conditions of contracts. However, absence of laws and regulations regarding the blockchain adoption and usage is the main barrier because there are no smart contracts or blockchain based procurement laws in Sri Lanka to handle them. Furthermore, experts suggested, if the industry is adopting a new technology, relevant law has to be there. Thus, it is required to develop laws and regulations regarding the adoption and usage of BCT for FM procurement in the Sri Lankan context.

Economical Barriers and Solutions to Overcome Them

As per the opinions of experts, there can be economical barriers. Most of the experts stated, financial incapability is the major barrier in blockchain adoption and organisations are reluctant to convert their current e-procurement systems or to adopt a new system. E5 stated, there additionally may be costs to run servers according to the designed platform. E6 and E7 added, another major barrier as costs related to hosting/ transactions and initial migration cost. Thus, economical barriers can be affected in the BCT implementation. Experts suggested that in order to reduce the unnecessary costs, existing procurement system should be analysed, and it is essential to identify what types of requirements should be addressed and how blockchain platform can conflict with the existing e-procurement system. Thus, a complete analysis is required to identify them and then it can be decided whether to proceed with a conversion or a completely new development. Further E1 added, blockchain implementation is not easy, therefore cost and implementation weight should be considered and addressing of most important requirements of the procurement process is required according to this use case.

Technical Barriers and Solutions to Overcome Them

E1 explained, it is not required to use blockchain 100% for the FM procurement process, because if everything is done through blockchain it can reduce flexibility of the system. Further, it was mentioned that integration of existing e-procurement systems is difficult. Experts stated, when compared to a normal system, there can be a transaction delay in a blockchain based system. According to E3, for example if a database system is used, thousands of transactions can be run per second unlike in a blockchain where less than a hundred transactions per second can be run. E4 supported, time factor can be an issue. Thus, when blockchain is used for the procurement process, there can be delays in transactions. E7 stated, a blockchain based system requires high computational power, but as plenty of hardware is available it is not a big issue. E4 added, if a digital system is currently available, additional special system requirements are not required and the minimum hardware requirement is there. Thus, it was suggested to utilise the available hardware according to the requirement. However, E3 added, absence of a strong internet connection can interrupt the performance of the system. E2 explained, another technical barrier is the absence of a customised solution for the use case which can directly incorporate for FM procurement. Thus, you have to customise specifically for the use case. When customising, it is required to write the smart contracts with the minimum level of customisation, incorporate different consensus and modify the eligibility of a party or an organisation to get involved.

E7 stated, conversion of current EP system to a BCT based system should be done based on the current design of the system. E1 suggested to design the system properly according to the requirement of proper integration of parties involved in the procurement process. Experts stated, in the system analysis, it is important to identify the most important FM procurement requirements and it is required to use blockchain

at the optimum level without overusing it. According to the requirement it can be developed, but within the scope of the solution. E2 added, blockchain should be explored properly, because it has its own set of use cases and at the same time it should not be overused.

Political and Administrative Barriers and Solutions to Overcome Them
Experts stated, in Sri Lanka there is less autonomy and less support is available for the start-ups when adopting a new technology like blockchain for developing industries like FM. Further, E2 added, appropriate cultural changes should be there in FM industry to welcome new technologies as required. Thus, experts suggested, organisational procurement policies and procedures should be reviewed and necessary resources should be utilised to support the new blockchain projects for FM procurement. Further E8 added, new proposals regarding BCT adoption for FM procurement should be developed and it is required to recruit experts on BCT for those developments.

## DISCUSSION

Data analysis and findings revealed that barriers in BCT adoption for FM procurement can be identified under socio-cultural, legal, economical, technical and political and administrative categories. Data analysis revealed, there are some socio-cultural barriers where FM industrial professionals lack the confidence in using blockchain and they are reluctant to participate in a blockchain based procurement system with the lack of knowledge and skilled resources. Though foreign banks are currently using cryptocurrencies on execution of payments, local banks have a low level of trust on them. Therefore, payment execution using cryptocurrencies is not possible at the moment. Further, the absence of laws and regulations regarding the blockchain adoption and usage for FM procurement was identified as the main legal barrier because for the execution of smart contracts and for them to be legally enforceable, there should be proper laws and regulations. Technical barriers were identified as absence of a customised solution for the use case, reduce flexibility by the over usage of BCT, absence of a strong internet connection, difficulties in integration of existing systems and parties involved in FM procurement process and delays in transactions compared to other systems. Further, this study identified some economical barriers related to adoption such as, financial incapability, additional cost to run servers, high costs related to hosting/ transactions and high initial migration cost. Findings revealed, political and administrative barriers as, less autonomy and availability of less support for start-ups.

Careful research, planning, designing, training, awareness and reviewing organisational procurement policies and procedures are required to solve the adoption barriers. Similarly, several solutions were identified by this study to overcome the above identified barriers. Mainly it was suggested to conduct training and awareness programmes on BCT because it is a new technology to Sri Lanka and most of the organisations are not aware of it. Further, when designing a BCT based procurement system it is required to analyse the most important requirements and to design the system according to those requirements without overusing the technology and within the scope. Proper integration of law and technology should be enabled by developing laws and regulations for BCT adoption and usage for FM procurement process.

## CONCLUSION

Adoption of BCT to FM procurement process is a challenge in the Sri Lankan context because of prevailing barriers in the industry. In this study, key barriers were identified under five main categories as socio-cultural, legal, technical, financial, political and administrative barriers. This research contributes by identifying the existing barriers for the adoption of BCT to FM procurement process and identifying solutions to overcome them. It was evident that FM procurement process can be further developed with BCT adoption if the required attitude changes, financial capability, organisational contributions, legal background and technical knowledge and strength are available in the Sri Lankan context. However, as identified in this study, FM and IT industries can work together to achieve a significant output if these barriers can be solved in the future. Outcomes of this research are useful for the FM industry and IT industry by guiding them towards blockchain adoption for FM industry. Therefore, it is required to analyse these barriers before moving towards BCT technological transformation by considering the recommended solutions. As BCT is at a preliminary stage in Sri Lanka, some unavoidable limitations were encountered when conducting this study because of the lack of IT experts who are proficient in BCT in Sri Lankan context. This was overcome by recruitment of interviewees who have actively contributed in developing blockchain based solutions for some industrial applications and who have actively conducted research on blockchain adoption. Therefore, it was able to obtain sufficient information with the data saturation to achieve the research aim.

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# COLLABORATIVE RISK MANAGEMENT WITHIN THE DESIGN PHASE OF GREEN BUILDINGS

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Green building projects are ambitious in terms of the complexity of structures, design requirements, information flows, stakeholder integration and technological integration. As a consequence, management of these projects is becoming increasingly integrated. However, risk management (RM) has taken little account of these emergent interconnected stakeholders, interdependent tasks, inseparable risks and iteration in the design process. This leads to poor risk management outcomes, where traditional risk management practices that rely on allocating risks to specific individual entities are not able to accommodate the complexities of a collaborative integrated design. As part of a comprehensive research into how project stakeholders in collaborative design teams manage inseparable risks within their interdependent design tasks, multiple case studies were analysed using empirical data from semi-structured interviews of experienced practitioners. The abductive approach provided explanations of the continuous interplay between theory and various real-life examples. To bridge the current research gap, a matrix-based approach of using Dependency Structure Matrix to integrate the stakeholder dimension and the task dimension to solve for inseparable risks, enabled Collaborative Risk Management (CRM) to filter out most complexities, so that efforts could be directed to appropriate risk sharing and analysis of important parts of the design process. In order to judge the collaborative climate and satisfaction of each stakeholder in the design team, stakeholders suggested a decentralized process that foster a co-operative culture, contract negotiation and communication as key to ensuring that all parties are able to perform their respective tasks adequately. To manage inseparable risk, stakeholders suggested proportional risk sharing approaches, regular team meetings and timeous information sharing. The project should have a shared insurance cover that will balance the risks fairly between stakeholders; in absence of bad faith; leading to a reasonable price; qualitative performance and the minimization of disputes.

Keywords: collaboration; design tasks; long-term relationships; risk sharing

## INTRODUCTION

Green building (GB) is defined as a process aiming to reduce the overall impact of the built environment on human health and the natural environment by efficiently using energy, water, and other resources and by reducing waste, pollution and environmental degradation (GBCSA, 2007). The design component of this process involves complex and comprehensive work activities requiring the cooperation of various specialties as collaborating stakeholders (Liu *et al.,* 2014). The multifaceted

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nature of green project designs has become increasingly difficult as it involves extensive interdependence of design information and design tasks across a large number of design disciplines requiring a major shift towards collaborative design approaches (El-Diraby *et al.,* 2017). However, the traditionally used planning methods such as CPM and PERT cannot model the iterative nature of design processes (Senthilkumar *et al.,* 2010), and similarly, risk management has not adapted to these new approaches to better cope with this increased complexity and interdependence. This study intends to explore how project stakeholders in collaborative teams manage inseparable risks within their different design tasks on green buildings and how the use of Dependency Structure Matrices (DSM) can be effective in representing both the design process and management of risk within the design processes.

Collaborative designs used in GB projects demand processes of coordination and cooperation of different stakeholders who share their knowledge in both design process and design content (Kleinmann, 2006) as a means of attaining the unified design goals in the most efficient and effective ways (Liu *et al.,* 2014). Traditionally risk management has given little consideration to the nature of collaboration within the interdisciplinary and iterative design process. Risk management practices continues to rely on allocating risks to specific individual entities (individuals or design disciplines), which is increasingly problematic given the non-coherence of the growing green building sector, where the design philosophy is holistic and treats the building as a complex integrated system (El-Diraby *et al.,* 2017), that is best designed, and efficiently executed through collaborative practices.

Green buildings foster the habit of collaboration and optimization among all building measures (Korkmaz *et al.,* 2010). Optimization is an inherently iterative process in collaborative green designs, assisting in the progressive generation of knowledge, enabling a degree of concurrency and collaboration (Wynn and Eckert, 2017). Chiu (2002) defined collaboration "as an activity that requires participation of individuals for sharing information and organizing design tasks and resources."(ibid: 187) This means that the stakeholders provide each other with new insights that enable each participant to fulfil his or her own design tasks without compromising the design of others whilst meeting the common objectives of green building. These objectives are typically to; lower energy consumption, lower investment costs, and reduced harmful impacts on the environment and on people (EPBD, 2015). In collaborative green designs, tasks are interdependent and iterative; with risks that are intricately connected (Al Hattab and Hamzeh, 2015). These risks are inseparable and cannot be transferred or allocated to an individual but have to be shared between stakeholders and can only be resolved or mitigated through collaboration (Laurent, 2017). To understand inseparable risks, it is helpful to identify the interconnected stakeholders and interdependent tasks as well as their effects. Since RM still have limitations for modelling the complexities of inseparable risks; these risks need dynamic management over time. This dynamic approach needs effective risk management and collaborative efforts among project stakeholders (Lam *et al.,* 2007; Gomes *et al.,* 2016). Such Collaborative Risk Management (CRM) is the dynamic management of risk (Rahman and Kumaraswamy, 2005) and plays a major role in achieving value-for-money and cost-efficiency in designing complex projects.

However, a good number of existing risk analysis methods are restricted to one of the two dimensions, namely, stakeholder and task, which also can reduce the effectiveness of risk management. Some methods represent the stakeholder dimension,

quantitatively evaluating the networks formed by stakeholders and their relationships but doesn't meet the dynamic changing characteristics of the network caused by the risk factors. At the same time, other methods focus on the task dimension, analysing the risk factors in the design phase and presenting risk mitigation actions. Yes, these do not reflect the interdependency of stakeholders and their interdependent tasks that give rise to inseparable risks and, they cannot portray the interrelationships between them and are thus unable to model complex interactions. Hence the need for a matrix-based approach using DSM to integrate both the stakeholder dimension and the task dimension to solve for inseparable risks, using a CRM method to improve the accuracy of risk analysis and the effectiveness of risk management.

The DSM tool is capable of dealing with a design process comprising thousands of activities and still be able to prioritize dependences (Austin *et al.,* 2000). Thus, CRM and DSM are powerful methods to solve for inseparable risks. The amalgamation of both approaches could result in an extremely powerful tool that can lead to technical, managerial, and economic benefits. The tool should also provide insights into the projects in a manageable way that all stakeholders can benefit from. Further, DSM has been shown to provide a better planning methodology for risk sharing decisions (Maheswari and Varghese, 2005).

**Collaborative Risk Management within Green Buildings**

Green Building designs are complex undertakings that have given rise to reciprocal interdependencies between multiple and diverse stakeholders, hence the high dependence on information, followed by the connectedness of tasks (Austin *et al.,* 2002; Ahn *et al.,* 2016). Bakhshi *et al.,* (2016) defines GBs' complexity as an intricate arrangement of the varied interrelated parts in which the elements can change and evolve constantly with an effect on project objectives. Yet, they are the most effective solutions to increase the efficiency of buildings through resource utilization and recycling, mitigating the negative impact of the construction industry on the environment (Zuo and Zhao, 2014). This has been made possible by through, inter alia; mutual collaboration, adjustments towards working collectively and responding to emergent, unforeseen problems in real-time. However, project realities are such that current risk practices promote competitive attitudes between the project stakeholders involved because they tend to work for their self-interests and thus safeguard their existence in the project life (Alsalman 2012). So, it is vital to change, not only risk management (RM) practices, but the associated mindsets to shift towards mutual adjustment and rapid adaptation, where stakeholders will be in a give-and-take interdependence (Morris 2013). The change from traditional RM to CRM is loaded with uncertainties on risk sharing among all project stakeholders and their response to this requires a cultural shift in how they approach the sharing and management of risk.

This cultural shift towards risk sharing requires all stakeholders within complex projects to take a closer look at their own risk universes. Risk sharing is a useful method for handling complex designs (Melese *et al.,* 2016). It is a collaborative way of managing risks which have an ability to take advantage of the different views from different stakeholders (Olander, 2007) and it also identifies risks that cannot just be shifted to one stakeholder but have to be collaboratively managed (Lam *et al.,* 2007). CRM appears to be a relevant problem as it emphasizes equitable and balanced risk sharing among contracting stakeholders and who wants to eliminate improper or unfavourable risk sharing outcomes which result in cost and time overrun and, undoubtedly, in legal disputes (Loosemore and McCarthy, 2008).

In this vein, the traditional tools (PERT, Gantt and CPM) are based on linear workflows; however, they have failed to address interdependency (feedback and iteration) and will would not be suitable for modelling information flows which those controls determine the design phase (Yassine *et al.,* 1999). A DSM will can be employed as a useful tool for coping with design issues (Steward, 1981). The matrix can be used to identify appropriate stakeholders, teams, and the ideal sequence of the tasks (Lindemann, 2009). A DSM involves a square matrix with an equal number of rows and columns that shows relationships between tasks in a system, and with interest, risks (Eppinger and Browning, 2012). Collectively, these complexities and interdependencies of tasks have resulted in inseparable design risks that would have to be shared collaboratively. How then do project stakeholders in collaborative teams deal with inseparable risks within their different design tasks?

**Managing Risk using Collaborative Risk Management Principles**

The emphasis of effective RM in dealing with the broad spectrum of risks is to move beyond the traditional RM mechanics to examine the sources of unknown risks (Jarkas and Haupt 2015). Though the construction industry has long managed to identify and analyse known risks, it has recognized that dealing with the hidden, less obvious aspects of uncertainty is complicated and results in inseparable risks, and this requires practitioners to be more proactive in their approach (Smith and Merritt 2002).

In practice, a typical approach to risks is trying to identify them as early as possible and respond to them as quickly as possible once identified (Kim, 2017). However, green projects anticipate unidentified risks, also known as 'unknown unknowns' that have traditionally been underemphasized by risk management (Thamhain, 2013). It is difficult to trace the causes and culprits of these unknown unknowns as they require inventive risk handling decisions on risk allocation (Jin *et al.,* 2017). Predicting and controlling such unknown risks has also developed impractical risk preferences for some project stakeholders because they sometimes actively ignore them (Alles 2009). These risk attitudes have made the risk sharing process challenging (Walker, 2015), as shown in Fig 1.

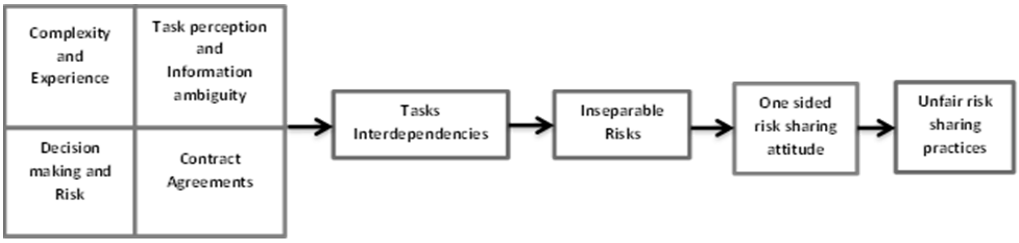


*Fig 1: Interdependent tasks and risks can lead to an unfair risk sharing situations*

The goal of identifying inseparable risks is to make the process of risk sharing more efficient through planning and coordination by mutual adjustment, so as to get a better information flow in design (Fundli and Drevland 2014). Design risks have been classified in a number of ways. Arguing that risks arise as a result of interactions between stakeholders, obsolete technology and organizational factors, Smith *et al.,* (2009) suggest that they may be grouped as either involuntary or voluntary, depending on whether the incidents that create the risk are uncertain or beyond the control of the people in charge.

The increasing complexity of projects and knowledge processes, makes it imperative for stakeholders to be keenly aware of the intricate connections of risk variables among complex systems and processes (Thamhain 2013), this limits the effectiveness

of traditional RM methods. Stakeholders argue that no single person has all the smarts and insight for assessing multi-variable risks and their cascading effects (Hartono *et al.,* 2014). Project stakeholders realize that, while there may be good RM methods which provide a critically important toolset for risk management, it takes the collective thinking and collaboration of all the stakeholders to identify and deal with the complexity of inseparable risks in green building projects.

## RESEARCH METHOD AND DATA ANALYSIS

In order to execute this study, a multiple case study approach was adopted, where real-life events showed different perspectives to enhance and support the different results from the semi-structured interviews (Zainal, 2007). The approach helped in testing the process which commenced with established RM theory, advancing the application of CRM in green projects. Participants were asked about their stakeholder techniques on carrying out inseparable tasks, as well as their options and suggestions on CRM processes of green projects. The underlying intention being to acquire in-depth knowledge for strong theory building (Amaratunga *et al.,* 2002).

CRM is a relatively innovative concept in South Africa, and, in the different case studies, it was important to obtain a detailed and comprehensive view of it by investigating it in past and ongoing projects. The completed projects are the residential apartments and the commercial development; and the project team of this case study reflects on the problems they faced. The other case studies were an academic pathology facility and the retirement apartments; these projects are in their design phases and the project teams are still engaging with their risks and experiences. In all projects, many stakeholders with various backgrounds were involved to see how their thought CRM could be applied.

The adoption of multiple case studies not only helped to explore or describe the data in a real-life environment but also to take multiple perspectives to the CRM progression like the complexities of real-life situations, the case studies, matrix-based applications and the reviewed literature to see a bigger picture (Stake, 1995; Zainal, 2007). It provided a stronger foundation for theory building, specifically, when solving design problems that have a holistic approach due to their integration in design and different stakeholders facing complexities and task interdependencies, which resulted in inseparable risks. In this instance, multiple case studies sought to understand the lived experiences of various stakeholders who have a shared experience of green building construction across different cases, with suggestions of a plausible process to understanding CRM as an effective RM practice (Chong, 1994).

The analysis and interpretation of research data form the major part of the research (Amaratunga *et al.,* 2002). The methodical process used was the DSM, which is a square matrix that focuses on dependencies between elements of one domain like task-task sequence relationships. Then, the Domain Mapping Matrix (DMM) was used as it examines the interactions across domains to represent enriched analysis results that provide an expanded view of the complex system (Bartolomei *et al.,* 2007). When applied, a DMM was constructed to map out the interdependencies, interactions, and exchange of information from design tasks and risks, identifying the optimal sequence of tasks, risk interactions and iterations across domains (Yang *et al.,* 2014). The combination of square DSM and rectangular DMM is called Multiple Domain Matrix (MDM) where useful information and transformation of flow is provided using intra- and inter-domain networks (Lindemann and Maurer, 2007), as shown in Table 1.

*Table 1: MDM Mapping System for capturing the Design Process Interfaces in various domains headings*

| | Stakeholders | Design Tasks | Design Components |
|---|---|---|---|
| Stakeholders | People DSM | People-Activity DMM | People-Design-Components DMM |
| Design Tasks | | Activity DSM | Activity-Design-Components DMM |
| Design Components | | | Component DSM |

The MDM provides valuable and structured information regarding the intended designs between different stakeholders, their design tasks and the design component domains. This reduces the required effort to construct high-definition DSMs. Also, the DMM process was utilized to identify clusters (Browning, 2015) in a matrix analysis approach that minimizes iterations and enhances efficiency in risk management (Jaber *et al.,* 2015). The high interaction of clusters encouraged stakeholders to collaborate, communicate and coordinate better, so to identify and examine interfaces between the clusters and keep iterations at a minimum; minimizing the number of task dependencies (Austin *et al.,* 2001).

## FINDINGS AND DISCUSSION

A total of 27 semi-structured interviews with different practitioners from the case studies and referrals were conducted, using a non-probability, snowballing sampling technique. These participants were involved in green building project designs. In addition to their knowledge and experience, the importance of availability and willingness to participate, and the ability to communicate experiences and opinions reflectively was also important; to understand the current risk sharing practices and the way inseparable risks can be managed in collaborative circumstances. The completed case studies were green building projects that were certified with an in-depth certification scheme that addresses all 9 categories of Green Star tools. The tools are based on 9 different categories, each with a range of credits that address environmental and sustainability aspects of designing, constructing and operating a building. In the cases that were still in their design phase, a design will have a certification of validated environmental initiatives.

In real life, practitioners are dealing simultaneously with risks in several dimensions. These risks are about issues of how to organize people in different simultaneous design processes. Moreover, how to manage the process of inseparable risks? How to organize the interdisciplinary environment, and lastly how to coordinate people and integrate their tasks in many interrelated processes? To manage all these dimensions, a Multiple Domain Matrix mapping system is included to improve design process understanding and communication. The case studies revealed that, to manage inseparable design risks, stakeholders suggested co-location, improved co-ordination between disciplines, as well as getting GB accreditation training where attendees have the opportunity to discuss and become familiar with suitable practices of design and risk. Furthermore, Effective, regular, and planned communication with all members

of the project community is necessary to reduce the levels of uncertainty and promote collective thinking and collaboration. Yet, there are still hindering factors that impede risk-sharing implementation as shown on Table 2. In seeking a new dimension for the study of collaborative risk management, GB design processes are chosen as a focus application area for exploration because of their strong influence on risk sharing agreements.

*Table 2: MDM of what impedes risk-sharing implementation*

| What impedes Risk Sharing | Contract Negotiation | Communication | Stakeholder Management | Green Building Development | Continuous Training | Mandatory GB Assessment | Regular team meetings | Unified design codes | Collaborative engagements | Shared insurance | Risk sharing capacity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Restrictive contractual clauses | x | | x | | | | | | | | |
| Clarity of roles | x | x | x | | | | x | | | | |
| Differing risk attitudes | | x | x | | | | | | | | |
| Client knowledge | | | | x | | x | | x | | x | |
| Green building skills | | | x | | x | x | | x | | | |
| Standardize application processes of GB | x | x | x | x | x | x | x | x | | | |
| Information sharing | | x | x | | | | x | | | | |
| Design Variations | | x | x | x | x | x | x | x | | | |
| Government bureaucracy | | x | x | | | | x | | x | | |
| GB specific insurance | | | x | | | | | | | x | |
| Unfair risk sharing | | x | x | | | | | | | | x |

To handle the dynamics of complexity, after the mapping of the interdependencies in the matrix, rows and columns were then altered optimised in order to find clusters that are highly related to each other, to enable coordination. Stakeholder knowledge and perception of inseparable risks can be organized to promote mutual understanding and communication based on completed projects and projects still in the design phase. Management of GBs stress's structure and quality communication systems.

Optimal CRM arrangements are on cognizing stakeholders' behaviour, where respondents highlighted that project teams with shared responsibility, should initiate, develop and implement collaborative practices that regularly evaluate each other's roles and responsibilities and accept joint responsibilities for the team's achievement. To ensure such shared responsibility, all stakeholders should embrace collaborative

attitudes such as decision synchronizing that focus on finding solutions when problems occur, risk management practices that are open to risk sharing agreements that are flexible and can lead to equitable risk sharing, as shown in Fig 2.

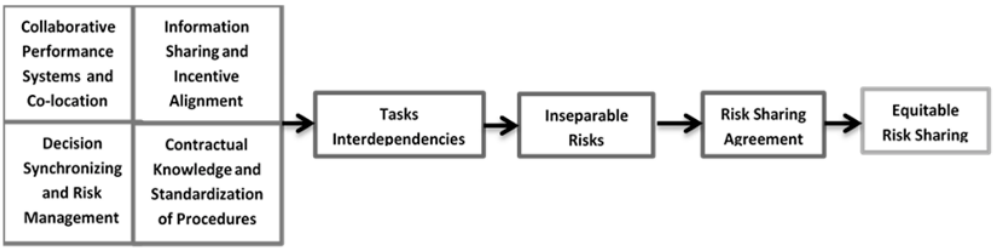


*Fig 2: MDM of what impedes risk-sharing implementation*

To achieve equitable risk sharing, CRM aims to deliver superior value by assembling, integrating and harnessing the collective skills and capabilities of all stakeholders by effective utilization of technology, unique leadership and communication. However, risk-sharing practices in a CRM arrangement cannot be considered individually but must be correlated between different RM practices. The interaction between these practices means there are different constraints considered to create a balance among the selected practices. These constraints attempt to consider prerequisites between risk-sharing practices and further prevent the selection of antithetical practices.

## CONCLUSION

Green design complexities have driven the industry to open systems that commanded collaboration and thus, have resulted in interdependency and risk. However, existing project management practices fail to incorporate complexity-based thinking and collaborative practices into risk management. This has led to poor risk management outcomes, where traditional risk management practices that rely on allocating risks to specific individual entities are not able to accommodate the collaborative facets. The DSM method was used to identify interdependencies and relations between items such as tasks, activities, risks and among designers and design teams. The parameters in inseparable risk networks were considered to give priority to certain risks and design more effective response actions. Mapping this information dependence revealed the underlying structure for design processes and the design teams setting was designed on the basis of this structure. However, tasks, specifications, and processes changed when new information was introduced. While the design process can be dynamic, the application of DSM, DMM or both is instant. To handle the dynamics of CDM, DSM and DMM analyses would need to have been done repeatedly. Should this be done, then this approach would be able to support stakeholders in making decisions, such as risk response planning and allocating available budget or resources. CRM encourages people to meet, communicate and coordinate better, to manage potential interactions. It underlines the need for cooperation and transversal communication in the design teams. Interviews prove that it does indeed improve communication between stakeholders and the understanding of responsibility and accountability.

This change of paradigm does not take place naturally or without resistance as the findings show that some professionals see CRM as an extreme alternative to current practice as it involves risk sharing. Future developments in collaboration will lead to the widespread use of CRM principles in project management. Direction for actions of people will come from the intensive interaction and understanding of the design

context, not from orders of the hierarchy structure bur rather from the knowledge of the end user's needs.

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# ACTANTS INFLUENCING THE SUCCESSFUL COMPILATION OF ECONOMIC FEASIBILITY STUDIES: THE QUANTITY SURVEYORS' PERSPECTIVE

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An economic feasibility study is a document that provides financial information, which supports informed investment decision-making for property development projects. These feasibilities, however, are inconsistent in content, neglected, lack standards, and creates confusion in practice, leading to undesired investment decisions. It is thus imperative to understand where the issues manifest, what they are and how it can be eliminated to ensure quality and successful feasibilities that provide the correct advice in terms of the economic feasibility of a proposed construction project. By employing the Actor-Network Theory (ANT), these objectives and aim were met through the identification of actants in the feasibility network, understanding the relationships between these actants, understanding and mapping the actor-network, and finally identifying where the issues manifest within this network. A literature review was conducted in addition to 23 interviews with quantity surveyors in South Africa. Through the literature review and semi-structured interviews, several actants were identified. The feasibility is a complex process that involves a substantial amount of actants that influence the success of the advice, investment decision and construction project. Descriptions of the relationships of these actants were noted and graphically depicted, while actions that destabilise the network were identified. With a deepening understanding of the feasibility network, the compilation and usage of feasibility studies could be enhanced by improved understanding, careful compilation, and successful investment decision-making.

Keywords: ANT; projects; information management; investment decisions

## INTRODUCTION

Quantity surveyors (QSs), also known as cost engineers (Cruywagen and Llale 2017), are consultants that primarily estimate and manage costs of construction projects. Additionally, they advise property developers on the optimum use of capital (Ismail, Drogemuller, Beazley and Owen 2016; Cruywagen and Llale 2017). This advice is dependent on and supported by an economic feasibility study report (from herein referred to as feasibility/s), a 'tool' often compiled by the QS as part of their responsibility. The feasibility is a document that provides financial information,

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which supports informed investment decision-making for property development projects (Basak 2006; ASAQS 2016). Therefore, the key stakeholders surrounding the compilation and usage of a feasibility is the QS and the developer, however only the QSs' perspective will be investigated.

Private developers are concerned with commercial success and aim for economic feasibility and benefits, whereas the public sector is concerned with developmental success and aims for social benefits (Rwelamila and Ogunlana 2015). Consequently, the focus will be on the private sector that utilizes feasibilities for private investments in building projects (commercial, retail, industrial and residential sector).

The quality and successfulness of feasibilities are in question, motivated by findings of previous studies. These studies found that feasibilities are inconsistent in content (Shen, Tam, Tam and Ji 2010), often incorrect (Huxham 2010; Kwaku Osei 2016; Kgaka 2018), inadequate (Oso Sunday 2020), neglected and problematic (Mohammed, Naji and Ali 2019). The feasibility is a professional output of a QS and a sub-quality report is neither good for the profession nor the investment decision that it supports (Terblanche, Ozumba and Root 2019). It is thus imperative to understand where the issues manifest, what they are and how it can be eliminated to ensure quality and successful feasibilities that provide the correct advice in terms of the economic feasibility of a proposed construction project.

By employing the Actor-Network Theory (ANT), these objectives and aim can be met through the identification of actants in the feasibility network, understanding the relationships between these actants, understanding and mapping the actor-network, and finally identifying where the issues manifest within this network. This could provide a basis for recommendations that assist the compilation of a quality and successful feasibility. ANT and the corresponding concepts are discussed in the next section.

## Actor-Network Theory

ANT was developed by Michael Callon, Bruno Latour and John Law, three Science and Technology studies scholars, in the early 1980's with the aim of explaining complex networks in the scientific research environment (Williams-Jones and Graham 2003). With ANT, certain concepts and terminology are used which will be introduced and briefly explained in this section. These include actor; actant; actor-network; agency; translation; problematisation; interessement; enrolment; mobilisation; black box; focal actant; source actant; target actant; and translating actant.

In essence, ANT recognise that complex relationships exist between actors, where actors are not only humans, but also inanimate objects, processes and concepts, allowing an actor-network to form (Latour 2005). Actors are often referred to as actants within ANT, since an actant is that which either accomplishes or undergoes an act (have agency) (Latour 1996). By using the word actant, the focus is shifted slightly towards the actions of the entity rather than the source of this action. Therefore, the term actant is deemed more appropriate, and will be referred to as such in the following discussions. Furthermore, ANT sees human and non-human actants as equally important and therefore assign agency to both (Callon 1984; Silvis and Alexander 2014). "An actant can literally be anything provided it is granted to be the source of an action." (Latour 1996).

Translation is the concept that explains the gap between the heterogeneous actants that form part of the same network and is the mechanism by which the network takes form (Callon 1984). Callon (1984) further explains that there are four stages to translation termed 'problematisation', 'interessement', 'enrolment', and 'mobilisation'. These four stages are interwoven and overlaps and not isolated events that occur sequentially. Problematisation occurs when initiating actants, also known as focal actants, identify an issue and propose a solution. In this stage, the initial actants are determined (Pak, Alwi and Ismail 2020). In the second stage, which is interessement, additional actants are recruited to become part of this solution. When the recruitment is successful, enrolment (stage three) takes place. Additionally, during the enrolment stage, the focal actants attempt to define roles in the network. Finally, mobilisation is in play when the network is stable, although temporarily, and the solution is widely accepted. Furthermore, complete translation does not necessarily have to occur, it could fail or stop at any stage (Callon 1984).

Black boxes are used in ANT as a means to simplify the actor-network by condensing parts of the network into a single actant. In these black boxes, it is assumed that the network within is stable (Silvis and Alexander 2014). Simultaneously, it is recognised that the black box can be "opened" at any time to reveal a complex network. Venturini (2012) emphasised the significance of the black box concept, "The basic tenet of ANT is that every actor can be decomposed into a network and that every network can be connected tightly enough to become a single actor."

ANT has been used to map the adoption process of standardisation (Troshani and Lymer 2009), understand development project implementation (Heeks and Stanforth 2014), theorise IT programmes in healthcare (Greenhalgh and Stones 2010), explore the accountability structure in construction projects (Burga and Rezania 2017), and study the privatisation of solid waste management while all applicable parties' interests are aligned (Pak *et al.,* 2020). ANT is thus widely adopted and used across many industries. Most of these studies, however, included only concrete actants in the network, for example: a company, cell phone, learning material, operating manual, etc. Granted that actants can be anything, provided that it is a source of an action, a study does not exploit the full potential of the theory if only concrete entities are given agency. Silvis and Alexander (2014) on the other hand, demonstrated the use of more abstract actants, for example: knowledge, an idea, objectives, perceptions, challenges, etc.

A prominent use of ANT is to examine a network of actants in order to address issues in the system, where the stability of the network directs the capability of the "solution" (Silvis and Alexander 2014). The rationale of using ANT as an analytical tool is twofold. Firstly, to understand the network revolving around the feasibility process and secondly, to identify issues in the network that destabilise the network.

In addition to ANT, Silvis and Alexander (2014) created a graphical syntax for ANT to provide a mechanism for visualising the actor-network. This graphical syntax is useful to identify actants and translations within the actor-network. There are three different roles that actants can take during the translation process (Silvis and Alexander 2014): (i) A source actant: an actant that is being translated (abbreviated as source); (ii) A target actant: an actant that is being translated for another actant (abbreviated as target); (iii) A translating actant: the actant that translates the source actant for the target actant (abbreviated as translator).

# LITERATURE REVIEW

## Components of a Feasibility

In summary, the main components of a feasibility are: duration and mile stones (Willemse, 2019), total capital outlay, total project income, cash flow projection (Lock, 2020), profitability indicators (Stefánsdóttir, 2015), sensitivity analysis (Karas, 2017), and recommendations towards the investment decision (Stefánsdóttir, 2015).

Total capital outlay includes land costs, construction costs escalated, professional fees, finance costs, and other development costs (Cloete 2006). The total project income requires the calculation of the gross income, net income, and interim income (income prior to opening date) (Huxham 2010). The net income is calculated by deducting the operational costs (Stefánsdóttir 2015). Furthermore, there are various profitability indicators, however most indicators require the total capital outlay and the net income to calculate the profitability (Cloete 2006). Hence, to provide an accurate profitability indicator, all projects' costs need to be accounted for in the total capital outlay, as well as the operational costs in the net income calculation.

## Actants in the Feasibility Network

The QS, being central to the compilation of the feasibility, needs to have the required expertise to provide a successful report (Lim, Nepal, Skitmore and Xiong 2016). Irrespective of the experience level, the estimation method used for the construction cost can be detrimental to the success since some estimation methods are too simplified in a complex calculation (Bettini, Longo, Alcoforado and Maia 2016). Furthermore, the QS's volume of work and time allowed/available for the compilation of the feasibility (Dandan, Sweis, Sukkari and Sweis 2019) impose on the amount of research done (Syed Alwee, Salehudin, Mohamed Sabli, Isnaini Janipha and Maisham 2019), compilation approach and estimation method. Finally, the over allowance of a contingency can overthrow the feasibility (Lim *et al.,* 2016).

In addition to the QS's experience, the developer's level of knowledge also influences the approach to a successful feasibility (Al-Hawsah 2020). While the QS compiles the feasibility, the QS requires certain information from the developer and the professional team (architects and engineers). Hence, the clarity of the developer's brief is essential to successful compilation (Dandan *et al.,* 2019), as well as the completeness of the information received from the team (Syed Alwee *et al.,* 2019). The completeness, however, is not the only concern, the level of experience of the team (Dandan *et al.,* 2019) along with a cost conscious approach (Bettini *et al.,* 2016) impact the feasibility. Furthermore, QSs sometimes make use of information from historical databases without questioning the applicability to the new feasibility (Lim *et al.,* 2016).

When a rental scheme is at play, the success of the feasibility is highly dependent on the availability of tenants (Karas 2017). Furthermore, external influences like change in exchange rates and inflation (Dandan *et al.,* 2019) and the volatility of the market (Kgaka 2018) impose on the overall validity of the outcome of a feasibility.

# METHODOLOGY

A fundamental principle of research based around ANT is that it should be able to tell a rich story of a particular network (Heeks and Stanforth 2014). Therefore, qualitative data was gathered by means of in-depth, semi-structured interviews with QSs in South Africa as the target population. The criteria for the QSs to be deemed adequate,

included QSs with more than five years of experience in the private commercial sector (commercial, retail, industrial, hospitality and bulk residential). After 43 adequate quantity surveyors were approached, a total of 23 agreed to be interviewed, resulting in a 53.49% success rate. The participants were identified by using a combination of the purposive sampling method and snowballing.

The interviews were recorded, then transcribed verbatim using Otter.ai. In the interviews, no personal identification questions were asked, and the recorded files were saved under a pseudonym. The uploaded file to Otter.ai had thus no personal information, while the login details to Otter.ai remained confidential, ensuring the protection of the participants' identity. A reflexive thematic analysis followed via the NVivo software program. Using ANT as an analytical framework, actants influencing the successful compilation of feasibilities were identified through arising themes.

Through the reflexive thematic analysis of the qualitative data, themes developed at a later stage from the codes while the theme development required considerable interpretive work from the researcher (Braun and Clarke 2021). Furthermore, coding in the reflexive thematic analysis approach is recognised as an inherently subjective process (Braun and Clarke 2021). In addition to this, an interpretation of actants within a system is required to map the network, motivating the adoption of the interpretivist philosophical view. The analysis is conducted with the ANT framework and the graphical syntax is used to interpret and demonstrate the actor-network. The syntax uses symbols to present an actants' state as well as the relationships within the network. Descriptions of these relationships were noted and graphically depicted.

**Interpretation and Graphical Presentation of the Actor-Network**

The graphical presentation of the network can be seen in Fig 1 and the interpretation of the actants, and the corresponding relationships are discussed hereunder.

With the objectives of giving and receiving correct advice in terms of economic feasibility of a proposed construction project (abbreviated as objective), the QS and developer form key actants of the network along with the economic feasibility study report. The empirical data gathered is from the perspective of the QS, a key actant. The literature review in combination with the interviews presented actants that form part of the actor-network. The two data sources are deemed complimentary in the mapping and interpretation of the feasibility actor-network.

The QS as the source actant impose on the objective (target) by their perception of a successful feasibility (translator) which should be aligned with the developers' view of a successful feasibility. Some QSs do recognise that the success of the study is dependent on the parameters set by the developer: "A successful feasibility study depends on what the client wants at the end of the day." Another perspective of a successful feasibility is that it is only deemed successful once the project is completed within the constraints of the study. Some argue that the success is directly related to the return presented by the study. An additional perspective is that the feasibility should be accurate and honest, irrespective of the predicted return. A final perspective is that the study is deemed successful once the project has been approved: "It's successful when we get to a point that we can turn a paper exercise into a real project." If the perception of the QS do not align with the developer the following happens: "And I think it's one of the biggest problems in the market generally, is that we as QSs are trying to, try and convince our clients that they must do this development. Every scheme is a good scheme, and it's not always the case." Or the

expected income is manipulated by the QS to make the project seem feasible to get the project approved (Kgaka 2018).

Given that various perspectives exist in the QS profession regarding what constitutes a successful feasibility, it is imperative that the QS's perspective is aligned with the developer's perspective to work towards the same goal. Further to the QS being the source actant, the QS is responsible for compiling the report and requests input (translator) from the professional team (architect and engineers) (target), from financiers (target) as well as the municipality (target). In turn, the input from the professional team (source), enact on the objective (target) by the level of completeness of the input and being cost conscious (translator): "In the end the feasibility is only as accurate as the information that you get." "Good architects, in my opinion are very good at design, but also have a sense of cost." "…makes a huge impact, you have consultants that is cost conscious, and you have ones that really doesn't care." If the team is not cost conscious, often tension would arise between the QS and the design team: "Tension builds, we fight with everyone because I need to protect the feasibility and protect the estimate."

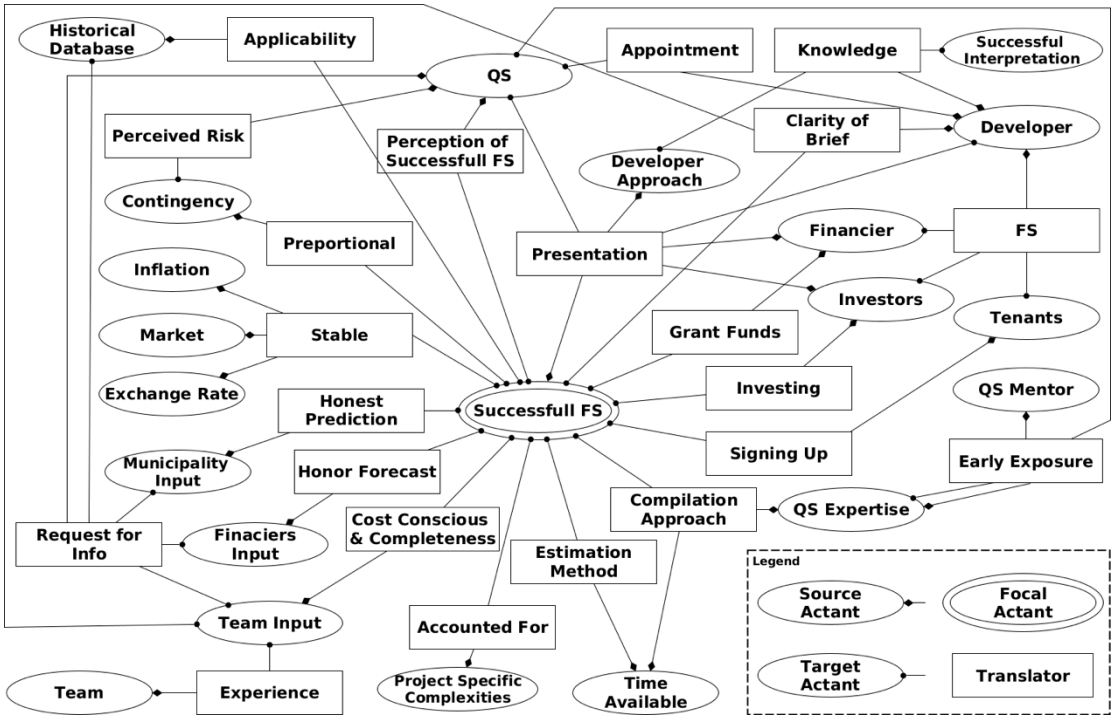


*Fig 1: Feasibility Actor-Network*

Similarly, the input from the municipality (source) effects the objective by giving an honest and trustworthy estimate (translator) of the expected rates and taxes. Unfortunately however, municipalities in South Africa seem to change their rates and taxes once the building is in use, causing a significant decrease in return: "There is things like increases in rates that can have a major effect on the feasibility, when the council ups his rates by 100% for no real reason." Additionally, the input from the financiers (source) influence the objective by honouring the forecasted interest rate (translator) when they were initially approached.

The QS (source) decide on the contingency (target) based on their perceived risk (translator) in the project. The contingency (source) however, needs to remain proportional (translator) to the total project cost to avoid overthrowing the potential

investment: "But we also find that contingency can kill a job and you got to be realistic with the contingency."

The QS level of expertise (source) change the QS (target) by early exposure of the required knowledge (translator). The QS level of expertise is deemed the source actant due to the knowledge reaching the QS instead of the QS finding the knowledge. However, the expertise level (target) is imposed by the mentor (source) of the QS by allowing the inexperienced QS to get exposure (translator) to feasibilities. Nonetheless, in the industry it is often seen that there is a delayed exposure to feasibilities and a reluctance of knowledge sharing: "Specifically the younger QSs don't get exposed to it." Furthermore, the QS level of expertise (source) contribute to the objective (target) by means of the compilation process (translator). Some participants referred to having "a feel for the feasibility". Kahneman (2011) explains that this 'knowing-without-knowing' is knowledge gained over time and stored in memory and this intuition is merely an experience of memory. Therefore, the "feel" occurs when a QS has a certain level of experience, which is a required actant to contribute to the stability of the network.

Irrespective of the expertise level of the QS, the time available (source) to compile the feasibility infringe on the objective (target) by means of the compilation approach (translator) and estimation method (translator): "We would go into as much detail as we've got time available, to be honest, because the more detail you can put into it, it's all the better for decision making". "Sometimes you do it in square meters, because the client wants it the next morning." Other participants expressed their concerns about the rate per square method of estimating: "They put a rate per square which is extremely dangerous, we don't ever do that, we do not recommend that."

While the QS is compiling the feasibility, project specific complexities (source) need to be accounted for (translator) to contribute to the objective (target). The complexities that manifest in a feasibility are the type of income stream, operational costs and projects done in phases and was expressed by various participants: "So the income side is always this sort of uncertain and operational costs as well." "And it's not only just the income, it is also the operational costs and we find ourselves getting more and more involved in." "And then the hard part comes which is operational costs." "If it is phased, it is more complicated."

External actants that impose on the success of a feasibility (target) is the exchange rate, inflation rate and market (sources). If the exchange rate, inflation and market remain stable (translator), the negative impact is mitigated: "60% of the building is reliant on import duties, and an exchange rate." "You need to actually have a look, is the project mechanically intensive, are there lots of lifts are there lots of important air conditioning equipment or whatever that might affect the Rand Dollar, that might affect your escalation."

Moving to the developer (source) - QS (target) relationship, the developer approaches the QS with the objective to get correct advice in terms of the economic feasibility of a proposed construction project. The relationship is translated through an appointment or an agreement with the QS. However, in South Africa, the compilation stage of the feasibility is often done as risk work: "Especially in South Africa, a lot of private sector commercial projects are done on a risk basis." Furthermore, the professional fees have been decreasing lately: "…the professional fees, and that's just getting less and less every year." Both the aforementioned factors motivate the limited time that

the QS profession is willing to spend on the compilation of a feasibility, which in turn negatively affect the quality of feasibilities.

As part of the feasibility process, financing needs to be sourced (if required), investors need to be attracted (if required) and tenants need to be signed up if it is rental scheme. The developer (source) approaches financiers (target) and investors (target) with a preliminary feasibility (translation) with the aim to source funding. The financier (source) acts on the success of a feasibility (target) by granting funds (translator). The investor (source) contributes to the success of a feasibility (target) by investing (translator). Additionally, the investors (source) and financiers (source) have requirements in terms of the presentation (translator) of the feasibility: "We've had a couple of specifications or criteria from financiers, how they want to see it, they would want to see specific calculations for financing purposes as well on the capex, which we have incorporated." "Does he plan to get partners involved, because that all kind of stipulates how you would present this feasibility." In a rental scheme, the developer (source) needs to sign tenants up (targets) and usually use the preliminary feasibility study (translator) as a negotiation medium. The tenants (source) impose on the success of the feasibility (target) by signing the tenant contract (translator): "Especially with retail, one day you've got 70% let scheme, the next day 30% of them is pulled out."

Once the feasibility is compiled, with the objective (source) to give correct advice in terms of the economic feasibility of a proposed construction project, the QS (source) presents the feasibility to the developer (target). The developer (source), with the right knowledge level (translator), interprets the feasibility and advice presented successfully. In the industry however, developers have various levels of knowledge when it comes to the feasibility: "All of the clients aren't educated in the built environment. So that is why you actually have to lecture them through your feasibility study." Additionally, the developer's (source) level of knowledge (translator) impacts the approach (target) the developer take in the feasibility process. This approach becomes a source actant and influence the presentation (translator) of the QS (target): "The one developer said to me now, I don't want to see all this, I want to see how much it costs. The other developer, he wants to see the nitty gritty."

## CONCLUSIONS

The economic feasibility study is a complex process that involves a substantial amount of actants that influence the success of the advice, investment decision and construction project. The actants are not limited to the stakeholders involved but includes abstract influencers such as what a QS deem a successful feasibility to be. The feasibility is faulty with various problems in practice. This can be seen in the fragile and often unstable feasibility actor-network. With a deepening understanding of the actants in the feasibility process, the compilation and usage of economic feasibility studies, for private commercial developments where profitability is key, could be enhanced globally by improved understanding, careful compilation and successful investment decision-making.

The methodology limits the findings to the perceptions of a small sample of South African QSs. Therefore, further studies including the developers' perspective and the feasibility document as an artefact could be further explored, as well as including international perspectives and/or larger sample sizes by means of quantitative data. The identified actants could be further explored and unboxed.

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# Infrastructure Development

# THE DARK SIDE OF COLLABORATION: THE RISKS OF STRONG TIES IN COLLABORATIVE PROJECT NETWORKS

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Collaborative project delivery models (CPDMs) have been introduced as a way of managing infrastructure projects to improve the adversarial mindset characteristic for the field and improve project outcomes. A plethora of valuable research exists pertaining to the relevance and benefits of increased collaboration; but is all collaboration positive? A recent rise in the interest in social networks and their impact on project implementation has highlighted the need for further research into the structure of project networks. We apply a project network lens to study the strength of collaboration in infrastructure projects in which CPDM is applied to increase collaboration. We have conducted a pre-study using a collaborative way of working and two case study projects utilising a CPDM during 2019-2020. The data consists of interviews, observations and document analysis. We found that strong ties between individuals enable rapid information exchange and build trust within the network; but if the initialising phase is incomplete; it can be hard to include all participants later on in the process. Strong ties can also become over-embedded, resulting in a restricted project network and a constricted information flow. This is an interesting aspect to consider especially in long-term; major projects, where a certain relocation or reassignment of people is to be expected during the project's life cycle. Another aspect to consider is the need for the project manager to rely on interpersonal relationships (i.e., strong ties) for efficient leadership as they lack traditional tools to manage project participants originating from other organisations, such as contractual ties. While strong ties are reported to bring several benefits, such as rapid information exchange and trust; they also carry risks restricting network development which become relevant for the application of CPDMs in large scale projects.

Keywords: collaboration; large-scale infrastructure; project network; ties

## INTRODUCTION

The infrastructure construction industry has recently introduced collaborative project delivery models, or CPDMs, (Lahdenperä 2012) in order to combat industry-characteristic adversity (Hansen-Addy and Nunoo 2014), project overruns (Rahman and Kumaraswamy 2004, Flyvbjerg 2014) and to manage more complex projects, a result of growing project sizes (Flyvbjerg 2014, Volker *et al.,* 2018). A plethora of valuable research exists pertaining to the relevance and benefits of increased collaboration as well as the procurement of such models.

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af Hällström, A and Bosch-Sijtsema, P (2021) The Dark Side of Collaboration: The Risks of Strong Ties in Collaborative Project Networks *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 37th Annual ARCOM Conference,* 6-7 September 2021, UK, Association of Researchers in Construction Management, 402-411

The benefits of collaboration are much discussed in this literature. It leads to improved project outcomes, lowers the risk of cost overrun and delays and facilitates efficient problem solving (Hansen-Addy and Nunoo 2014, Adami and Verschoore 2018). These are all core concepts in CPDMs, who are characterised by early involvement of all key actors, joint decision-making and sharing resources, risks and responsibilities (Lahdenperä 2012). However, little is known about the possible downsides of collaborative relationships, the basis of CPDMs. Only few studies mention risks of collaboration of CPDMs and relate to e.g., groupthink (c.f. Hietajärvi 2016).

Furthermore, many of the traditional theoretical frameworks, such as transaction cost theory and agency theory give valuable insights into the mechanics of interactions but leave the social structures and networks unattended (Uzzi 1997). While network theory discusses positive and to some extent negative consequences of strong networks, this has not been discussed in project management or construction management literature.

A recent rise in the interest in social networks and their impact on project implementation in the construction industry has highlighted the need for further research into the structure of project networks. We apply a project network lens to study the consequences of the strength of collaboration in infrastructure projects in which CPDM is applied to increase collaboration.

## THEORY

*Project networks and CPDMs*

Recently, network approaches have increased in popularity in the construction sector (Zheng *et al.,* 2016) as a network view allows for in-depth understanding of behaviour and ties between network actors (Pryke *et al.,* 2017). Actors can be either individuals or organisations and the ties can be divided into formal and informal (af Hällström 2021). Formal ties can be observed or measured (Papadonikolaki *et al.,* 2017, Wang *et al.,* 2018) while informal ties are less visible and often are a social relationship between two actors (Papadonikolaki *et al.,* 2017).

One of the most common networks to study are social networks, which is especially concerned with the network structure (Loosemore *et al.,* 2020). Loosemore *et al.,* (2020, p.1062) defines social networks as "self-organising, emergent and complex and form repeatable patterns of relationships which can be used to understand organisational phenomena (such as construction project organisational outcomes)".

In this study, we focus on the informal social ties between actors in a project network. A project network is here defined as the network that forms around the project organisation by the project participants and the ties connecting them (Hellgren and Stjernberg 1995, Adami and Verschoore 2018), as this enables us to study the ties in a specific context and possibly uncover before unseen connections.

A CPDM consists of multiple levels of actors (individuals, project, organisations, industry) which interact with each other and the project (Sydow and Braun 2018). In this perspective, the project network is shaped both by the individual actors partaking in the project and their role in the project organisation, as determined by their home organisation and their employment contract, but also by the organisations who are contracted to deliver the finished product. These organisations are furthermore connected by social ties to each other, born from the interaction and action of their employees as they meet in different projects and form social ties.

*Collaboration in networks*

CPDMs are based on the collaboration between key actors in early stages of the process and equal partaking and sharing in the project process. The practicalities of the model rely on the interplay between the project organisation and process, as laid down in the governing contract, but particularly on the social relationships created between actors (Lahdenperä 2012, Walker and Lloyd-Walker 2015). Collaboration, or the shared, interactively developed understanding of the rules and norms governing the context (Wood and Gray 1991) is based on close relationship between project actors. Although literature has discussed the models themselves, this relationship has received less attention.

Close social relationships, or ties between individual actors (af Hällström 2021) in a project network can assist in coordinating adaptation and adjustment within the network, which helps in shifting the perspective to cultivating long-term relationships rather than chasing short-term gains (Uzzi 1996). According to Uzzi (1997), such close social ties build on the three principal components of trust, close information transfer and joint problem-solving processes. These components are also part of the CPDMs (Lahdenperä 2012), indicating the relevance of social ties for the model.

Although benefits of collaboration make CPDMs attractive to use, there are two aspects of collaboration-related challenges that are little discussed in current literature. First, the homogeneity of social networks and second, the creation of in- and out-groups and the related groupthink.

First, a weakness in strong social ties is related to the classic statement "similarity breeds connection" (McPherson *et al.,* 2001, p. 415): dense social networks are often homogeneous, leading to implications regarding the interactions within the network as well as the project process itself (ibid.).

Second, project networks are formed by several clusters, often based on the individual's home organisation. This, coupled with differing roles in the project and amount of time spent there, can create in- and outgroups which have implications for both intergroup and interpersonal behaviour (Tajfel and Turner 1979). For example, according to Hietajärvi (2017), studying alliances, "although a collaborative project identity mostly supports and enhances performance" (p.44), there is a risk of groupthink as the "strong impetus for unanimity can in some instances hinder continuous improvement" (p.44). This risk can be mitigated by involving outside experts and discussing matters with people outside the network (Hietajärvi 2017).

*Embedded relationships*

How the quality and relationships of a network influence the activities within is related to the concept of structural embeddedness (Uzzi 1997). Although literature on structural embeddedness (see e.g., Granovetter 1985, Uzzi 1997, Nell and Andersson 2012) focuses on economic activity and exchange, this concept can be applied to network theory in general as it is concerned with the interaction of the network ties.

Embedded relationships relate to the way relationships between project actors shape the project network (Uzzi 1996, Nell and Andersson 2012). A high level of embeddedness enables trust and collaboration, while a low level of embeddedness results in an arms-length relationship between the actors (Nell and Andersson 2012). A high level of embeddedness of relationships “shifts actors' motivations away from the narrow pursuit of immediate economic gains toward the enrichment of relationships through trust and reciprocity” (Uzzi 1996, p. 677). It can also help shape goals and behaviours through close ties between actors, as well as coordinate

actor adaptation and adjustment. This shifts the focus away from short-term gains to cultivating long-term relationships: the project network moves from low to high levels of embedded relationships (Uzzi 1996). A high level of embedded relationships supports the formation of collaborative relationships (Uzzi 1997).

Uzzi (1997) furthermore identifies several risks connected to over-embeddedness in networks, leaving actors vulnerable to sudden changes, making adaptation difficult and reducing the flow of novel ideas and innovations within the network.

Over-embedded ties in a classical organisational network constrain information flow and hinder innovations from arising (Uzzi 1997, Nell and Andersson 2012). Close social ties are furthermore easiest to create with people similar to oneself (McPherson *et al.,* 2001). However, when people in a group are too similar, innovation and new ideas are stifled (Granovetter 1985, Uzzi 1997, McPherson *et al.,* 2001). Close social ties can therefore hinder information sharing and the rise of innovations, if not managed properly.

The difference in levels of embeddedness, combined with the changing project models, has raised interest in the new demands placed on actors, globally but also in the Nordic countries where CPDMs have become more common in recent years.

## RESEARCH DESIGN

In order to study collaboration in major infrastructure projects, we focused on three projects in a Nordic context: one pre-study and two main studies (see Table 1). The pre-study was governed by a traditional bid-build contract based on collaboration while the main studies used a CPDM, divided into a tendering phase, phase 1 (design and project planning) and phase 2 (detailed design and construction). The studies focused on the three main roles of client, design engineer and contractor.

44 interviews were conducted with respondents from all levels of the project hierarchy and from all participating main organisations. The respondents were selected by snowball sampling, the chain starting from the project manager. All interviews were taped and transcribed. Notes were also taken during all interviews to ensure data safety in case something happened to the tapes and/or transcriptions. The shared office space was also observed in the two main cases (58 hours in total, see table 1). Moreover, documents obtained from the projects and from publicly available sources were analysed. The data was inductively coded in NVivo, and main themes related to collaboration were coded according to an inductive approach.

## FINDINGS

The nature of collaboration was seen as a key to the project's success and that it enabled several benefits, most notably related to time savings. The main themes related to collaboration visible in the data related firstly to the impact of the initial phase on collaboration later on in the project and secondly, to the role of strong social ties for collaboration and information exchange.

*On the impact of the initial phase*

The initial phase here refers to the start of the project, after the tendering process is done and when the project is starting with the establishment of collaborative spaces, the allocation of roles and tasks and the introduction of the individual project participants to the project.

*Table 1: Case descriptions*

| | Pre-study | Case A | Case B |
|---|---|---|---|
| Length | 1 year | 9,5 years (estimated) | 6,5 years (estimated) |
| Monetary value | - | 475 million € | 390 million € |
| Contract type | Collaborative bilateral between client-contractor | Bilateral (client-contractor) | Multi-party (main participating organisations) |
| Interviews | 3 interviews | 20 interviews | 21 interviews |
| Interview lengths | 1-1,5 hours | 1-1,5 hours | 1-3 hours |
| Roles interviewed | Client (1), design engineer (1), contractor (1) | Client (8), design engineer (6), contractor (6) | Client (5), design engineer (7), contractor (9) |
| Observations | - | Observations of meetings and big room activities | Observations of meetings and big room activities |

In case A, the winning team, consisting of the contractor and their team, had already created a strong network during the tendering phase according to respondents from both contractor and design engineer. According to a design engineer, "because we had worked together during the project planning document stage, then we worked really intensely together with [the contractor] during the tendering stage. So, when we got there, we were a really tight team. And there we- now that I look at it afterwards, we should have understood how strong a team we were, …we didn't get [the client] on board. Or it was a challenge for [the client], I think, to be a part of it". In case B, the client had decided to choose the design engineer and the contractor at different occasions to be able to "choose the best ones" as a client representative said. The client and design engineer started to work on the project organisation and plan the project before the contractor was chosen, approximately two months after the design engineer. Thus, during the initial project phase a strong tie either formed (case B) or had formed previously (case A) between two of the actor organisations, leaving one organisation outside the resulting dyadic relationship. Respondents commented on this during phase 2, indicating long-term impact of these early ties on the project network.

Moreover, respondents commented on the role change for all parties in this initial phase in both main cases. The client and the design engineer lacked experience in working almost full-time in a project office, as opposed to the contractor. The contractor, however, was not used to the early input they were required to give, and many respondents commented on the lack of "real work" during phase 1 in general, but in the initial phase in particular. The contractor was also seen to lack experience in giving input to the design process, but they still saw the early involvement as a positive concept overall. In the pre-study, the process followed a more traditional construction route, where the client first contracted the design engineer, after which the contractor was chosen.

*The role of strong social ties for collaboration and information sharing*

All three cases showed strong social ties between actors, which was seen to facilitate collaboration and its beneficiary information sharing by the respondents. In general, however, collaboration was seen to demand more resources than traditional ways of working during the whole project process, both in terms of time and personnel. "It takes time to get to know each other", several respondents mentioned. Respondents from both cases discussed the time required to create a shared understanding of both project goals and of the need for a common concept of collaboration in the project network. As a respondent from the contractor stated in case A, "let's agree together what collaboration is in this project. If I walk around and think we should collaborate

in one way and you think another way is better; well, that's a bit silly. Isn't it better that we discuss and together decide that 'this is how we're going to collaborate in this project'." The sentiment was echoed by other respondents from both cases.

Collaboration moreover "demands active participation" as a client representative stated, echoed by several respondents from all organisations as exemplified by a contractor statement: "collaboration requires all parties to be seated around the same table". A traditional project focuses heavily on the contract, which was seen to enable a more confrontational approach to the project in comparison to a collaborative model. This traditional way was visible in case A, where the design engineer mentioned that they couldn't approach the client directly, as the main contractual relationship was between the contractor and the client. Another key aspect of collaboration was a willingness to be open, to share and understand each other in order to build mutual trust and relations between the participants. Furthermore, collaboration was seen to be working towards the same goal and finding the best solution for the project.

Social ties were seen as the result of time and active engagement, building trust and a shared understanding. The individual attitude towards collaboration and 'personal chemistry' was also seen as a major factor in the creation of collaborative social ties. As one respondent from the designer put it, "in many projects you can sidestep the question about 'personal chemistry' but in this [collaborative] process, I think it has a surprisingly large role if 'we get along'." The respondents were, however, most comfortable with actors they knew from before. In case A, the contractor and the design engineer had a history of working together and regarding the individual level, a design engineer from case B remarked that "where you seek that… those collaborations, those are also sought from your familiar circle instead of… a designer seeking a discussion partner in a contractor, or a contractor from a designer."

Furthermore, the shared project office, or co-located space, was highlighted as a major contributor to creating social ties, information sharing and collaboration in both the pre-study and case B, as it enabled people to spend time together and get to know each other as well as provided a quick way to access key actors in the project. There were, however, also some negative aspects highlighted with the co-located space, as not all who partook in the project were there constantly. This left these actors outside the created social network and made their collaborative efforts harder. We did not map the whole project network, this is outside the scope of our research, but is an interesting aspect to focus on in later studies.

All studied projects exhibited a close relationship between two key actors, leaving the third outside, as visualised in Fig 1. In the pre-study, the contractor and client were actively using the co-located space and talked in positive terms about the collaboration in the project, while the design engineer was seated at their home office and spoke of the project in more traditional terms. In case A, the contractor and design engineer consortium had previous experience of working together and had already created a strong network in the tender phase before the project properly started. In case B, the client and design engineer started planning the project and setting up the project organisation before the contractor was chosen and created a strong network in the early months of the project, although all actors were active in the co-located space. This initial over-embeddedness between client and designer was perceived as a reason for difficulties between designer and contractor later on in the project, as they lacked understanding of the other. The over-embeddedness between two of the three actors was seen as a problem in all studied projects, as this exclusion was seen to restrict

collaboration and diminish information flow and relational aspects of the project. This was furthermore commented on during phase 2, indicating a long-term impact on social tie formation. Several respondents remarked on the challenge of introducing new project participants to the project.

Another topic brought up in case B was the lack of formal management tools regarding project participants from other organisations. If a person was unsuitable for a certain role, the project organisation and management had to rely on interpersonal relationships (i.e., strong ties) to organise project activities and actors, while employment-related issues were dealt with at the home organisation. This was seen as a problem in interorganisational projects in general, not only in CPDMs.

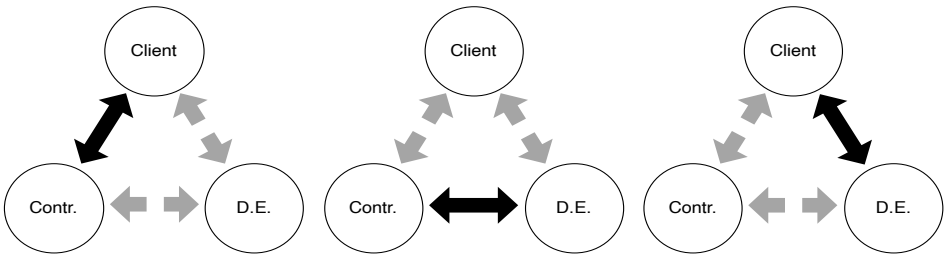


*Fig 1: The main relationships between actor organisations client, contractor and design engineer (D.E.) (pre-study, case A, case B); the dark arrow is the strongest relationship.*

## DISCUSSION

*On collaboration and the impact of the initial phase*

The initial phase seemed to have a major impact on collaboration later in the project. The early relationships between selected actors made later inclusion of additional actors difficult, which was seen even during phase 2.

The uncertainty inherent in the initial phase combined with the role changes and new demands placed on the actors, both individual and organisational, originating from the CPDM, made this phase especially challenging from a collaborative point of view: when faced with uncertainty and change, it is easy to fall back in traditional roles and routines.

Since the language about collaboration was similar across all respondents and organisations, there seems to be a relative consensus regarding the definition. It is however important to ensure a shared understanding of the concept in the project network in question, as remarked by respondents. This requires all parties to be seated around the same table - both physically and contractually. First, as was evidenced by the findings related to co-location, a shared understanding is easier to achieve through time spent together and learning to know each other. Second, a common contract enables parties to discuss directly facilitating information flow and decision-making. Although case A had a shared view, their actions were not in line with this, leading to differing practices.

*The risk of over-embedded ties*

The greatest challenge of collaboration came from the strong social ties between individuals created in the initial phase of the project, whose effect was still visible in phase 2. These ties could be classed as over-embedded, (Uzzi 1997, Nell and Andersson 2012), creating in- and out-groups (Tajfel and Turner 1979) in the project network, restricting the participation of one of the actors by limiting their access to the network structure.

This restricted network, which can be expected from over-embedded ties, was seen in case A where intra-organisational ties were much stronger than inter-organisational ties, making information exchange difficult and reliant on meetings and processual/contractual aspects. In case B the ties were more in balance, although there were difficulties between contractor and designer. These were, however, related to the actor's changing roles and not to over-embeddedness. Moreover, there was a risk of being shut out from the project network in case B, depending on the time an individual spent at the co-located space. This led to people not knowing who to approach when they had questions, knowledge people gained tacitly when they spent a considerable amount time at the project office. This could be seen to lead to a formation of in-group and out-group identities, or under- and over-embedded actors in the network.

Strong ties can also become over-embedded, resulting in a restricted project network and a constricted information flow. This is an interesting aspect to consider especially in long-term, major projects, where a certain relocation or reassignment of people is to be expected during the project's life cycle. Another aspect to consider is the need for the project manager to rely on interpersonal relationships (i.e. strong ties) for efficient leadership as they lack traditional tools to manage project participants originating from other organisations, such as contractual ties. While strong ties are reported to bring several benefits, such as rapid information exchange and trust, they also carry risks, restricting network development which become relevant for the application of CPDMs in large scale projects

*The challenges of collaboration*

The benefits of collaboration are much discussed in literature as improved project outcomes, lower risks of cost overrun and delays and more efficient problem solving (Hansen-Addy and Nunoo 2014, Adami and Verschoore 2018, Volker *et al.,* 2018). In order to reap the greatest result from these benefits, it is natural that the construction sector has introduced CPDMs.

Our findings show that a collaborative project network can be difficult to achieve if some actors form close relationships in the initial phase of the project, leaving some project participants outside and thus creating an incomplete project network. The resulting dyadic relationship can work well, but since the basis for a CPDM is the equal involvement of all key actors, this partial network undermines this basic tenet of the model. There is also the question of how to include individual actors, a group of project actors with a lot of interchangeability due to the long duration of major infrastructure projects, in the network. Another problem related to the social ties which underpin collaboration within the network are managerial issues. Since a project organisation lacks the formal contractual ties necessary for traditional management practices, the role of the informal social ties grew stronger in the project process.

The dark side of collaboration discussed in the article, however, are the restrictions it can place on the network. Over-embedded social ties and too similar actors can hinder conflict resolution and the introduction of new ideas (Uzzi 1997, Nell and Andersson 2012, McPherson *et al.,* 2001). As our respondents remarked, it is easier to go to those you know for help before approaching someone new. This implies both trust (you want to approach this actor) but also a restriction on the new input (you know them and how they are likely to act).

The benefit of a functioning collaborative project network lies in the balance between different viewpoints and actors. Since the definition of collaboration seems quite similar across the Nordics, although the actions might differ if the views on the project differ, there is hope that enough time spent at the beginning of the project to create a shared understanding will facilitate a functioning project network - if all actors are included from the start and the project process ensures that new actors are introduced into the network properly and are not left outside of the shared project office.

## CONCLUSIONS

Collaborative models have been introduced as an alternative to manage complex projects, but little attention has been paid to the challenges of the concept, mainly the risk of over-embedding the ties in the project network, constraining information flow and the introduction of new ideas while creating in- and out-groups within the project network.

Collaboration has several benefits, which is the key reason why CPDMs are introduced in the construction industry. It is, however, difficult to form a collaborative project network if not all organisational actors are included from the start as this creates a dyadic relationship instead of an inclusive network, reverberating throughout the project process. There is also the question of how to include individual actors, who are bound to change during the long duration of major infrastructure projects, in the network. These "dark sides of collaboration" are less explored in the current literature and warrant further investigation. Future research should also consider these more negative elements of collaboration. An interesting approach would be to analyse the interplay between the uncertainty inherent in complex projects and collaboration.

The findings are limited by the geographical scope and nature of the cases studied, as well as the inductive research mode.

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# DEVELOPING A FINANCIAL RISK MATURITY MODEL FOR PUBLIC-PRIVATE PARTNERSHIP PROJECTS

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Globally, the management of financial risk is a topic that has gained much attention in the construction management research community in recent years. Existing studies rank financial risks among the top three risk factors that leads to the failure of a PPP project. Available literature on Public Private Partnership (PPP) projects also acknowledges the need for specific and suitable maturity models to tackle this problem of financial risks. However, there are limited (almost non-existent) studies on specific maturity models on financial risks of PPP projects. In this paper, we developed, tested and validated a financial risk maturity model (FRMM) to enhance the management of financial losses of PPP projects. The FRMM uses a list of statements extracted from financial risk management literature on PPP projects. The statements in the designed model were tested and validated with data from surveys and interviews of experts and practitioners in the PPP market in Australia, China and Ghana. According to the findings backed by experts and literature, FRMM improves the financial success of PPPs. Project managers could use the FRMM as a guide to control financial losses of the project, and the results support further research.

Keywords: finance; risk management; maturity model; PPP projects

## INTRODUCTION

The participation of the private sector in the development and management of public infrastructure projects has tremendously increased in the 21st century (Cui *et al.,*2018, Välilä, 2020). This involvement by the private sector in the public space has led to a term coined in the built environment as Public-Private Partnership (PPP). PPP has no agreed and recognised definition so different researchers, countries, project managers and international organisations explained the concept differently depending on where it is applied and its associated benefits or challenges (Aldrete *et al.,* 2012). World Bank (2021) estimates that more than 14, 000 PPP projects (both ongoing and completed) have been developed at an investment value of $1.7 trillion around the world. The PPP model has been helpful in the construction of new school buildings, airports, energy plants, light rails, mega road networks, health centres, renovation of dilapidated public facilities, and rendering of essential services (Deng *et al.,* 2016, Rossi and Civitillo, 2014).

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However, PPP projects like all other construction projects encounter unforeseen and unavoidable risks which threatens the success of the projects (Gupta and Verma, 2020). Among all the potential risks, one of the topmost identified by researchers in the construction industry is the financial risks (Akomea-Frimpong *et al.,* 2020, Aladağ and Işik, 2017). Financial risks are explained as the potential financial losses which limit the expected revenue from the project, increases the cost overrun of the project and the risks of inability to repay a contracted debt capital in the project's lifecycle (Xenidis and Angelides, 2005). Studies have strongly related the poor management of financial risks to struggling (or total failure) of PPP projects (Kumar *et al.,* 2018, Lam and Chow, 1999). This claim is supported by huge financial losses incurred (or complete failure of the project) with usage of the PPP model in projects such as Sydney's Cross City Tunnel in Australia, Jakarta Outer Ring Road in Indonesia and Kuala Lumpur Light-rail Transit in Malaysia. Despite this evidence, practical financial risk management models are either avoided (non-existent) or poorly implemented on PPP projects especially in developing economies to avert this problem. Another problem is that mostly, the management of financial risks is lumped up with all risks on PPP projects making it difficult to single it out and deal with it holistically.

To solve these problems and ensure continuous improvement upon the current financial control measures on PPP projects, there must be a specific risk maturity model to tackle financial risks of the projects (Akomea-Frimpong *et al.,* 2020, Jin and Zhang, 2011). The concept of developing risk maturity models to control project risks is not new. Existing studies such as Wibowo and Taufik (2017), Hoseini *et al.,* (2019), Hillson (1997) and Chapman (2019) have presented a close relationship between the usage of risk maturity models and the overall success of construction projects. These studies concentrated on the whole risk management of construction projects with a generic risk maturity model not specifically financial risks of PPP projects. Moreover, a theory-built and validated financial risk maturity model on PPP projects is missing in the literature. Against these backdrops and as part of bigger research project, the objective of this article is to: 1) theoretically construct a financial risk maturity model (FRMM) on PPP projects and 2) test and validate FRMM of PPP projects using practitioners and experts from Ghana, China and Australia.

The contributions of this research are mainly twofold. To contribute to the ongoing discussions among researchers in the PPP market to design practical models to address financial risks and improve financial success of PPP projects. Practically, practitioners will be guided to develop a holistic financial risk models taking from a multidimensional approach.

## METHODOLOGY

As shown in Fig 1, the research began with a comprehensive systematic review of existing literature on financial risk management, risk maturity models and Public-Private Partnerships. The *literature was searched and retrieved from academic database such Google Scholar, Web of Science and Scopus. Qualitatively, the retrieved literature and documents were subjected to content analysis leading to the extraction of relevant variables and statements for this article* (Hwang *et al.,* 2013, Kavishe and Chileshe, 2019). Next, the theoretical model of FRMM was developed from the statements and theories obtained from the literature to address the first objective backed by risk maturity theories from the field of finance, economics and construction management. It is followed by empirical test and validation of the model

and the rationale for the application of the model to practical PPP projects. The test and validation the theoretical model began with the design of survey questionnaires on the outcome of the literature review which forms the basis of the FRMM theoretical model. The survey questionnaire was divided into two main sections. Section 1 of the survey asked questions about the country, profession, and experience of participants. Section 2 captured the financial risk maturity practices of PPP projects structured as: identify and plan financial risk (28 variables), analysis and allocate financial risks (24 variables), and control measures on financial risks (32 variables). The variables in the survey were measured on a Likert scale (Saunders *et al.,* 2007) ranging from 1 to 5-point. The interpretation of the Likert scale is: (1) remotely not critical; (2) not critical; (3) neutral; (4) critical; (5) extremely critical. A pilot test was conducted with eighteen (18) experts with international experiences on PPP projects and risk management to ensure the suitability of the variables included in the survey. Consensually, the experts agreed and approved the criticality of all the variables with no additional recommendations.

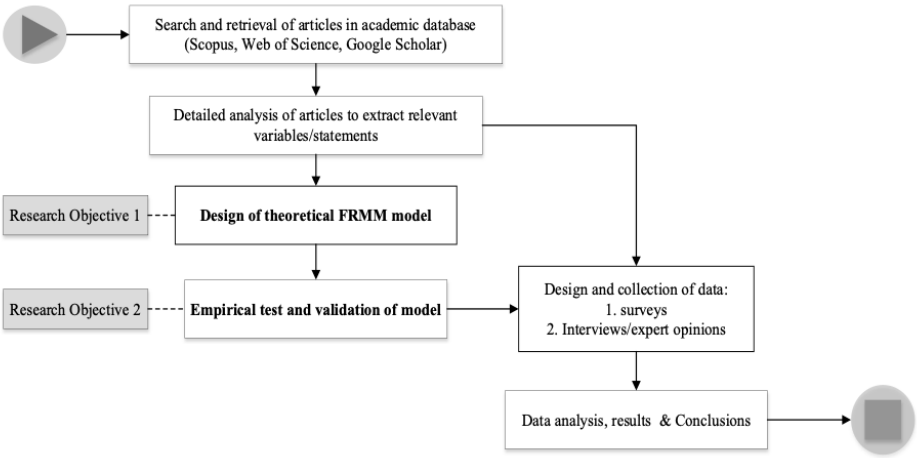


*Fig 1: Research method flowchart (Authors, 2021)*

The distribution of the survey started with the *search of participants.* We targeted 100 participants with vast experiences in PPP projects in each of the three countries we selected for this study. The countries used in this study are Australia, China and Ghana. These three countries represent the three main phases of development of the global PPP market: developed (Australia), mildly or moderately developed (China) and developing (Ghana) (Jin, 2010, Osei-Kyei *et al.,* 2019). Physically, we could not distribute a paper-based surveys to the participants due to the COVID-19 restrictions, so we utilised the online Qualtrics software with the aid of e-mails. E-mails were retrieved from institutional websites and social media platforms of Facebook and LinkedIn. Also, participants were asked to recommend experts and colleagues who are vastly knowledgeable in project risks and project management to be part of the study. This exercise led to additional participants for the distribution of the survey. A list of the e-mail addresses of all the potential participants were compiled and a survey link from the Qualtrics software was shared with all the participants via the e-mails. We received 184 responses against our target of 300 responses. We took 12 responses out due to incomplete filling of the survey with a remaining 172 responses. In Table 1, the number of responses we obtained from Australia is only 19 percent of the total responses even though it is a developed PPP market. China reported 34 percent of the responses and the largest responses came from Ghana, 47 percent. As an emerging market, Ghana is currently using PPP to overcome its large infrastructural deficit

(Ahenkan, 2019). *Also, Table 1 shows that* 40 percent of the participants having a vast knowledge on project risk whiles 60 percent were project management practitioners (architects, quantity surveyors, consultants, and project managers). Furthermore, Table 1 displays the experiences participants in the survey have on financial risks of PPP projects. It was recorded that 44 percent of the participants have knowledge or experienced financial risks on PPP projects for 6 to 10 years; 16 percent for 5 or less years; 30 percent for 11 to 15 years and 10 percent for 15 or more years.

*Table 1: Profile of participants in the survey*

| Variable | Category | Frequency (n=172) | Percent (%) |
|---|---|---|---|
| Country | Australia (developed market) | 32 | 19 |
| | China (middle developed market) | 59 | 34 |
| | Ghana (developing market) | 81 | 47 |
| Profession (job title) | Project risk expert | 69 | 40 |
| | Project management practitioner | 103 | 60 |
| Work experience on PPP projects | 5 or less | 28 | 16 |
| | 6 to 10 | 76 | 44 |
| | 11 to 15 | 51 | 30 |
| | 15 or beyond | 17 | 10 |

We tested the data obtained from the survey with a factor analysis (FA). The FA was used to assess the criticality of the variables and extract the most relevant statements to arrive at a conclusion. Also, the FA was run to test the relationships between the variables to reduce correlated statements which serve the same purpose (Umar *et al.,* 2019, Wang *et al.,* 2020). Ideally, the FA is used when conditions such as internal consistency, reliability and normality distribution are met, and we run and tested these conditions before the results from the FA were included in this article. The foremost test was internal consistency and reliability with a Cronbach's Alpha. A coefficient of 0.792 was attained for the reliability which is supported by Field (2013), who mentioned that a Cronbach Alpha's score beyond 0.7 is acceptable as reliable. Next, the normality distribution of the data was ascertained by Shapiro-Wilk Test. The test generated p-values less than 0.05 proving the data is not skewed but normally spread (McNeish, 2017). A Kruskal-Wallis Test was run to assess the differences in the responses given by the participants. It was revealed that there were no significant variations in the responses at p-values of greater than 0.05 from the three countries used in this study. The outcome of these tests paved for the FA to be run and interpreted shown in Table 2. Furthermore, we tested the sampling adequacy of the survey data with Kaiser-Meyer-Olkin (KMO) Test and got a result of 0.882 higher than the standard threshold of 0.6 (Hair, 2009). The results support the suitability of the data for the FA analysis. The varimax rotation was used to extract and confirm the three principal processes in the FRMM model. Varimax simplifies the main components of data compared to other rotational techniques such as promax, equamax and quartimax (Umar *et al.,* 2019). The results showed a greater eigenvalue more than 1.0 with 73.15 percent variances in the data.

Lastly, the results from the survey were validated through interviews which were conducted with the participants who answered the survey. Similar studies such as Ahmadabadi and Heravi (2019), Jin and Zhang (2011) and Xu *et al.,* (2010) used interviews to validate theoretical models on PPP projects This request was included in

the concluding part of the Qualtrics survey where interested participants were asked to leave their names and e-mails. An interview guide was designed based on the results from the analysis of the survey. Subsequently, the interview process was initiated with 28 participants whose contacts (or e-mail address) were collected and compiled from the Qualtrics platform. The interview questions, the results from survey data together with consent forms (to obtain the participants' agreement to record the interviews) were sent out two weeks prior to the scheduled date of the interview via e-mail. In addition, an online Zoom link was sent to all the participants. The actual interview session took place within 1 hour for each participant. Interview questions were centred around the clarity, criticality and usefulness of the FRMM as well the willingness to apply the model to their PPP projects. The information gathered during the interview process were recorded, transcribed, and analysed.

## RESULTS AND DISCUSSION

### Model Development

The bedrock of our financial risk maturity model (FRMM) is the risk maturity models, capability theories, enterprise risk theories and project risk theories (Hartono *et al.,* 2014, Hoseini *et al.,* 2019, Jankensgård, 2019). The key aim of this FRMM is to improve upon the processes of an organisation towards attaining the lowest project costs and improve upon the overall financial returns of the project considering all areas of endeavour and the lifecycle of the PPP project (Qureshi *et al.,* 2009). Scholars have suggested different levels of maturity levels being it four or five or six levels (Chapman, 2019, Yeo and Ren, 2009). However, we have formulated four levels of FRMM with three attributes/processes of managing financial risks of PPP projects. In Fig 2, the FRMM is a top-down maturity model theorised on two conditions. First, the improvement in pertinent matters on financial risk at the organisational level such as commitment of top management, knowledge management, culture, stakeholder management, training, defined policies, and actionable strategies. To meet this condition, the first level of the FRMM is akin to naivety of the Hillson (1997) study where the top managers are either unaware of the prevailing financial risks pertaining to the project or they are aware but have not formulated practical programs to deal with the identified risks and unexpected occurrences. At this point, top managers drive the existing processes of the project including financial risks repetitively (Wibowo and Taufik, 2017). Additionally, top managers do little or grossly neglect to learn from the past with undefined plans to deal with the similar financial losses to the project. At level 2, the top managers (or the organisation) recognise the financial risks of the project but the structures to tackle the problem is not formalised due to limited knowledge of individuals and poor stakeholder management. The attempts of the organisation to formalise the financial risks processes spearheaded by a small number of nominated individuals with little personal knowledge of the financial risks deprive the process of gaining its full benefits (Hoseini *et al.,* 2019). Continuous training to improve the competencies of individuals with allocation of appropriate resources will yield greater positive effects. At level 3, the organisation builds a comprehensive and robust processes on financial risks into the organisational culture. Formerly, the unattended and generic processes on financial risks are formalised and widely implemented in the organisation. It becomes an integral part of the organisation's culture (Qureshi *et al.,* 2009). It is understood and accepted to cutting down financial losses but not in all circumstances. Level 4 represents a well-defined and proactive risk-aware policies and strategies of the organisation. All aspects of the organisation and financial transactions is actively

infused with information and actionable strategies on financial risks of the project (Chapman, 2019). Continuously, this is used to gain competitive edge, take advantage of opportunities and improve upon the financial success of PPP projects.

The second condition underlying our FRMM model is the activities ensuring the application of the policies and strategies on financial risks of PPP projects. Categorically, it is grouped into three processes: plan and identify; analysis and allocation; and control measures on financial risks on PPP projects. Financial risks are identified from relevant documents and broad stakeholder consultation which are grouped into project-specific and externally induced financial risks (Akomea-Frimpong *et al.,* 2020). The project-specific financial risks include constructions costs, costs of labour, cost of materials, cost overruns among others. Whiles the externally induced financial risks include high interest charges, taxation risk, forex/currency risk, and inflation risk (Kagne and Vyas, 2020, Xenidis and Angelides, 2005). At the analysis and allocation of the financial risk stage, financial risks should be examined thoroughly by considering the probability of occurrence or frequency of the risk with the right financial risk assessment techniques. Fair allocation of the financial risks must be allotted to key principal partners of the project. Lastly, the control measures must be implemented to reduce (or eliminate) the losses associated with the financial risks. The model works well when applied to control financial risks on mega projects such as roads, affordable housing, railway, and underground tunnels built through the PPP arrangements.

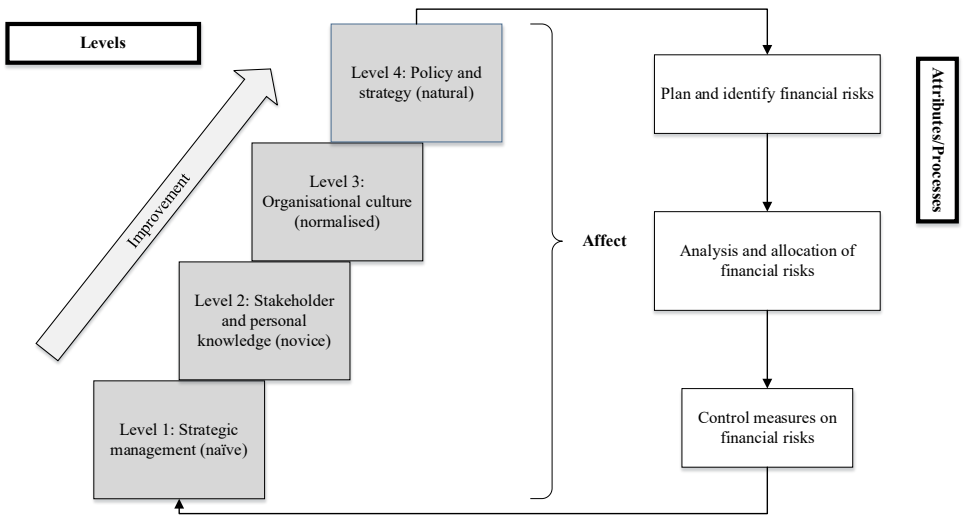


*Fig 2: FRMM model (Authors, 2021)*

## Empirical Tests and Validation of Model

The first step in validating the FRMM model was to test the statements (variables) empirically using exploratory factor analysis to extract relevant statements at each level in Fig 2. The results are shown in Table 2 with details of the statements underlying the model. As mentioned in the research methodology section, the 28 participants in the interview process were given enough time to read the results from the survey (Table 2) and do further research into the topic.

In Fig 2, the significance level is 5 percent, MS= Mean Scores, WS=Wilk-Shapiro test (p-value), KW=Kruskal-Wallis (p-value), and L1-L4 is the Level 1 to 4 of FRMM. Participants who took part in the interview suggested we remove some of the statements from the results of the factor analysis. We took some out but turned down

some of the requests. We argued that some statements are irrelevant to their settings but useful in other jurisdictions and projects. Subsequently, they agreed to this proposition. Also, there was a modification of a number of statements to suit the practical settings of PPP projects.

*Table 2: Criticality and relevance of the principal component variables in the FRMM model*

| | Criticality | | | Relevance | | | |
|---|---|---|---|---|---|---|---|
| Variables/statements | MS | WS | KW | L1 | L2 | L3 | L4 |
| Plan and identify financial risks | | | | | | | |
| Review reports from World Bank, IMF and auditing firms on similar PPP projects | 4.4 | 0.00** | 0.274 | | | X | |
| Initiate broad consultations with local authorities and experts to ascertain the financial risks | 4 | 0.00** | 0.723 | | X | | |
| Seek top management commitment on financial risk management | 3.9 | 0.00** | 0.569 | X | | | |
| A threshold level of exposure on financial risks of the project is set | 3.9 | 0.00** | 0.641 | | | X | |
| Published research articles is systematically reviewed to identify dominant financial risks | 3.9 | 0.00** | 0.021 | | | | X |
| Thoroughly review contractual agreements to establish the financial risks on the PPP project | 3.8 | 0.00** | 0.321 | | X | | |
| Analysis and allocation of financial risks | | | | | | | |
| Find the root causes of all the financial risks relating to the project | 4.7 | 0.00** | 0.351 | | X | | |
| Consequences of the financial risks are ascertained and analysed | 4.5 | 0.00* | 0.436 | | | X | |
| Fairly allocate the financial risks based on expert judgements | 3.9 | 0.00* | 0.723 | | | | X |
| Use appropriate financial techniques such as NPV to assess and share the financial risks | 3.8 | 0.00* | 0.004 | | X | | |
| Control measures on financial risks | | | | | | | |
| A Minimum Revenue Guarantee (MRG) is established to lessen the financial losses of the investors | 4.9 | 0.00* | 0.402 | | | | X |
| Real option analysis is employed to hedge against financial risks | 4.7 | 0.00* | 0.469 | | X | | |
| Government support through subsidies on construction materials | 4.4 | 0.00* | 0.008 | | | X | |
| Establish fixed loan interest rate to avoid paying extra interest charges | 4.3 | 0.00* | 0.154 | | | | X |
| Reassessment and renegotiation of financial agreements | 4.1 | 0.00* | 0.542 | | | | X |
| Participative budgets involving key partners of the project | 3.9 | 0.00* | 0.732 | | X | | |
| Extend concession period to recoup investments | 3.8 | 0.00* | 0.615 | | | | X |

Additionally, they pointed out the misstatements and errors in the statements and proposed new statements for the level of improvement in the organisation and the processes on managing financial risks. Statements related to Level 1 and Level 4 received many suggestions for continuous improvement. We observed from these suggestions that project management firms have different approaches of tackling financial risks related to PPPs. A participant recounted: 'I realised that my current organisation's financial risk maturity model differs from where I used to work as an assistant project manager 5 years ago where we implemented a simplistic two-level

approach to tackle financial risks'. Besides the modifications suggested by the participants, new statements were added to the final model. The participants confirmed the support the FRMM model will provide to project managers to improve the control measures on financial risks of PPP projects taking a holistic approach at both organisation and project levels. A participant recounted that "this FRMM covers relevant issues on financial risks of PPP projects, and it comes handy to assist measures to ensure continuous improvement of processes to score high financial success on a PPP project". Similarly, a participant mentioned the receptivity and flexibility of the model to further discussions and improvements. Participants scored the relevance of the FRMM at more than 80 percent and accepted to use it as a guide to ensure to reduce financial losses.

## CONCLUSIONS

In this article, a theoretical model was developed, tested and validated on managing financial risks of PPP projects. The results of our research showcase the paucity of research on this topic in the construction literature, and the authors efforts to bridge this gap in academia and practice. The study used mixed data analysis techniques to address two questions formulated in the opening sections of the article. With regard to the financial risk maturity levels, four levels to ensure continuous improvement from top-level managers to the overall policy and strategy on financial risks of PPP projects were established. The underlying attributes or processes to ensure this happen include plan and identify, analyse, and allocate, and monitor and control financial risks. Relevant statements related to FRMM model was tested with exploratory factor analysis which led to the extraction of significant variables from the survey data. Experts (participants) were given the opportunity to comment and validate the applicability and suitability of the model to PPP projects they have significantly led. The result of this study gives a basis for further investigations and discussions on financial risk management in academia. It could also serve as a guide to project managers to develop models to manage financial risks relating to PPP projects since the participants were selected from countries which bear similarities with other countries classified by World Bank in terms of development and income status (Fantom and Serajuddin, 2016). However, this research is hugely constrained to the opinions of few PPP experts. Thus, an expanded scope of covering many countries with different conditions and large sample size will propel the acceptance of the FRMM model for PPP projects. Further studies must expand the sample size and ensure cross sectional application of the model to real projects.

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# ENHANCING PRODUCTIVITY IN INFRASTRUCTURE DEVELOPMENT: THE KEY ROLE OF PROJECT MANAGEMENT OFFICES

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Infrastructure development contributes to economic growth and constitutes the backbone of industries. The importance of this underpinning sector of the construction industry has led contracting organizations to adopt robust project management mechanisms; enabling them to tackle ever-increasing complexities and uncertainties associated with infrastructure delivery. Project management Office (PMO) is one of the emerging concepts that has been introduced to centrally coordinate projects and integrate project management arrangements in support of on-target delivery of large-scale infrastructure projects. Previous research underlines the potential benefits of employing these entities in the construction industry. However, there is a paucity of research on the role of these units in enhancing productivity in construction operations. This study focuses on this area and explains the requirements for boosting productivity in infrastructure delivery. The opinions of 20 construction management experts in Australian organizations were obtained and their suggestions were thematically analysed to develop a framework for boosting productivity by leveraging PMO units. The results revealed that employing such units can result in achieving higher productivity outcomes by emphasizing initiatives such as resource optimization; safety improvement; cost minimization; and waste control. The suggested approach provides construction contractors with insights on how to employ PMO entities and run them effectively to achieve satisfactory outcomes in infrastructure delivery.

Keywords: development; infrastructure delivery; project management office

## INTRODUCTION

Infrastructure development is known as a risky, uncertain, labour-intensive, and multi-discipline sector with high project management complexities (Khattak and Mustafa, 2019). In today's modern construction industry, projects are considered as key components of an integrated system (Trinh and Feng, 2019). They share business benefits and objectives which makes their delivery process complex. Furthermore, a systematic perspective should be adopted to manage both the interrelations of individual projects and the relevant subprojects of a large infrastructure megaproject.

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Previous research has argued that PMO incorporates characteristics to address project management matters concerning both the internal and external environment of an organization (Parchami Jalal and Matin Koosha, 2015). Regarding the interdisciplinary nature of construction projects, the internal environment deals with the interactions of several functional teams under the leadership of executives to achieve a specified target. Meeting the design and engineering specifications of deliverables also requires meticulous quality assurance throughout construction to enable project managers in identifying deviations and rectifying errors in advance.

Performing quality assurance requires interdisciplinary coordination by creating a common language both among technical teams, as well as between technical teams and auditors. More importantly, the organizational culture which depends upon the project management maturity level impacts PMO features in an organization. Mature organizations are more willing to adopt advanced PM technologies towards promoting resource productivity; while those with a lower level of maturity are more likely to rely on simple and traditional stand-alone project controlling and reporting mechanisms (Oliveira *et al.,* 2017).

Achieving productivity in managing all types of resources has been among major concerns of researchers (Zhan *et al.,* 2020). Recently, some studies in the construction sector endeavoured to improve labour productivity (Nguyen *et al.,* 2020, Toan *et al.,* 2020), a group of studies emphasized productivity in assets in construction projects (Cooper *et al.,* 2020), and another category of researchers attempted to explore how productivity can be achieved from a business and organizational perspective (Snyman and Smallwood, 2017). There is a need to study productivity from a systematic perspective so that key types of resources can be considered. PMO as a hub for project management can undertake key roles in addressing important aspects of productivity in projects. The present study explains one of the important applications of the PMO concept in enhancing productivity outcomes in infrastructure development projects.

*PMO Phenomenon in the Construction Industry*

The PMO phenomenon was first introduced to the literature in the late 1990s. This organizational concept has been theorized as a hub for the establishment of project management practice, as well as the centralized management of projects under its domain (Oliveira *et al.,* 2017). Three roles are generally assumed for PMOs: supportive, controlling, and directive. They are complementary to each other to provide full support of the project management practice in project-based organizations. The supportive role involves providing infrastructure such as processes, databases, knowledge repositories, etc. The controlling aspect refers to the operational oversight of operations in terms of complying with tools and methods; while the directive aspect extends the span of control to cover strategic matters of managing projects such as governance and portfolio-level decisions (Project Management Institute, 2017). These roles are interrelated since emphasizing just one aspect while neglecting others would not guarantee to make a difference in the PM environment.

The functions and services that PMOs deliver to a construction organization justify their existence and their value to the construction business. The PMO services for construction organizations aim to not only support projects but also to track business benefits (Szalay *et al.,* 2017). According to a survey conducted by Desta (Desta *et al.,* 2006) in the German AEC sector, the frequent tasks undertaking by PMOs in this

sector include (1) Information dissemination (73.5%), (2) methodology development (67.6%), (3) monitoring and control (64.7%), (4) document lessons learned (52.9%), (5) resource allocation (50%).

*Studies on PMO Roles in the Construction Sector*

An effective PMO is expected to support projects, control operations, and execute strategies. In this regard, proper support mechanisms such as reporting systems and methodologies are required to allow for informed decisions at the portfolio level. A mere focus on supportive functions makes PMO a passive entity without the capability of enforcing methods and policies in projects. It is advised in previous research that without establishing a structure for project governance, the PMO may fail to deliver its expected value (Singh *et al.,* 2009). A culture of governance should be established to intervene in project operations and decisions in order to minimize deviations from targets and maximize the productivity of all parties that contribute to the project delivery. PMO units fulfil a variety of functions towards addressing these three roles in order to bring maximum value to all aspects of a multi-project environment.

Evidence from previous research reveals that PMO contributes to organizational project management and can help address the complexities of megaprojects such as infrastructure development projects (Khalema *et al.,* 2015). Infrastructure development projects employ a wide variety of resources and multiple stakeholders are involved in their execution. Any improvement in the allocation and utilization of resources would bring significant value to the whole project. Introducing the concept of PMO in the construction industry has opened up windows for practitioners to seek more productive resources and apply them effectively throughout the project with minimum resource idleness and overallocation. Table 1 maps out the findings of previous studies about the role of PMO in the construction context. While other studies focused on the general roles, this study specifially elaborates on the roles of PMO in enhancing resource productivity.

## METHODS

This study was conducted using a literature review and expert opinion on the role of PMO in promoting productivity in infrastructure development. Literature reviews assess the current state of research on a topic by bringing together relevant ideas, theoretical discussions, and findings from separate studies. The retrieval of the extant literature helps to achieve a better understanding of the topic and different perspectives of researchers around relevant concepts. The role of PMO was investigated by reviewing relevant literature and eliciting theoretical discussions and findings concerning the topic.

Then, the opinions of experts were obtained through an online survey tool. They were asked to provide their view on the findings of the literature review. A purposive method was used to select participants to provide their comments on the implications of PMO role concerning three aspects of resource productivity. In this method of sampling, researchers rely on their judgement on recruiting the most suitable participants based on a set of criteria. The criteria which were used for purposive sampling include (1) employees who work in collaboration with a PMO unit in main construction contracting companies based in New South Wales, Australia, (2) more than 5 years of experience in project management. Initially, a list of 65 eligible participants was developed and invitation email was sent to all the potential participants, out of which 20 participants agreed to complete the survey.

The link of the online questionnaire was shared with the selected experts via email invitations. A total of twenty responses were received in the survey tool. The demographic analysis revealed that 40% had more than 15 years of PM experience, 40% with 11 to 15 years, and 20% with 5 to 10 years.

*Table 1: An overview of previous research on PMOs in the construction industry*

| Study | Country | Contribution of the study | Findings on PMO roles |
|---|---|---|---|
| (Desta *et al.*, 2006) | Germany | Discusses the role of PMO in achieving a higher level of PM maturity in the German Architecture, Engineering, and Construction (AEC) industry. | Major roles include (1) disseminating information, (2) develop methodology, (3) project monitor and control |
| (Qi *et al.*, 2014) | China | Explores the relationship between PMOs and other levels of organisational project management, including single projects, programmes, and portfolios. | The role of the PMO is more significant with the increase in the number of projects and the delivery complexity. |
| (Parchami Jalal and Matin Koosha, 2015) | Iran | Suggests variables in the context of organisations that relate to project management offices' characteristics in the Iranian construction industry. | In organizations that have considered project management in organization strategies and visions; the supporting role of PMO is more evident. |
| (Kiani *et al.*, 2015) | Iran | Explores the relationship between the existence of PMOs and the success of projects. | PMO plays a prominent role in enhancing the chance of project success. |
| (Wood *et al.*, 2016) | Australia | 1) Identifies the motivations encouraging construction organisations to deploy PMOs. 2) Explains the important role of PMOs in construction organisations. | The roles which always seen in PMOs include (1) auditing, (2) admin support, (3) coordination, and (4) facilitation of decisions. |
| (Oliveira *et al.*, 2017) | Portugal | Proposes a set of functions for supportive PMOs in the construction sector. | To determine PMO roles in an organization, it is essential to consult the needs and ideas of stakeholders |
| (Bredillet *et al.*, 2018) | Canada | 1) Conceptualises the co-evolution of PMO and project portfolio management. 2) Analyses how PMOs change and evolve. | PMO plays a role in evolving portfolio management and adapts to organizational context influence |

The literature review resulted in identifying eight roles that should be undertaken by PMOs to ensure a satisfactory level of resource productivity. Content Validity Ratio (CVR) was used for ensuring an acceptable level of validity using the following formula. All eight items achieved a minimum CVR ratio of 0.8 and were confirmed as valid roles to be considered. This CVR ratio determines the validity of individual items and ranges from +1 to -1 with positive values indicating that at least half the experts rated the item as essential. In formula 1, "$n_e$" represents the number of participants indicating the item is "essential" and "N=20" indicates the total number of participants (Alberti, 2016):

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}}, \quad (1)$$

## RESULTS AND DISCUSSION

*The importance of resource productivity in infrastructure development projects*
According to the resource-based view, organizations exploit strategic resources to achieve sustainable competitive advantage. A different set of resources need to be used optimally to deliver the maximum value to the business (Chahal *et al.,* 2020). Three kinds of resources need to be taken into account in projects to achieve business objectives in light of sustainability principles, which include human resources, capital resources, and material resources (Zhong *et al.,* 2018). Human capital resources include labour, technicians, supervisors, professionals, and managers who are employed in projects to undertake specified responsibilities towards the accomplishment of project activities. This category of resources constitutes the main pillar of project performance and proper allocation, and management of these resources play a prominent role in productivity outcomes (Felberbauer *et al.,* 2019).

Physical capital resources as another category of resources refer to real estate, equipment, tools, assets, machinery, and inventory of materials, which are used throughout the project lifecycle to deliver the final facility and infrastructure (Perkins *et al.,* 2019). As a primary source of production, this group of resources should be applied productively to ensure maximum benefits. The third type of resources refers to financial capital, which encompasses resources in terms of funds. Promoting productivity of financial resources enables construction organizations to maximize their revenues from their investments (Fulford and Standing, 2014). Productivity improvement should be sought in all these three types of resources to achieve expected business outcomes. The next section introduces findings related to the role of PMO in improving resource productivity in infrastructure development projects.

*PMO roles in achieving resource productivity*
The roles validated by obtaining experts' comments have been discussed as follows:

PM developer: One of the fundamental roles of PMOs is to develop project management tools and methods (Ershadi and Atashfaraz, 2016, Barbalho *et al.,* 2017). This contribution is necessary to ensure that tools and methodologies are in place to support project management activities across an organization. It enhances collaboration and improves task delegation for managing and controlling project activities. Industry best practices are benchmarked by PMOs to set a basis for optimal PM procedures and methods (Wood and Ma, 2008).

Auditor: The role of PMO is not limited to the development of tools and methods; but also includes auditing to ensure that project management tasks are being executed based on the developed tools and methods (Desta *et al.,* 2006, Oliveira *et al.,* 2017). Compliance with methods and procedures improves the consistency of processes and is necessary for process integration across different projects. Auditing projects in terms of compliance with the project management processes help to identify bottlenecks and barriers to productivity.

Director: Providing strategic direction to projects in the framework of a governance structure is another potential role that can be considered towards boosting productivity (Parchami Jalal and Matin Koosha, 2015, Aubry and Brunet, 2016). Achieving productivity targets requires setting clear objectives and directing project teams to implement corrective actions and initiatives towards meeting them. Interventions in project activities may be required to help in resolving operational and managerial issues which hinder productivity targets.

Performance manager: PMO is partly or fully accountable for the delivery of projects. Monitoring the performance and taking proper actions in response to deviations is a necessity for these entities towards achieving higher resource productivity (Parchami Jalal and Matin Koosha, 2015, Amer and Elayoty, 2018, Sandhu *et al.,* 2019). PMOs manage the performance of project teams to ensure that they are aligned with the organization's productivity goals. They act as decision support centers for senior managers to ensure that all projects are on track and meet performance baselines.

Mentor: PMOs assist project managers and other team members in their decisions and actions, which is a key to adding higher value to the project management environment. Mentoring connects experienced project managers to junior project team members so that they can share best practices and experience (Singh *et al.,* 2009). These units have access to an extensive body of knowledge and best practices from current and previous projects to share with staff. Their advice would decrease human errors and improve their decisions throughout the project life cycle.

Coordinator and facilitator: Infrastructure development projects are among large undertakings which require extensive coordination and communications. PMOs play a central role in the project management environment to reconcile conflicting priorities and influence conflict resolutions. They support project teams in identifying and managing stakeholders (Parchami Jalal and Matin Koosha, 2015). Facilitation of cross-departmental and cross-organizational communications enable PMOs to speed up collaborative decisions on day-to-day project concerns.

Resource manager: Optimal allocation and application of resources in infrastructure projects ensures that the right resources are assigned to the right activities at the right time. PMOs contribute to achieving a higher level of productivity by centralized allocation, monitoring, and control of an organization's resource pool (Qi *et al.,* 2014). This role of PMO capacitates construction organizations to run more projects with limited resources without compromising sustainability objectives.

Risk controller: Infrastructure development projects are among risky large-scale undertakings which are affected by numerous uncertainties. PMOs can take a key role in capturing risks and providing directions to address them (Qi *et al.,* 2014). Assessment and prioritization of risks are necessary to focus resources on tackling the most critical risks which may derail projects from their baseline.

*Mapping PMO roles against three aspects of resource productivity*

To clarify the role of PMOs in achieving resource productivity, the eight roles are mapped against the corresponding aspects of resources. These roles contribute to enhancing the productivity of human, physical, and financial capital resources by emphasizing relevant mechanisms, tools, and management approaches as detailed in Table 2. This table summarizes the suggestion of experts on the potential impacts of these roles in boosting resource productivity.

## CONCLUSIONS

While previous studies highlight the general roles of PMO in the construction industry, this paper contributes to the body of knowledge by shedding light on its specific role in enhancing the productivity of resources. Maintaining a high level of resource productivity is vitally important in large infrastructure development projects that are multi-discipline and risky. Well-defined project management mechanisms would contribute to encouraging consistency and integration in managing projects. This study introduced PMOs as effective structures to provide a suitable basis for

achieving resource productivity. They capture improvement opportunities and coordinate all involved parties to minimize risks and maximize productivity. It was found that eight roles are vital to enhancing productivity by these entities in the infrastructure development projects. Their systematic analysis of project management issues gives the decision-makers a deeper understanding of the root causes of issues and potential solutions to deal with them.

*Table 2: PMO roles and three aspects of resource productivity*

| Roles | Resource productivity | | |
|---|---|---|---|
| | Human capital resources | Physical capital resources | Financial capital resources |
| 1) PM developer | Role boundaries and responsibilities | Methods of managing physical assets | Methods of project budgeting and cost planning |
| 2) Auditor | Compliance with assigned responsibilities | Asset auditing | The accordance of financial statements with standards |
| 3) Director | Dismissal and appointment in project teams | Asset management strategies | Strategies of project financing |
| 4) Performance manager | Performance appraisal of the project team | Monitoring the performance indicators of equipment | Cash flow management |
| 5) Mentor | Best practices to manage human resources | Best practices to optimize the operation of equipment | Best practices to manage cash flow and control costs |
| 6) Coordinator and facilitator | Facilitate collaborations with stakeholders | Collaborative asset management decisions | Collaborative decisions on project budgeting and financing |
| 7) Resource manager | Employ qualified team members | Optimize project procurement and control the construction waste | Optimize allocation of funds |
| 8) Risk controller | Addressing human resource risks and improving safety | Addressing risks of physical asset | Addressing financial risks |

The contribution of PMOs influences and enriches management practices in three areas of human, physical, and financial capital resources. Failure to define and establish productivity targets and metrics would lead to unsatisfactory outcomes in the proper allocation and control of these three types of resources. This study shed light on the impact of PMO roles to enhance productivity in these three categories of resources. However, more research still needs to be carried out to quantify this impact and model the relationship of PMO capabilities. The authors suggest that future research considers focusing on a case study to empirically examine and develop the findings of the present study.

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# IMPACT OF PROPERTY TAX ON HOUSING PRICE: AN ANALYSIS FOR REAL ESTATE DEVELOPMENT AND SUSTAINABLE RENEWAL

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The housing price is an equilibrium result of the demand and supply of houses, according to the neoclassic economic theory. In order to restrain the overheated real estate market, China introduced a property tax in two cities in 2011, Chongqing and Shanghai. The tax was targeted at second houses and high-end houses. This paper illustrates how property tax influences housing prices by affecting people's willingness to buy houses. The difference-in-difference (DiD) method was applied, and a two-phase panel micro model was constructed, with housing prices as the explained variable and family total assets, net income, and house size as explanatory variables. The results indicate that the property tax in Shanghai and Chongqing has no significant inhibitory effect on housing prices due to the narrow tax base, low tax rates, and an excessively large tax-exempt area. In the post-COVID19 era, despite the decline in housing prices, the income of the working class in many economies has also decreased. On the contrary, investors are given more opportunities to invest in speculative properties. The failure of the property tax pilot in China discussed in this paper, can serve as a warning for policymakers in other cities in China and around the world to consider the strengths of their policies and the response of the targeted groups. The results can also help to suppress negative trends and ensure a healthy real estate market development for post-COVID19 housing sustainable renewal.

Keywords: property tax; difference-in-difference model; real estate development

## INTRODUCTION

As of May 2021, most countries around the world are still suffering from the effects of the COVID-19 pandemic. Even though China has announced its primary success in the battle against the virus in the first stage, its national economy has been hit severely. In terms of real estate, the housing prices of many big cities are expected to stay steady for a long time to allow their local economies to recover from losses in 2020. This could be a great opportunity for the government to control the overheated real estate market. To achieve this goal, the Chinese government has carried out various policies in the past decade, such as the house purchase restrictions, which are still applied in some cities. Another fiscal policy that was put into practice, a property tax, was implemented in two specific cities in China, Shanghai and Chongqing in 2011.

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This study explores the effectiveness of the property tax policy and how it works in the Chinese market, applying the difference-in-difference (DiD) method with analysis of micro data. It differs from past studies, which analysed changes in housing prices with macro variables such as the economical and sociable factors, so that it can better present the individual conditions of each household.

## LITERATURE REVIEW

*Property tax as a measure of fiscal policy*

During depression times, countries must work out ways to stimulate the economy. Likewise, when the market is overheated, measures should be taken to restrain inflation. In 1930s, John Maynard Keynes proposed two economic instruments to manage the national economy, the monetary and fiscal policy (Keynes, 1936). These policies usually work together to promote national employment, ease economic fluctuation, prevent inflation and achieve steady growth by influencing the total demand. Monetary policies are implemented by the central bank via interest rates and money supply, while the government carries out the fiscal policies through government revenue and expenditure.

Taxation is the main source of government revenue, and it can affect the economy in two ways through tax rates and the tax structure (Ai, 2018). Firstly, as taxation is substantially a kind of redistribution of social income, countries can adjust the class of income by levying tax on specific groups. Additionally, taxation can affect production factors, for example, the labour supply realised through the income effect and tax substitution effect, the savings via income tax and indirect tax, and the investment via corporate tax, tax deduction, and tax allowance. Therefore, tax is one of the most widely used methods of fiscal policy. In addition, tax policy can be targeted at specific groups, communities, industries and commodities, so it can have improved pertinence. To some extent, the levy of property tax can change the consuming habit of people thus influencing the social demand for housing.

*Neoclassic economic theory-the relationship between demand and supply*

The concept of neoclassic economic theory proposed in the 1900s, in contrast with classic economic theory that believed that prices are only relevant for production costs, stressed the decisive factor of price-the equilibrium of demand and supply. Furthermore, the neoclassic theory states that the demand and supply also depend on other non-price factors such as the number of participants in the market, consumer income and preferences, and tax among others (Keynes, 1936). Fig 1 shows the equilibrium price.

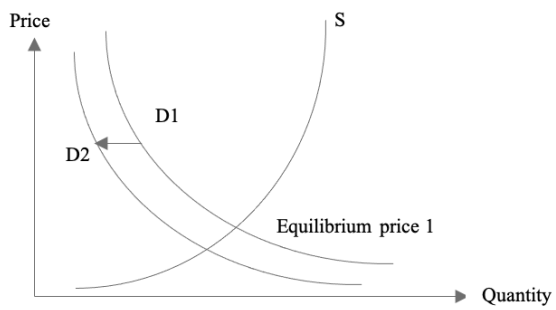


*Fig 1: Supply and demand curve*

On the one hand, the property tax will raise the cost for buying houses. For consumers buying houses for investment, their primary goal is to benefit from the

appreciation. If the costs increase, the need for buying will be reconsidered. Thus, the demand can be controlled. On the other hand, the rise of purchasing costs will prevent an overheated market, so real estate developers will hold the stock and the total supply of houses may be reduced. However, the reduction of supply is not a rapid process, so in the short term, the swift of demand will pull the equilibrium housing prices to a lower level (see Fig 1).

*Property tax capitalisation*

Property tax capitalization is the reflection of property taxes in the value of real property (Lilywhite, 1994). Jensen proposed this concept back in 1931 when he was researching property tax in the United States, and it is thought to be the major issue when scholars study the effect of property tax on housing value. According to studies conducted before 1980, the capitalization rate of property tax can vary from 50% to 100% (Oates, 1969, 1973; Edel and Sclar, 1974; Gustely, 1976; King, 1977; Rosen and Fullerton, 1977). These figures have many flaws, because of they use inaccurate discount rates and time zone, revealing the lack of control over the characteristics of each house and region and flaws in the capitalization models. After 1980, the survey scope was widened, the equation was amended, and more variables were included (Richardson and Thalhemier, 1981). Recent studies found that a significant negative effect of property tax on housing prices, which is between 50% and 60% negative capitalization rates, are using a 3% real discount rate (Yinger, 2020).

By investigating property tax rates, property taxes, and housing prices in 18 countries, Ai (2018) concluded that in the long run, the effect of property taxes brought to housing prices is gradually weakening. In the short term, property taxes in different countries vary widely via unit root test, VAR modelling, cointegration test, the impulse response function analysis, and variance decomposition. However, this study used the macroeconomic factors of housing price index, long-term interest rate, GDP growth rate, and price index as the endogenous variables of the model. As a result, from a macro point of view, the study of impact of property tax will definitely be affected by the fluctuation of housing prices in the long run.

## Property Tax in China

Property tax, as a type of national tax, was firstly mentioned in 1950 in the "Guidelines for the Implementation of National Tax Administration". However, the property tax was not officially put into place until 1986. The Interim Action of the People's Republic of China on Property Tax regulated the levy of property tax on industrial and mining areas in cities and towns exempting on individual properties.

Due to the huge difference in economic development, population, and social customs (among other factors), it is difficult to levy property tax nationally in China. Therefore, Shanghai and Chongqing in 2011 were pointed as the pilot cities for the implementation of property tax targeted at individual properties. This application was expected to be the first move of national property tax to control the overheated real estate market. In Shanghai, a first-class city in China, the housing prices have remained high for years. In the sixth edition of the CBRE Global Living 2020 report (see Fig 2), the housing prices of Shanghai ranked number 4 in the world for an average of USD 905,834.

Similarly, Chongqing, located in the southwest of China, is the crucial hub for the One Belt One Road policy, ranking number 5 of Chinese cities in the GDP in 2019 for an average of USD 345 billion (see Fig 3). As a result, these two cities can be

representatives of the research object to study the impact of property tax on housing prices.

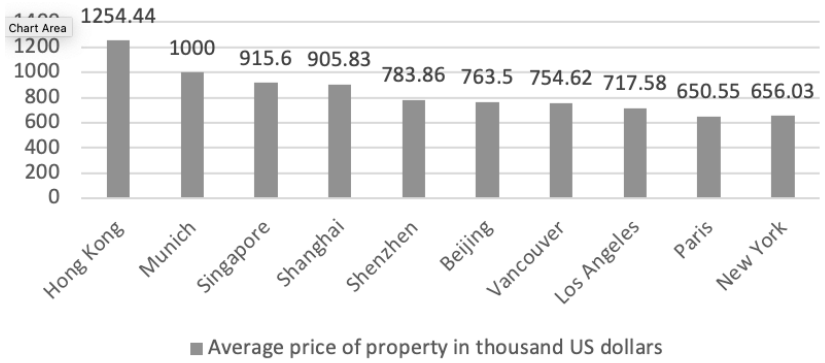


*Fig 2: Most expensive residential property markets worldwide in 2020 (Source Statista)*

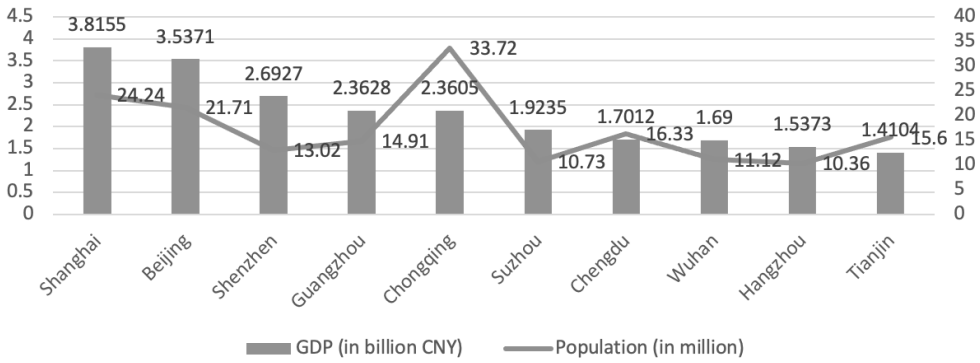


*Fig 3: Top Ten Chinese Cities by GDP (Gross Economy) in 2019*

The property tax policies in Shanghai and Chongqing have differences in specific terms (see Table 1). Overall, these policies mainly target high-end houses and second or above houses, in order to restrain the speculative purpose of house purchases.

*Table 1: Comparison of property tax policy in Shanghai and Chongqing City*

| Applicable area | Shanghai | Chongqing |
|---|---|---|
| | Shanghai administrative area | Nine urban areas in main city |
| Taxable objects | (1) Second or above houses (including second-hand stock houses and newly built houses)<br>(2) purchased by local resident<br>New houses purchased by non-local residents | (1) Commercial condos and high-end houses owned by individuals;<br>(2) Newly purchased second and above houses purchased by individuals without household registration or work |
| Tax base | 70% of the transaction price of the house | Full transaction price |
| Tax rate | (1) 0.4% for houses whose unit price is below twice the standard price<br>(2) 0.6% for houses whose unit price is over twice the standard price<br>(standard price = the price of the commercial housing built the previous year) | (1) 0.5%/1%/1.2% for houses whose unit price is below three times/between three to four times/over four times the standard price<br>(2) 0.5% for newly purchased houses by individuals without household registration or job<br>(standard price = average price of newly built commercial housing of the nine urban areas in the past two years) |
| Tax-free area | 60 square meters per capita | 180 square meters for commercial condo stock; 100 square meters for newly purchased condos and high-end houses. (zero for houses purchased by individuals without household registration or job) |

# METHOD

The difference-in-difference (DiD) model used in this paper is widely applied in studies of public policy reforms and project implementation in quantitative economics. Such studies usually have extensive samples in geographical distribution, so it is difficult to control the scope of the research object and ensure the randomness of the samples. In addition, before the implementation of the policy, samples in different groups show priori differences. Only to adopt horizontal comparison or vertical comparison will ignore these differences, leading to biased estimates of the effect of policy implementation. Therefore, the DiD model combines the "pre and post difference" and "with and without difference" and adds other covariates to the model to control the effect of other factors other than the explanatory variables. This will result in a better model for the study of the impact of property tax reform instead of a simple analysis using regression (Elinder and Persson, 2017). The formula used to analyse the effect of property tax is expressed as (Li, 2020):

$$\ln(price_{it}) = \beta_{0+}\beta_1 \ln(asset_{it}) + \beta_2 \ln(income_{it}) + \beta_3 \ln(size_{it}) + \beta_4 year_t + \beta_5 region_i + \rho * region_{it}$$

The variables $\mathrm{price_{it}}$, $\mathrm{asset_{it}}$ and, $\mathrm{size_{it}}$, represent the housing price per square meter, the net asset and the family size of the i-th family, respectively. The variable $\mathrm{year_t}$ represents the time dummy variable, where $\mathrm{year_{2010}} = 0$ and $\mathrm{year_{2016}} = 1$; $\mathrm{region_i}$ represents the policy dummy variable, where $\mathrm{region_{Shanghai\ and\ Chnongqing}} = 1$ and $\mathrm{region_{Beijing\ and\ Chengdu}} = 0$. Furthermore, $* \mathrm{region_{it}}$ represents the differential dummy variable. The DiD dummy variable and its estimator, $\rho * \mathrm{region_{it}}$, represents the net effect of property tax (Li, 2020). Only when the samples are for Shanghai and Chongqing in 2012, $* \mathrm{region_{it}} = 1$. Otherwise, $* \mathrm{region_{it}} = 0$.

## Data and Variables

This study focuses on the micro level change in housing prices by exploring the relationship between supply and demand. The supply of houses is assumed to remain at a certain level, that is, each individual family decides the demand of houses, so the willingness to buy a house will be the main factor. Furthermore, previous research efforts mostly use housing prices of newly built houses as the explained variables, which in this case is not reasonable as the property tax in Shanghai and Chongqing mainly targets at second-hand houses. The housing prices here refer to the market prices obtained by dividing the total market price of a family house by the building area of the house, representing actual transaction prices.

The variables are obtained from the China Family Panel Survey (CFPS) database, which is managed and conducted by the Institute of Social Science Survey (ISSS) and Peking University and funded by the Chinese government. The database covers most Chinese cities and the time zones before and after the property tax policy. This paper uses the data of 2010 pre-implementation, and the latest data of 2018. Some data that may affect the housing prices was eliminated from the model, considering their incompleteness and confidentiality such as house type and distance to the city centre. In addition, some data was also eliminated for multicollinearity, for example the family income and expenditure. As a result, to ensure the accuracy of the model, the explanatory variables considered are family total asset, family net income, and family size.

# RESULTS

*Descriptive statistics*

As shown in Table 2, the housing prices of Shanghai and Beijing are at a high level in China, though actions have been taken to control the real estate market. However, the standard deviations are also relatively high, showing a large gap between the rich and the poor in these two cities.

*Table 2: Descriptive statistics of Shanghai and Beijing as for 2018*

| Variable | Sample size | Average | Standard deviation | Min | Max |
|---|---|---|---|---|---|
| Price (CNY¥) | 142 | 43,257.61 | 33,488.46 | 1,923.08 | 250,000 |
| Total asset (CNY¥) | 142 | 3,424,220.18 | 2,649,095.08 | 79,200 | 16,150,000 |
| Net income (CNY¥) | 142 | 304,059.37 | 1,039,224.50 | 7,000 | 9,158,800 |
| Family size | 142 | 2.24 | 1.21 | 1 | 6 |

Compared to the prices in Table 2, Table 3 shows that the housing prices in Chongqing and Chengdu seem to remain mildly, allowing more choices for people to buy houses.

*Table 3: Descriptive statistics of Chongqing and Chengdu as of 2018*

| Variable | Sample size | Average | Standard deviation | Min | Max |
|---|---|---|---|---|---|
| Price (CNY¥) | 84 | 7,292.66 | 9,474.86 | 66.67 | 63,125.89 |
| Total asset (CNY¥) | 84 | 714,318.26 | 740,146.16 | 7,812.50 | 4,715,000 |
| Net income | 84 | 97,208.36 | 102,161.51 | 3,900 | 575,000 |
| Family size | 84 | 2.76 | 1.99 | 1 | 10 |

*Difference-in-difference analysis*

Different from the case in Shanghai and Beijing, the estimator of DiD dummy is negative in the analysis of property tax in Chongqing and Chengdu, indicating that the property tax did work in controlling housing prices in Chongqing, and this impact is rather significant.

*Table 4: DiD analysing the cities of Shanghai and Beijing*

| | Estimator | Standard error | P-value |
|---|---|---|---|
| Total asset | 0.677875 | 0.028179 | < 2e-16 |
| Net income | -0.007907 | 0.026420 | 0.7648 |
| Family size | -0.354271 | 0.055816 | 3.60e-10 |
| Time dummy | 0.095872 | 0.151038 | 0.5258 |
| Region dummy | -0.624821 | 0.115945 | 9.23e-08 |
| DiD dummy | 0.377745 | 0.163395 | 0.0210 |
| Intercept | 0.829109 | 0.412627 | 0.0448 |

Note that the effects of family total asset, family income, and family size are the same as those of Shanghai and Beijing.

### Analysis of the Results

Based on the above analysis, the data suggests that property tax did not play an important role in controlling the housing prices. It also shows a different influence in both cities as the estimators of DiD dummy for both analyses are not significant. For the city of Shanghai, the property tax revenue for 2018 is 21.4 billion RMB (USD

3.34 billion), only accounting for 1.24% of the total tax revenue of Shanghai for 2018 of 1720.2 billion RMB (USD 268.46 billion).

*Table 5: DiD analysing of Chongqing and Chengdu*

| | Estimator | Standard error | p-value |
|---|---|---|---|
| Total asset | 0.781792 | 0.045723 | < 2e-16 |
| Net income | -0.005509 | 0.045489 | 0.9037 |
| Family size | -0.369002 | 0.081448 | 8.14e-06 |
| Time dummy | 0.658095 | 0.130584 | 7.57e-07 |
| Region dummy | 0.666373 | 0.107709 | 1.75e-09 |
| DiD dummy | -0.547195 | 0.217390 | 0.0123 |
| Intercept | -2.184044 | 0.523682 | 3.86e-05 |

It is far less, compared with the index of 15% for the American local government, 20% for the South Korean local government, and 40% for the Japanese local government. As the consumption level of Shanghai citizens is relatively high, the consumption elasticity is extremely low, and the majority are not sensitive to the mild property tax policy. For the city of Chongqing, the property tax revenue for 2018 is 6.7 billion RMB (USD 1.05 billion), accounting for 4.2% of the total tax revenue of Chongqing for 2018 of 160.3 billion RMB (USD 25.02 billion. It is also lower than the average percentages of other mature markets. In general, the housing prices of these two cities were not reduced as expected. Firstly, this may be caused by the lag in time of the effect of property tax. In addition, multiple factors may have opposite effects against property tax on housing prices. Even more, as shown in the results, the tax policies in Shanghai and Chongqing are relatively mild with low tax rates and narrow range of taxable houses. Therefore, the present property tax policies still have many limitations, and many reasons may lead to this result, leaving plenty of room for the Chinese government to improve.

## CONCLUSIONS

This paper studied the impact of property tax, implemented in 2011 in the cities of Shanghai and Chongqing, on the housing prices from the perspective of demand of houses. It firstly looked into the relationship of supply and demand as in the neoclassic economic theory and their decisive role in affecting the price. Then, the detailed property tax rules were discussed, which allowed making comparisons between the two cities. The micro data of 2010 and 2018 was used to analyse the effect of property tax with the application of a DiD model, which showed an unapparent impact of the tax. Excluding the error caused by the data, the results may inform policy making. Additionally, a few recommendations for the government are provided for future improvement.

First, the range of taxable can be widen for the stock houses rather than only the incremental ones. Second, a more reasonable tax base and tax rates need to be considered. The lack of a uniform standard of valuation of housing market prices can cause deviations in the calculation of tax. Additionally, the low tax rate in China compared with 1% to 3% in the UK and US will show a faint impact on restrict the speculative demand for high-end houses. Finally, the property tax system is still not incomplete and a unified platform to register is much needed to improve the efficiency of the government officer. In the post-COVID19 era, the economy in each country is waiting for recovery. However, for the over-heated real estate market in some countries, this is a great opportunity to carry out a forceful property tax policy to take control of it and provide a sustainable industry renewal.

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# RESEARCH ON FRAUDULENT, CORRUPT AND COLLUSIVE PRACTICES IN INFRASTRUCTURE PROJECTS

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Based on the existing research, fraud, corrupt and collusion are serious impediments for infrastructure development. To explain the reasons of fraudulent, corrupt and collusive practices, this paper proposes that the effects of control of corruption (CC) and regulatory quality (RQ). We collected total 146 sanctioned and normal infrastructure projects from World Bank Projects and Operations database and searched the control of corruption and regulatory quality scores of different counties from World Governance Indicators. Logistic regression model is applied in this paper to test the correlation between fraudulent, corrupt and collusive practices and CC and RQ. Based on the regression results, this paper presents that the control of corruption and regulatory quality are both negatively related with fraudulent, corrupt and collusive practices. Besides, the effect of interaction between control of corruption and regulatory quality on fraudulent, corrupt and collusive practices is positive. In other words, the worse control of corruption and regulatory quality results in the higher possibility to cause fraudulent, corrupt and collusive practices. Also, the worse regulatory quality will aggravate control of corruption obviously. This research provides suggestions to World Bank Group (WBG) and other similar organizations that more supervision and investigation is necessary for the firms/individuals with higher possibility of fraudulent, corrupt or collusive practices in infrastructure projects.

Keywords: infrastructure; control of corruption; regulatory quality; fraud; corrupt

## INTRODUCTION

The health and stable development of the infrastructure is very important for every country worldwide, especially for developing countries. Infrastructure is the indispensable foundation to guarantee the basic public demands, ensure the public welfare and improve economic growth in developing countries, such as China, India, Malaysia, Romania, sub-Saharan Africa countries (Sahoo and Dash, 2009; Mbekeani, 2010; Frone, 2014; Yii *et al.,* 2018). The World Bank Group (WBG) also considers that infrastructure is a key vehicle for social and economic transformation, especially for economic growth (World Bank, 2012). Aims to end extreme poverty and to promote shared prosperity, WBG supports a wide range of infrastructure projects (including education, transportation, health, public administration and so on) by

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providing low-interest loans. Until 2020, WBG supports over 20,000 approved infrastructure projects in the worldwide.

Corruption is the obstacle for the development of infrastructure in developing countries. It does not only shorten an infrastructure project's life, but also worsens the time, cost, and quality of every project (Kenny, 2012; Owusu *et al.,* 2020). To ensure the health and sustainable development of infrastructure projects, WBG have fought with corruption behaviours over 20 years and set the World Bank Group Sanctions System since 1998. WBG's policies on fighting corruption in project procurement. The corrupt practices contain rejecting a proposal for award, cancelling loan allocated for contractual arrangements on projects, and imposing ineligibility for a stated period (Aguilar *et al.,* 2000). WBG Sanctions System improved and developed continuously from investigative Integrity Vice Presidency into Compliance Integrity Compliance Officer, which aims to sanction fraudulent, corrupt and collusive practices, and debarred or prohibited companies/individuals from participating WBG-funded projects (World Bank, 2018). Accountability and transparency are important during the development process of infrastructure projects, which contribute to prevent fraudulent and corrupt activities in WBG-funded projects (World Bank, 2004). Until 2011, WBG applied a policy of transparency to publish the sanction decisions. Based on this, the deterrent value of imposed sanctions from WBG have increased significantly (Leroy and Fariello, 2011).

Although WBG improved the sanction system continuously and publish the debarred firms/individuals annually, the reasons of the fraudulent, corrupt and collusive practices in infrastructure projects funded by WBG are still unclear. Based on this situation, this paper aims to explain the fraudulent, corrupt and collusive practices in WBG-funded projects from governance capacities aspect, and provide prevention suggestions for fraudulent, corrupt and collusive practices.

## LITERATURE REVIEW

There are many researches presents that corruption has a significant effect on many aspects, such as economic growth (Park, 2012; Saha and Gounder, 2013; Cieślik and Goczek, 2018), investment (Robertson and Watson, 2004; Wu, 2006; Javorcik and Wei, 2009), inflation (Al-Marhubi, 2000; Samimi and Abedini, 2012; Akca *et al.,* 2012), business environment (Dutta and Sobel, 2016; Xie *et al.,* 2017; Ojeka *et al.,* 2019), domestic savings (Swaleheen, 2008), energy (Auriol and Blanc, 2009; Ozturk *et al.,* 2019) and public resources (Xiao *et al.,* 2020). Besides, Corruption has a significant effect on regional infrastructure and harms the infrastructure development (Gillanders, 2014). Corrupt practices in infrastructure projects attributed to high risks, caused irregularities, and even resulted into the failure of the infrastructure projects (Le *et al.,* 2014a; Le *et al.,* 2014; Zhang *et al.,* 2017).

### Control of Corruption

To prevent fraudulent, corrupt and collusive practices and promote things run smoothly, the control of corruption is important. Ikola-Norrbacka (2007) researched five factors related with administrative corruption: benefits of good administration, integrity of civil servants, key anti-corruption acts, investigations of Ombudsman and Chancellor, and financial and performance audit. Mungiu-Pippidi (2013) suggested that an explanatory model for control of corruption is described as an equilibrium between opportunities for corruption and deterrents imposed, the opportunities contain power discretion and material resources, the deterrents are combined of legal and

normative. This equilibrium formula has been tested empirically in a large number of countries (Mungiu-Pippidi, 2011). Tiwari (2012) researched the relationship between corruption and democracy/bureaucracy in over 80 different countries. They found that democracy, rule of law and control of corruption decreases the corruption level. Asongu and Nwachukwu (2015) presented that less control of corruption increases the confidence of impunity and fuels corruption practices further. Therefore, control of corruption prevents the illegal behaviours to a certain degree.

**Regulatory Quality**

Besides good control of corruption, regulatory quality also plays an important role in anti-corruption (Fazekas, 2017; Mungiu-Pippidi, 2018). Fugazza and Jacques (2004) shown that the governmental regulation may affect a firm's corrupt practices with the governmental officials to gain the project approval. Through the research on the relationship between corruption and labour supply. Kaller *et al.,* (2018) assessed the effects of regulatory quality and non-compliance with law on electricity market and figured out that the improvement of regulatory quality and reduction of corruption both influence the electricity prices. Capasso (2019) examined the determinants of corruption and concluded that strengthening regulatory quality to improve institutions has better results than just increasing enforcement employment. Then, the better regulatory quality could reduce the corruption related behaviours.

The interaction between control of corruption and regulatory quality has been explored in many studies. Villarreal (2012) observed the interaction between regulatory quality and control of corruption influence the corruption. Cooray and Dzhumashev (2018) examined the interaction of corruption and regulatory quality and suggested that better regulatory quality weaken the impact of corruption. They proposed that to reduce the negative effect of corruption, corruption control, regulation improvement and policy promotion are all necessary measures. These researches provide abundant theoretical support that the regulatory quality and control of corruption influence the corruption together.

Based on the above analysis, three hypotheses are proposed as follow:

- Hypothesis 1: Control of corruption is negatively related to fraudulent, corrupt and collusive practices in infrastructure projects
- Hypothesis 2: Regulatory quality is negatively related to fraudulent, corrupt and collusive practices in infrastructure projects
- Hypothesis 3: The interaction between control of corruption and regulatory quality is positively related to fraudulent, corrupt and collusive practices in infrastructure projects.

## METHOD

*Dependent variable: Fraudulent, corrupt and collusive practices*

First, debarred firms/individuals because of fraudulent, corrupt and collusive practices are announced in World Bank Group Sanction System Annual Report. Fraudulent, corrupt and collusive practices have been defined as "any act or omission, including a misrepresentation, that knowingly or recklessly misleads, or attempts to mislead, a party to obtain a financial or other benefit or to avoid an obligation", " offering, giving, receiving, or soliciting, directly or indirectly, of anything of value to influence improperly the actions of another party", and " an arrangement between two or more parties designed to achieve an improper purpose, including influencing improperly the actions of another party" (World Bank, 2020). Then, based on the information about

the debarred firms/individuals, we searched World Bank's Chief Suspension and Debarment Officer (SDO) Uncontested Determinations and Sanctions Board Decision to collect the project name corresponding to the debarred firms/individuals. After that, the detailed sanctioned projects information was supplemented through the World Bank Projects and Operations database, and 73 sanctioned project samples were generated. At last, the same number of the normal project samples were randomly selected through World Bank Projects and Operations database. Combining these two kinds of samples, the final project samples were generated.

*Independent variables*

Independent variables in this research are control of corruption and regulatory quality, which are two parts of World Governance Indicators. Control of corruption and regulatory quality are explained as " reflects perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption" and " Reflects perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. "…in World Governance Indicators. The value of the two indicators is estimated and scored from -2.5 to 2.5, which mean the weakest to the strongest.

*Control variables*

For control variables, we select series of economic, population, business environment and other related governance indicators which might influence the fraudulent, corrupt and collusive practices from World Development Indicators, World Bank Doing Business Data and World Governance Indicators, including GDP (current billion US$), population growth, starting a business score, rule of law, government effectiveness and political stability.

As whether the project is sanctioned because of fraudulent, corrupt and collusive practices is a binary classification problem, we use logistic regression model to examine the above hypotheses. The examination is divided into three parts:

First, a logistic regression model is established to test the effects of control of corruption on fraudulent, corrupt and collusive practices. The model specification is as follows:

$$Sanction = \alpha + \beta_1 CC + \gamma X + \varepsilon \qquad (1)$$

Where is dependent variable indicating whether the project was sanctioned because of fraudulent, corrupt and collusive practices by WBG. is an independent variable indicating the scores of control of corruption in different countries.

presents control variables including GDP (current billion US$), population growth, starting a business score, rule of law, government effectiveness and political stability.

Then, the effect of regulation quality on fraudulent, corrupt and collusive practices is examined in following model:

$$Sanction = \alpha + \beta_1 RQ + \gamma X + \varepsilon \qquad (2)$$

In equation (2), also is an independent variable indicating the scores of regulatory quality in different countries. Other variables are the same with equation (1).

At last, the effect of the interaction between control of corruption and regulation quality on fraudulent, corrupt and collusive practices is examined in following model:

$$Sanction = \alpha + \beta_1 CC + \beta_2 RQ + \beta_3 CC \times RQ + \gamma X + \varepsilon \quad (3)$$

In equation (3), is an independent variable indicating the interaction between control of corruption and regulation quality in different countries. Other variables are also the same with equation (1).

Table 1 summarizes the descriptive statistics for variables in equation (1), (2) and (3).

*Table 1: Summary statistics*

| Variable | Definition | Obs. | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|---|
| Sanction | Whether the project is sanctioned because of corruption-practices by WBG: 1=yes; 0=no | 146 | 0.5 | 0.50 | 0 | 1 |
| CC | Control of Corruption: ranges from approximately -2.5 (weak) to 2.5 (strong) | 146 | -0.54 | 0.53 | -1.68 | 1.62 |
| RQ | Regulatory Quality: ranges from approximately -2.5 (weak) to 2.5 (strong) | 146 | -0.38 | 0.50 | -1.66 | 1.12 |
| GE | Government Effectiveness: ranges from approximately -2.5 (weak) to 2.5 (strong) | 146 | -0.38 | 0.61 | -2.28 | 0.99 |
| RL | Rule of Law: ranges from approximately -2.5 (weak) to 2.5 (strong) | 146 | -0.50 | 0.51 | -1.77 | 1.08 |
| PV | Political Stability and Absence of Violence/Terrorism: ranges from approximately -2.5 (weak) to 2.5 (strong) | 146 | -0.65 | 0.84 | -2.77 | 1.12 |
| GDP | Gross Domestic Product (current billion US$) | 146 | 1375.90 | 3758.55 | 0.85 | 14342.9 |
| POP | Population growth (annual %) | 146 | 1.41 | 1.03 | -1.81 | 3.56 |
| Start_b | Starting a Business score: ranges from approximately 0 (hard) to 100 (easy) | 146 | 84.97 | 8.27 | 36.4 | 99.6 |
| Interaction | CC*RQ | 146 | 0.40 | 0.52 | -0.53 | 2.79 |

## RESULTS

The regression results of equation (1) ~ (3) are presented in Table 2, which are the central estimates of this paper.

*Fraudulent, corrupt and collusive practices and control of corruption*

In column (1), we present the logistic regression estimation of the effect of control of corruption on fraudulent, corrupt and collusive practices for all samples. The coefficient of control of corruption is negative and statistically significant at 1% level, indicating that the stronger control of corruption reduces the probability of fraudulent, corrupt and collusive practices. This result confirms the first proposed hypothesis: Control of corruption is negatively related to fraudulent, corrupt and collusive practices in infrastructure projects.

*Table 2: Regression results*

| Variable | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| CC | -2.62*** | | -2.51*** | -2.50*** |
| | (0.81) | | (0.81) | (0.82) |
| RQ | | -1.64** | -1.64** | -1.44* |
| | | (0.74) | (0.79) | (0.80) |
| Interaction | | | | 1.12* |
| | | | | (0.58) |
| GE | 0.31 | 0.35 | 1.20 | 1.67* |
| | (0.68) | (0.75) | (0.80) | (0.87) |
| RL | 1.20* | 0.63 | 1.56** | 1.67** |
| | (0.72) | (0.67) | (0.75) | (0.77) |
| PV | 0.32 | -0.09 | 0.26 | 0.36 |
| | (0.29) | (0.27) | (0.30) | (0.32) |
| GDP | 0.00 | 0.00 | 0.00 | 0.00 |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| POP | -0.20 | -0.32 | -0.27 | -0.27 |
| | (0.22) | (0.21) | (0.21) | (0.22) |
| Start_b | -0.01 | -0.02 | -0.01 | -0.01 |
| | (0.03) | (0.02) | (0.03) | (0.03) |
| Obs. | 146 | 146 | 146 | 146 |
| R-squared | 0.0838 | 0.0482 | 0.1054 | 0.1238 |

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

*Fraudulent, corrupt and collusive practices and regulatory quality*

In column (2), we present the logistic regression estimation of the effect of regulatory quality on fraudulent, corrupt and collusive practices for all samples. The coefficient of regulatory quality is negative and statistically significant at 5% level, indicating that the stronger control of corruption reduces the probability of fraudulent, corrupt and collusive practices. This result confirms the second proposed hypothesis: Regulatory quality is negatively related to fraudulent, corrupt and collusive practices in infrastructure projects. In column (3), the effects of both control of corruption and regulatory quality on fraudulent, corrupt and collusive practices have been estimated, the statistically significant levels of these two variables remain unchanged.

*Fraudulent, corrupt and collusive practices and interaction between control of corruption and regulatory quality*

Through column (1) ~ (3), the effects of control of corruption and regulatory quality on fraudulent, corrupt and collusive practices are verified. Considering the joint effect of control of corruption and regulatory quality, the interaction between control of corruption and regulatory quality is involved in column (4) to examine the effect of the interaction on fraudulent, corrupt and collusive practices. The coefficient on the interaction term however is positive suggesting that the negative effects of control of corruption outweigh the negative effects of regulatory quality. From column (4), the interaction is positive and statistically significant at 5~10% level, indicating that the

better regulatory quality, promote better control of corruption, and then reduce the probability of fraudulent, corrupt and collusive practices together. Therefore, the last hypothesis is confirmed: The interaction between control of corruption and regulatory quality is positively related to fraudulent, corrupt and collusive practices in infrastructure projects.

Besides, after involving the interaction of control of corruption and regulatory quality, the statistically significant level of regulatory quality decreases into 5~10% level, but the statistically significant level of control of corruption remains unchanged. Therefore, the regression results are stable and reliable.

## DISCUSSION

Based on the results above, the proposed three hypothesises have been confirmed. The results indicate that control of corruption and regulatory quality are two main factors influencing the fraudulent, corrupt and collusive practices in infrastructure projects. For the countries with high control of corruption or regulatory quality scores, it is less probability to happen fraudulent, corrupt and collusive practices in infrastructure funded by WBG. Control of corruption has significant effect on the fraudulent, corrupt and collusive practices as less public power is used or exercised for private gain. Then the cost and difficulty of fraudulent, corrupt and collusive practices are increased significantly. Regulatory quality reflects the government ability to regulate and promote sound policies. As the development of private sectors ensured through the policy implementation, there is less motivations and incentives for private sectors to conduct fraudulent, corrupt and collusive practices. If the government owns the ability to promote the implementation of sound policies and guarantee the development of private sector, then the public power is less used for private gain. Therefore, the better regulatory quality will enhance the control of corruption.

## CONCLUSIONS

We argue that fraudulent, corrupt and collusive practices in infrastructure projects funded by WBG can be partly explained through two governance aspects: control of corruption and regulatory quality. Based on the research results, control of corruption and regulatory quality are both negatively related to fraudulent, corrupt and collusive practices in infrastructure projects. Which means that the better control of corruption or greater regulatory quality significantly reduced the possibility of fraudulent, corrupt and collusive practices in infrastructure projects. Besides, we explore the influence of interaction between control of corruption and regulatory quality on fraudulent, corrupt and collusive practices. The results shows that the interaction between control of corruption and regulatory quality is positively related to fraudulent, corrupt and collusive practices in infrastructure projects. Which means, control of corruption and regulatory quality enhance the effect of each other on fraudulent, corrupt and collusive practices. The greater regulatory quality improves the control of corruption, and then promote the restraint of fraudulent, corrupt and collusive practices in infrastructure projects.

Based on the results, when funding or conducting infostructure projects, WBG could check and inspect the control of corruption and regulatory quality levels of the project countries. Then, for the countries with worse control of corruption and regulatory quality, more supervision and investigation are necessary to prevent fraudulent, corrupt and collusive practices. Also, for developing countries, improve of control of

corruption and regulatory quality are vital to enhance the health development of infrastructure.

There are also some limitations and future expectations of this initial research. First, more control variables which might influence fraudulent, corrupt and collusive practices can be involved in the logistic regression model, to test the hypotheses. Second, more samples of infrastructure project could be collected to conduct the robust test. Finally, the causes of fraudulent, corrupt and collusive practices could be analysed from enterprise aspect and provide more constructive suggestion for participator factor.

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# EXPLORING THE INNOVATION ECOSYSTEM CONCEPT FOR A CONSTRUCTION INDUSTRY IN TRANSITION

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The construction industry is increasingly facing societal challenges, such as climate change, resource scarcity, and digitalization. Traditional ways of organizing construction appear to be unsuitable for coping with these challenges. This calls for more systemic solutions in construction that reach beyond single projects or sectors to transform to a more resilient society. In this research, the innovation ecosystem perspective is explored to open up new horizons for dealing with the challenges. The innovation ecosystem can be understood as a multi-stakeholder network around certain innovative value propositions. Several theoretical innovation ecosystems characteristics are applied to the construction context by means of two illustrative cases from the Dutch construction sector. Results indicate that the innovation ecosystem perspective has the potential to both deal with the challenges involved and foster the innovativeness required for transitioning the sector. Benefits include the consideration of actors that are outside the construction domain, such as organizations for data management in the context of the circular economy, as well the long-term relation building among interdependent actors. However, additional case study research is needed to explore the full potential of its application in construction.

Keywords: ecosystem; collaboration; innovation; projects; societal challenges

## INTRODUCTION

Construction projects become increasingly multi-disciplinary, complex and interdependent (Luo *et al.,* 2017). In addition, the industry is facing societal challenges such as climate change, Circular Economy, digitalization and changing mobility demand. These challenges require changes and innovations that exceed the knowledge, skills and capacity of single organizations (Shiu *et al.,* 2014). To contribute to these challenges in the increasingly complex construction context, new ways of producing, managing and innovating are needed throughout the sector (Wieser *et al.,* 2019). Therefore, both collaboration and thoughtful alignment of processes are required to take advantage of the complementary attributes of actors involved in construction works (Melander and Pazirandeh, 2019).

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Although collaboration is considered critical for innovation in construction (Loosemore, 2015), several systemic barriers to collaboration remain. The traditional project-oriented structure poses major barriers to diffusion of knowledge and innovation (Blayse and Manley, 2004). Besides, fragmentation and instability of stakeholder relations in projects prevent successful uptake of innovation (Van Oorschot *et al.,* 2020). Considering these barriers, a shift is required beyond single organizations to establish the right conditions for dealing with the societal challenges on a systemic level.

Dealing with these challenges and barriers requires efforts from all actors involved, as well as new concepts or perspectives that help to understand the complex collaborations needed for innovation. A promising concept is the innovation ecosystem (Thomas and Autio, 2020). Pulkka *et al.,* (2016) have effectively shown the applicability of ecosystems in construction projects and networks, which is so far the only systematic study on the ecosystem concept in construction. In this paper, the application of the innovation ecosystem concept in a construction context will be explored, considering network relations on a project-transcending level. To this end, theoretical innovation ecosystem characteristics are applied to two cases in the Dutch construction sector. As such, it is studied whether and to what extent the concept could contribute to the shifts towards a systemic, project-transcending approach to collaborative innovation in construction to deal with the challenges ahead.

## Theoretical background

### *Innovation in the Construction Sector*

In the construction context, innovations are often single elements in largely conventional end-products. In addition, given the context-dependency and unicity of construction projects, end-products often consist of many tailored solutions to context-dependent project requirements. Innovation is considered to be a collective act (Iansiti and Levien, 2004). Even if a particular novel technology or process is developed by a single organization, it is affected by the context in which it is implemented, while affecting society in turn. In such an innovation process, the innovating organization is but one actor in the network that affects the construction project. The network includes, next to the supply chain, for example, interest groups, standardization bodies, governmental agencies and financers (Bygballe and Ingemansson, 2014). Hence, there is a need for a more comprehensive perspective on how systems deal with collaboration and innovation.

### *The Innovation Ecosystem Perspective*

The innovation ecosystem perspective deals with the overarching multi-actor view on innovation. Since the late 1990s, the ecosystem concept found its way as an approach to describe organizational systems. This is particularly - and analogously to the rooting ecology domain - because of the concept's strong emphasis on the interaction between system elements and the system's environment (Tsujimoto *et al.,* 2018). Considering the extensive reviews of Scaringella and Radziwon (2018), Tsujimoto *et al.,* (2018) and Thomas and Autio (2020) on the many approaches to the ecosystem concept, the innovation ecosystem perspective seems to be particularly useful in supporting innovation and change to align the level of complexity of projects with the complexity of the socio-institutional context (Walrave *et al.,* 2018).

## Innovation Ecosystem Characteristics

Extant literature on innovation ecosystems focuses primarily on organizations around single value propositions in a rather continuous process flow or around a particular

platform. However, in public project-based sectors, such as construction, conditions for collaboration are different. Value creation is usually organized in projects in the shape of temporary cross-firm organizations in which different stakeholders have conflicting interests (Olander and Landin, 2008). Project- or asset-transcending perspectives on collaboration and innovation in construction are scarce. To explore the applicability of innovation ecosystems to the construction context, a theoretical foundation is required. Inspired by the ecosystem characteristics proposed by Thomas and Autio (2020), the concept is operationalized by four characteristics to understand how the cases relate to the innovation ecosystem perspective.

*Involvement of heterogeneous actors*
Ecosystem networks tend to exhibit high levels of actor heterogeneity (Thomas and Autio, 2020). The actors, their roles and interlinkages within the network change constantly, resulting in a dynamic network in which actors collaborate complementarily to the value proposition (Valkokari, 2015). The participant heterogeneity displayed by ecosystems can extend to cross-industry networks and transcends the boundary between public and private sectors (Thomas and Autio, 2020). This network may involve the full quadruple helix, including government, market, societal and research actors. As such, the collaboration in ecosystems transcends regular construction participants, such as contractors, clients, and engineering firms, and may include actors from industries, such as material suppliers, technological innovators or other specialized firms that might improve construction products or processes.

*Strategic alignment of actors*
Ecosystems are characterized by coopetition (Bacon *et al.,* 2020). Coopetition can be understood as the collaboration of actors that operate in each other's competitive areas through alignment of incentives, which creates interdependencies. This interdependency can, according to Thomas and Autio (2020) be viewed from three perspectives. First, a technological perspective where actors involved are co-specialized. An example in construction is the interdependence between suppliers of windows and window frames. Second, an economic perspective where benefits that an actor gains from participating in the ecosystem depend on the simultaneous availability of compatible offerings by other participants. In construction, this can be exemplified by the interdependency between client and contractor in executing a construction work. Third, the cognitive perspective, where the ecosystem network is structured by social rules, assumptions, values, beliefs and practices (Adner and Kapoor, 2010). Such interdependency may arise when actors within a network develop a shared identity as a group. Given these interdependencies, actors develop strategies to align innovation and collaboration processes and to establish a position within the network (Visscher *et al.,* 2021).

*Alignment with respect to value proposition*
Innovation ecosystems are centred around one or several value propositions (Adner, 2016). As such, the effort of the individual participants towards certain envisioned outputs must be aligned. This can be regarding certain product platforms in which several actors add parts that, together, constitute the end-product, such as a group of heterogeneous participants that together deliver an industrial modular housebuilding concept. Nonetheless, this can also be less-structured contributions in terms of knowledge, ideas, resources, and physical parts. The purposes, knowledge flows, engagement rules and the actors' contributions need to be aligned among the ecosystem participants to achieve such outputs (Adner, 2016). Next to innovations as

novel products or processes, novel business models can be outputs of ecosystems too (Autio and Thomas, 2018). Here, the participation in the ecosystem that introduces a new business model creates competitive advantage over actors outside the ecosystem. Together, the diverse combination of stakeholders incorporates a wealth of ideas, perspectives, and knowledge. This is particularly useful to explore problems and solutions and to maintain a wide solution space. Therefore, ecosystem outputs are both unpredictable and beyond the capacity of single actors yet shared among actors.

*Non-formal governance*

The strictness of the requirements to participate in ecosystems vary from basic rules to strong control or formal agreements. Generally, relations and governance of actors and actions are largely non-contractual and may change over time (Jacobides *et al.,* 2018). In public construction, procurement law poses barriers to forming long-term and informal relationships, particularly between public clients and private parties (Kuitert *et al.,* 2019). A less-formal governance allows participants to take dynamic roles in the venture towards the value proposition. Rather than being directed by a leading actor, participants may, in contrast to, e.g., formal supply chains, act independent (although being interdependent). System boundaries are blurry because of this relatively informal and dynamic structure (Phillips and Ritala, 2019), and actors might change their intensity and period of involvement and their relations with others. This can be regarding the development of particular components as part of the overall value proposition, the relevance of particular knowledge, or an actor's changing interests or changing contextual factors. These collaborative and interdependent changes towards fulfilment of a value proposition, including actors, activities, relations, institutions, environment, and legislation, are explained through the concept of coevolution (Gomes *et al.,* 2018).

## RESEARCH CONTEXT AND APPROACH

To explore the applicability of the innovation ecosystem concept in construction, the cases of the Waterschapsbedrijf Limburg (WBL) and of the Collaboration in aspHalt APplications with LIgniN (CHAPLIN) were analysed because of their project-transcending approach to collaboration and innovation.

WBL is the executive organization of two waterboards in the Netherlands and is responsible for the regional wastewater treatment. To do so, WBL created in 2017 and 2018 a network around their asset-portfolio by dividing the portfolio into five parcels. For each parcel, three contractors were formally contracted in a framework agreement for a period of four to six years and these contracts will end between 2021 and 2024. Next to the parcels, a so-called "shopping mall" was set up, which consisted of a catalogue of multiple technological solutions provided by various suppliers. WBL could directly draw from this through the contractors to promote standardization. This framework agreement in combination with the "shopping mall" enabled WBL to collaboratively seek for the best solutions utilizing the expertise of particular actors. The WBL case is selected for this research as it represents collaboration on a project-transcending level in which multiple actors are involved. Unique for the construction industry, but in line with the innovation ecosystem concept, is that coopetition is central in this network and the actors involved collectively strive for a certain outcome: a process innovation on collaboration and a product innovation on modularity of wastewater treatment plants.

The CHAPLIN case represents a programme driven by a platform around a collective aim to develop and commercialize lignin biobased asphalt, including research,

development, and pilots. In line with innovation ecosystems, the programme revolves around a central value proposition - the development of lignin biobased asphalt. The network consists of 22 different organizations, such as governments, knowledge institutes, contractors, and suppliers. Unique for the construction industry is that the CHAPLIN network is based on informal relations which are dynamic and change over time, whereby organizations from non-construction sectors are involved.

Case data was obtained through desk research, by attending network events and by conducting interviews. Extensive semi-structured interviews were conducted with the framework agreement manager and contract manager from WBL, and with a manager in one of the contractor companies. After data collection, first, the cases were systematically analysed using the four characteristics introduced in the theoretical background section, resulting in a broad and divergent list of ecosystem characteristics present in these cases. After this analysis, the researchers sought for the typical characteristics that are unique for the construction industry and were explainable as a consequence of the application of the innovation ecosystem concept in this sector. Next, the most striking aspects were studied per case. Finally, the potential opportunities, benefits, and challenges of the application of the innovation ecosystem perspective in the construction industry were explored.

## RESULTS

*Involvement of Heterogeneous Actors*

In the WBL case, both the framework agreement and the "shopping mall" were initiated by WBL, who organized public tender procedures to select participants. This resulted in a heterogeneity comparable to regular construction projects. Yet, the actors were involved throughout the entire construction processes rather than only specific phases to safeguard an integral approach to the potential solutions, and the possibility to select suppliers through subcontracting ensured access to organizations outside the framework. Contrarily, the network in the CHAPLIN case exhibited a high level of heterogeneity. Organizations were able to join the network on their own account, enabling them to act in different roles with respect to the central value proposition. In both cases, non-conventional contractors and suppliers were involved, of whom the intensity of involvement varied over time. In conventional construction projects, contractors in the construction industry team up with suppliers from a rather fixed group, based on, among other aspects, past performance, geographic boundaries, and existing relationships. Nevertheless, in the WBL case this change was managed by WBL, while in the CHAPLIN case the change evolved naturally. Yet, this allowed both cases to adapt to the changing system demands.

*Strategic Alignment of Actors*

Both cases involved a high level of actor interdependence. In both networks, knowledge sharing was a central element and the actors in the network were dependent of the outputs of other actors in the development and optimization of the product or process. In the case of WBL, actor interdependency was premediated and contractually arranged with agreements on knowledge sharing and developments. In contrast, the interdependency between actors in the CHAPLIN case emerged as a result of the joint development of the biobased asphalt. The construction industry depends in many subsectors on only a few parties per specific component.

For example, viaduct clients in the Netherlands are dependent on only two suppliers that can deliver large pre-cast girders.

*Table 1: Case analysis based on four characteristics of an ecosystem*

| | WBL | CHAPLIN |
|---|---|---|
| *Involvement of heterogeneous actors* | Broad network consisting of actors comparable to regular projects<br>Framework agreement and "shopping mall" that enables project-specific task-actor fit<br>Contractors and suppliers actively involved along all project phases<br>Team composition depends on the type of work in the parcel | Cross-industry collaboration<br>Quadruple helix involved representing a broad diversity of organizations<br>Dynamic network enabling specialized and non-construction actors to participate<br>Aiming for international collaboration |
| *Strategic alignment of actors* | Coopetition by contractors and suppliers within framework contract<br>Co-creation in early project stages<br>Deliberate knowledge sharing<br>Trust and collaboration as a basis for distribution of work between contractors<br>Increased overall process efficiency results in aligned incentives towards collaboration | Coopetition and cross-sector collaboration<br>Actors involved from varying backgrounds and varying specialisms, each contributing a "piece of the puzzle"<br>Collective knowledge development and distribution<br>Knowledge development as input for pilots and vice versa |
| *Alignment with respect to value proposition* | Project delivery with lower failure costs<br>Increased efficiency through accelerated and circumvented processes<br>(Sustainable) innovation<br>Wide (non-contractual) solution space<br>Technological standardization<br>Knowledge on collaboration, technology, and processes<br>Strong business case for both client and contractors through alignment of incentives regarding value proposition | Contribution to SDG's<br>Sustainable innovation (bio-based road pavement)<br>Knowledge development on bio-based asphalt<br>Potential future competitive advantage<br>Potential for large-scale value capture in future<br>Potential formation of new markets and supply chains |
| *Non-formal governance* | Governance formalized in collaboration-oriented framework contracts for 4 to 6 years<br>Framework agreements aimed at particular types of work, resulting in multiple sub-ecosystems<br>Knowledge sharing contractually embedded<br>WBL as orchestrator of the ecosystem. Mediation by external party<br>Boundaries between contractors in framework are blurry; Contractually unspecified amount of work | Non-contractual relations quasi-formalized in voluntary consortium<br>Participation in ecosystem by formal and informal networking<br>Ecosystem boundaries are blurry and dynamic<br>Commitment to make effort<br>CBBD as orchestrator of the network<br>Pilot projects are partly contractually formalized<br>Funds both through participants and subsidies |

Given this inescapable interdependence, in both cases alignment of incentives contributed to collaboration by turning competitive relations into cooperative relations. The WBL case demonstrated the benefits of a collaborative attitude in their framework agreements in which project-transcending challenges were included, resulting in opportunities for standardization, novel wastewater treatment plant systems and wider innovations. At the same time, lower costs of failure, lower project durations and pleasant collaboration processes were achieved.

*Alignment with Respect to Value Proposition*
Central to the innovation ecosystem concept is a common purpose which results in aligned incentives. In the CHAPLIN case this purpose was a sustainable innovation that could deliver future competitive advantage for the contractors and helped public clients with achieving societal challenges and to create public value. This goal was clearly defined by the non-profit organization who initiated the platform.

In the WBL case, this was achieved by changing the cost and benefit structure. By replacing an output-driven contract with a collaboration-driven contract where profits and risks were shared fairly, it was in everyone's interest to deliver a "good" end-product for the lowest costs possible. As such, the output of the WBL parcels continually adapted to current challenges and was a result of both the WBL mission as the knowledge of all participants of the parcel. While the output in the CHAPLIN case - development and commercialization of lignin-based pavement - was clearly predefined, the output in the WBL case was less clearly delineated and rather comparable to the output of regular projects in the wastewater treatment sector.

The CHAPLIN case offered a clear example of an output that would have had little chance in a conventional construction project context, since it would have been difficult to reach and involve the various industries that each delivered a part of the puzzle to the value proposition for single application. The shared value proposition was, as such, the connection between the parties that were involved in the CHAPLIN network. In contrast to regular construction projects, this allowed the innovation trajectory to evolve in a rather explorative way. While the physical output of the WBL case was not so different from regular outcomes in the sector, the changed organization and longer-term collaboration contracts resulted in fundamental changes in processes, which resulted in lower costs of failure, lower project durations, pleasant project collaborations, as well as favourable conditions for innovation.

*Non-Formal Governance*
Innovation ecosystems are characterized by a loose and informal way of governance - or self-organizing capacity. Given the dependency on public funds in the construction sector and the accompanying procurement law, this informal governance is not easily achievable. Nevertheless, contracts can be shaped in many ways with many different degrees of freedom for the actors involved. In the WBL case this was achieved by contracting several contractors for a fixed period with a partially unknown assignment. Within the boundaries of this contracted period, the formality was rather low and the collaboration largely trust-based, which offered space for the participants to utilize their specific knowledge and unique capabilities. The framework agreement manager noted that a shift of mind-set from wariness (relying on contracts) to trust (relying on good intention) has been a continual and precarious challenge, particularly since it contradicts traditional practice. In the CHAPLIN case, the platform structure allowed participants to join and leave the consortium and to contribute at specific times on specific parts. Here, the structure was informal and largely non-contractual. However, the individual pilot projects in which the lignin was applied in pavement were more organized as conventional projects and hence employed a more formal management and governance structure.

## DISCUSSION

The results in the previous section reveal similarities and differences between two cases of novel approaches regarding project-transcending collaboration in the Dutch construction sector. Both cases revealed similarities with core characteristics of the

innovation ecosystem, in particular the alignment of incentives towards a common goal, strong focus on collaboration and complementarity of the various actors involved and low level of (top-down) governance within projects. The diversity and plurality of actors was larger than in conventional projects, which can be a potentially valuable source of radical innovation in construction. Particularly the CHAPLIN case showed how the involvement and trust-based collaboration between industries creates innovative business value beyond single projects, but also in the WBL case a way was found to deal with procurement regulation and gain access to a wider pool of organizations simultaneously. Moreover, the fair distribution of risk and profits in the WBL case showed benefits of trust-based collaboration, which is known to be an important condition for innovation (Lloyd-walker *et al.,* 2014).

In contrast to traditional projects, where power lies primarily at client organizations and where innovation and change is constrained by rigid rules and legislation (Briscoe *et al.,* 2004), both cases reveal a more equally distributed and larger degree of freedom for innovative solutions for the actors. In consonance with the findings from Pulkka *et al.,* (2016), it shows that the innovation ecosystem concept can be beneficial for analysing and organizing value creation in the construction context. However, where the cases studied by Pulkka *et al.,* (2016) are primarily fixed, market-driven networks aimed at a specific physical end-product as purpose, this study emphasizes dynamic networks with a project-transcending character aiming for more abstract purposes. Next to value creation, this study shows that the innovation ecosystem concept is promising as a strategy to foster innovation and facilitate collaboration required to deal with the societal challenges. It seems that particularly the project-transcending character enabled participants to invest in longer-term relationships. Especially in the WBL case, this was visible in the tendency of the contractors to contribute to standardization of wastewater treatment plant components, where in regular construction projects standardization is often resisted by market parties, for it limits their opportunities to differentiate and hence might restrict competitiveness.

Furthermore, studies by Leviäkangas *et al.,* (2016) and Davies *et al.,* (2014) have explored the ecosystem concept in construction and infrastructure. Despite the benefits of such approaches in terms of alignment of incentives and offering the right conditions for innovation, the temporality is limited to that of an asset or (project) organization. The cases studied in this research show that the long-term relationships are particularly valuable for achieving change and innovation in line with the societal challenges. Therefore, the innovation ecosystem approach could be valuable in contributing to the long-term challenges the construction industry is facing. Although we do not expect fundamental differences in applicability of the ecosystem concept outside the Netherlands, it could be worthwhile to explore further cases also outside the Dutch context.

## CONCLUSION

In this research, the adoption of the innovation ecosystem concept is proposed as an approach to enable long-term collaboration to provide the conditions for innovation and change, required to enable the construction industry to deal with the upcoming societal challenges. The aim of this research was to explore the application of the innovation ecosystem concept on a project-transcending level by analysing two unique cases. Four ecosystem characteristics were used for this analysis. It was found that underlying principles of the innovation ecosystem perspective can already be found in the industry, particularly the alignment of project-transcending incentives towards a

shared value proposition. To bring this concept further, the conceptual development of the innovation ecosystem concept to fit construction is required. By exploiting these traits in the future, the innovation ecosystem concept could contribute to the shifts towards an integral and project-transcending approach to collaboration to provide the conditions needed for a construction industry in transition.

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# Law and Contracts

# FORENSIC DELAY ANALYSIS: AN INVESTIGATION OF THE REASONS FOR DISAGREEMENTS IN TIME-RELATED DISPUTES

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Construction project delays are widespread and persistent. Disputes frequently occur, and their complexity and value has produced a role for experts specialising in Forensic Delay Analysis (FDA). Previous literature suggests that the main problem (and the main generator of escalated disputes) lies with the insufficiency and/or poor quality of available information. In this study, twelve disputes were examined for their key points of disagreement. These cases indicate that there are, in fact, four distinct factors: namely the availability, validity, and disclosure of relevant information, and the approach taken to its analysis. Insufficiency and poor quality of information was indeed a factor in these disputes, but not the only one; the apparently deliberate lack of transparency, the selective interpretation of information, and the subjective adoption of delay analysis method are at least as important in creating and amplifying the dispute. The resulting interplay between the availability of reliable data, the readiness of actors in providing it, and the conflicting motives behind the way it is analysed by experts results in a zero-sum gamble for the parties seeking the resolution of delays and their consequences. This could be partially or fully avoided by (i) exploiting advances in information technology; (ii) the introduction of agreed contractual delay protocols; and/or (iii) radical changes to the concept of 'ownership' of information. The work presented here is part of a wider study examining the impact of advances in information technology on the more efficient resolution (or even avoidance) of contractual disputes.

Keywords: case studies; contractual disputes; information technology; project delay

## INTRODUCTION

Construction project delays are widespread and persistent (Adam, *et al.,* 2017; Ansah, *et al.,* 2018; Durdyev and Hosseini, 2019; Larsen, *et al.,* 2016), expensive and time consuming (Arcadis, 2020), one of the leading causes for disputes in the UK (NBS, 2018), and can lead to significant transaction costs (Atanasov, et. al. 2020). This study focusses on the evaluation of the issues that lead to time-related disputes, specifically the primary reasons for the divergence in delay expert opinion during dispute resolution proceedings. The empirical analysis reported here is based on twelve case studies and addresses those three propositions by evaluation, organisation and categorisation of (i) the arguments currently relied upon by delay experts, (ii) the

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critique and alternative case provided by their counterparts and (iii) the criticism of the parties and their delay experts by the decision makers. First, the contextual background is presented, and a literature-based summary is provided of the reasons for divergence in delay expert opinions in dispute resolution proceedings. The methodology describes a case study approach to data collection, the results of which were analysed to (i) provide further insight into the primary causes for divergence in expert opinion and (ii) identify the key issues for further examination. Finally, and with a view to the larger body of work that this study forms part of, a consideration of mitigation measures is provided to enable the more efficient resolution (or even avoidance) of contractual disputes.

## LITERATURE REVIEW

### Forensic Delay Analysis

In this paper the term delay relates "Delay to completion of the works by the completion date" is "an adverse effect upon completion by the date by which C [sc. The Contractor] is contractually obliged to complete the works, or any contractually defined section of the works…" (Burr, 2016:11). Project delays can lead to financial losses for all parties embroiled in disputes. However, the current contractual mechanisms are ineffective in preventing time-related disagreements. For example, the causes of dispute can vary from interpretation of terms, (like the word 'delay') to arguments relating to the most suitable delay analysis method (DAM) in the context (Parry, 2015 and Pickavance, 2010). The complexity and value of construction disputes has created opportunities for contentious lawyers (solicitors and barristers), claims management and dispute resolution consultants, and experts who specialise in 'Forensic Delay Analysis' (Kumaraswamy, 1997). Forensic Delay Analysis (FDA) experts form their opinions on records (such as contemporaneous programmes and progress reports) that are processed with the assistance of a delay analysis method (DAM) and a quantification technique like the Critical Path Method (CPM). It is the interaction between records and DAMs that is the focus of this paper, specifically the inconsistent (even contradictory) motives for selecting a specific DAM as driving force in delay disputes.

### Delay Analysis Methods and Data Requirements

There are several widely recognised DAMs that can be generally divided into two categories: prospective and retrospective (SCL, 2002; 2017 and AACE, 2011). Although a detailed analysis of those methods is outside the scope of this paper, it is important to state that the categorisation derives from two key industry bodies - the UK Society of Construction Law (SCL) and the American Association of Cost Engineering (ACCE) - who use marginally different terminology to describe comparable methods. This paper adopts the SCL's description of those methods. The two so-called prospective methods are: Impacted As-Planned Analysis (IAP) and Time Impact Analysis (TIA), and four retrospective methods are: Collapsed As-built Analysis (CAB), Retrospective Longest Path (RLP) Analysis, As-planned vs As-built Analysis in Windows (Windows) Analysis and As-planned vs. As-built Time Slice (Time Slice) Analysis. The relative merits of different FDA techniques have been discussed in the literature (e.g., Kraiem and Diekmann, 1987; Braimah, 2013; Society of Construction Law, 2002, 2017; Scott *et al.,* 2004; American Association of Cost Engineering, 2011). Opinion as to what may be the most appropriate delay analysis method in a specific context varies, depending on criteria that are both objective and subjective. For example, the 2017 SCL Delay and Disruption Protocol (Society of

Construction Law, 2017: 13) recognises that any FDA method adopted must depend on objective criteria such as the nature extent and quality of both the programme information and records. Similarly, commentators have argued that it is the objective reasons (e.g., the availability and quality of records) that is the leading cause for disagreement between delay experts, rather than subjective criteria (Gibbs *et al.,* 2013:48 and Sanchez *et al.,* 2019). However, there is currently little to prevent players from selecting one DAM over another to prioritise their client's interest. Although it is accepted that insufficiency and poor quality of information can be important to the uncertainty of outcome, the argument presented here is that (i) currently the parties are rarely compelled to share such information, (ii) information is often available in various sources of divergent quality, (iii) information is not uniformly distributed among all players and (iv) its analysis can be subjective. Consequently, opportunities exist to perpetuate delay disputes by applying subjective motives and debateable reasoning for reliance on specific types of records and/or unrecognised DAM.

Quantification of project delays is usually supported by CPM-type analysis and is reliant upon the availability of regular and reliable programme updates. If the project records that are required to validate construction programmes are unavailable (as they often are) the CPM analysis can be highly speculative and subjective. The role of the FD Analyst may be to assist a party or its legal team in building a case or to act as an independent expert in dispute resolution. CPM is currently supported by CPM-software products (Barry, 2009; Keane and Caletka, 2015) and is a widely accepted method for quantification of critical construction project delay (Wickwire and Ockman, 1999).

## METHODOLOGY

The purpose of the data collection is (i) identification of the primary reasons for disagreement among delay experts, (ii) categorisation of those reasons by using standard industry language and (iii) consideration of the interplay between the availability of reliable data, the readiness of actors in providing it, and the conflicting motives behind the way it is analysed by experts. The methodological approach is primarily archival and based upon analysis of the records of twelve contemporary case study projects (which include examples of the most common forms of dispute resolution) chosen from an initial sample of 38. Many types of dispute require the creation of expert reports to substantiate the EOT/LD claims (or referrals). Similar reports are produced for the defending (or responding) parties to (i) rebut the claimant's case and (ii) offer an alternative assessment. This process may involve an opportunity to produce a formal reply to the defending expert report and/or a schedule that provides a summary of the experts' position and areas of disagreement (i.e. adjudication or arbitration). Such disputes can also involve independent delay experts, that are appointed by the decision makers, to assist them with the evaluation of the delay analyses and, generally, terminate with a decision. These documents are rich sources of data for identifying, categorising and provide an analysis of the reasons for disagreements between delay experts.

The selection of cases was based on two criteria. The first was the existence of delay expert reports commissioned by both parties (where only one such report was available the case was excluded) and the second was recency: the case studies were selected from the period between January 2015 and January 2021.

**Case studies**

The sample includes projects based in the UK and overseas that were managed by various organisations. The project archives were provided by one private entity. Although these records are available to the several organisations involved in these disputes, they are unavailable to the public. For ethical reasons the cases have been anonymised and described by their function (i.e. Packaging Plant; Teaching Facility; Infrastructure deign) and location (i.e. UK or overseas). The key reasons for disagreement are outlined below on a case-by-case basis.

*Case 1: Packaging Plant (UK)*
The parties disputed the robustness of all programmes due to absent activity logic and validation. Consequently, the defendant (D) created a database to substantiate the actual progress of the works which was challenged by the claimant (C) because some of the activity descriptions in D's records did not match those in their programmes. The disagreement relating to the selection of a DAM and causation were related as the parties modified the former to justify the latter. C's expert was criticised for using a bespoke DAM and relying upon a global assessment of delay, and not changing their opinions and findings when further information was provided by D in their defence statement.

*Case 2: Teaching Facility (UK)*
Like Case 1, there were issues relating to the completeness of the programmes. The electronic version of these programmes (EV) was unavailable to D, even though D reasoned that a robust delay assessment cannot be produced without it. Similarly, some of the activities description in the records did not match those in the programmes. Many contemporaneous records were unavailable to D and the use of the as built in C's expert report was inconsistent (i.e. C selected the most advantageous dates from multiple sources, instead of using a single as built source). Thus, C's expert was criticised for modifying a recognised DAM and CPM by providing a partial analysis that lacked detail. D's expert response was limited to a critique as they were unable to complete a robust delay analysis due to the lack of records.

*Case 3: Multi-storey Building (UK)*
The experts disagreed on the most suitable baseline programme (BP). Like Case 2, C did not provide the EV to the experts. C's expert produced a partial delay analysis by using a modified retrospective DAM and incomplete CPM to substantiate their causation assessment. Thus, D's expert described their analysis as impractical and inaccurate, as the identification the critical path is unfeasible without an assessment of the construction process from start to finish.

*Case 4: Infrastructure Design - Road (UK)*
Like Case 3, the experts disagreed on the baseline and the EV was unavailable. C relied upon unvalidated PUs that D proved unreliable due to inaccurate representation of the as built. Neither expert used a recognised DAM and unmodified CPM.

*Case 5: Infrastructure Design - Road (UK)*
The main reason for disagreement in this case was C's expert decided to conduct a partial delay analysis. As with all previous cases, the existence of compensation events was not in dispute, but the parties disputed the effect of those events on the completion date.

*Case 6: Infrastructure - Motorway (UK)*
Like cases 3 and 4, the experts disagreed on the most suitable BP. It was accepted that the logic must be altered for the purpose of their analysis, but the changes completed by each expert were different. C's analysis excluded some aspects of the project. Both experts relied upon a modified DAM where C's expert argued this was required due to the incompleteness of records and the status of the project, specifically that it was incomplete at the time of the dispute. Originally, D's expert argued that TIA was the most suitable DAM because as built data was available, but changed their opinion, after C's expert adopted TIA, in that a retrospective delay analysis method is most appropriate. C's expert disagreed that a retrospective method is suitable in this context as the project was incomplete.

*Case 7: Power Plant (overseas)*
Like cases 3, 4 and 6 the experts disagreed on the BP and criticised each other for making assumptions that were advantageous to their client. D's expert successfully discredited the accuracy of C's records, and thus their case, because their DAM relied upon those records. The decision maker instructed an additional expert who preferred the D's delay expert report.

*Case 8: Shopping Centre (overseas)*
In this case, the parties formalised the dispute because C used a modified version of the contractual DAM due to unavailability of programmes and records. The scope of the formal dispute was affected by the tribunal's instruction that moving away from the contractual DAM would require compelling justifications. Here the experts disagreed on criticality even though they used identical DAM, records and programmes.

*Case 9: Infrastructure Design - Motorway (UK)*
Similarly, the experts disputed the suitability of the BP, used modified DAM/CPM and based their causation analyses on such unrecognised techniques.

*Case 10: Infrastructure - Tunnelling (UK)*
As with other case studies, the experts disagreed on the BP where C's expert was criticised for relying on the most advantages to their client PU. Furthermore, the decision maker suggested that (a) C used the fact that the project was incomplete to reply upon a prospective DAM, (b) the quantification of the effect of compensation events on the project should be conducted retrospectively to consider the facts and therefore (c) contract procedure should allow sufficient time for the contract administrator to conduct such assessments.

*Case 11: Bridge (overseas)*
The parties disagreed on the BP; however, D did not suggest an alternative BP and did not appoint an expert. C's expert used a recognised DAM whilst the D relied upon a bespoke DAM. The decision maker disagreed with both methods and relied upon a relatively more theoretical DAM (CAB) than the C's expert (Windows).

*Case 12: Multi-storey Building (UK)*
C's decision not to instruct a delay expert was criticised by the decision maker. The claim was described as 'global' as it did not rely upon a recognised DAM. D's expert relied upon a recognised DAM (IAP) but was criticised due to their reliance on a modified BP and absent reliance upon contemporaneous records associated with TIA. Consequently, the decision maker conducted their own analysis to reach judgement.

**Data Analysis**

The initial analysis revealed that the primary type of disagreement falls into two categories; records and analysis that can be categorised in terms of key issues, as follows:

*Issue 1: Baseline Programme*
Disputed robustness and integrity of the baseline programme (BP) was one reasons for disagreement, as it was critical to CPM analysis. The decision makers' rulings from the sample indicate that this was a relatively weak cause for argument because the baseline programme in all cases was a contractual document and, as such, formed an integral part of the agreement. Consequently, arguments against the use of the BP were rejected unless the BP lacked important detail, or logic.

*Issue 2: Programme Updates and As-Built Programme*
Unavailability of robust and credible programme updates (PU) was also a common reason for dispute. This includes criticism by the decision makers for withholding the electronic version of the programmes by the holder/owner.

*Issue 3: Contemporaneous Records*
Unavailability of accurate contemporaneous records was rarely a fundamental cause for disagreement in the sample. However, validation of the PU was required in all cases to provide an accurate status of the works. This was often the basis for disagreements because (i) more than one source was used to validate progress and (ii) the sources often included conflicting start or completion dates for different activities. Consequently, the conflict in the as built data was relied upon in the CPM analysis.

*Issue 4: Delay Analysis Methods (DAM)*
Contradictory rationale for the selection of the most appropriate DAM and the relative robustness of the chosen DAM was another reason for disagreement. In all case studies, it was alleged (by at least one of the delay experts) or ruled (by the decision maker) that at least one of the parties, or their delay expert, employed a 'novel', 'modified', 'unrecognised' or a 'bespoke' DAM to arrive with their conclusions as to the measurement and causation of delay. The cases indicate that this was a key disagreement, and the decision makers were often asked to prefer one side's method over the other.

In other cases, the decision maker adopted a DAM different to the ones adopted by the parties' delay expert on grounds of robustness and contextual considerations. This indicates that the motives behind the use current approach to delay analysis can be controversial at best. For example, in Case 8 the decision maker instructed the parties to use an unrecognised DAM. When this instruction was resisted, the decision maker employed a relatively more theoretical DAM to quantify the delay.

*Issue 5: Causation Analysis*
Although all cases involved disagreements relating to causation, in all instances at least one delay expert was criticised for partiality, specifically that their analysis suggested that they altered the critical path without strong justification which misrepresented the criticality of events. The criticism suggested that the causation analysis results depended on the selection of an 'unrecognised' DAM, or modification of programmes when conducting the CPM assessment. Consequently, the data suggests that the causation analysis issue was linked to the selection of the DAM and the robustness of the CPM assessment.

Table 1 provides a summary of the key reasons for disagreement in relation to the project delays relating to the twelve case studies (C1 to C12).

*Table 1: Summary of key reasons for disagreement*

| Category | | | Reason | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Problem - reasons for disagreement | Records | Baseline | High level or Incomplete | × | × | | × | | × | × | | | | | |
| | | | Lack of logic - assumption of logic | × | | | | | | × | | | | | |
| | | | Erred logic - modification of logic | | × | × | × | | × | × | | × | | | × |
| | | | Disagreement on BP/reliance on a different baseline | | | × | × | | × | × | | × | × | × | × |
| | | | Electronic version unavailable to one party | | × | × | × | × | | | | | | | × |
| | | PU | Lack of detail | | × | × | | | | | | | | | |
| | | | Lack/modification of logic | × | × | × | | | × | × | | | | | × |
| | | | Inaccurate representation of the progress of the works | × | × | | × | × | × | × | | | | × | × |
| | | | Electronic version unavailable | × | × | × | × | × | | | | × | | | × |
| | | | Irregular programme updates | × | × | | | | × | | | | | × | × |
| | | Records | Unavailable to the project | | | | | | | | | | | | |
| | | | Unavailable to one of the parties | | × | | × | | | | | | | | × |
| | | | Available but incomplete | × | × | | × | × | | | | | | | × |
| | | | Availability of multiple conflicting as-built records | × | | × | | × | × | × | | | | | |
| | | | Disputed accuracy of records | × | × | | × | × | × | × | | | | × | × |
| | | | Inconsistent as built source selection | | × | | × | | | | | | | | × |
| | Analysis | Delay | Disagreement on the most suitable DAM | × | × | | × | × | × | × | | × | × | × | × |
| | | | Reliance upon a modified/unrecognised DAM | × | × | × | × | × | × | × | | × | × | × | × |
| | | | Modified CPM | × | × | × | × | × | × | × | × | × | × | × | × |
| | | | Weak selection rational for DAM | × | × | × | × | × | × | × | | × | × | × | × |
| | | | High level analysis by one or both parties | × | × | | × | | × | | | | | × | × |
| | | | Partial analysis by one or both parties | | × | × | | × | × | | | | | | |

The table above indicates that the key issues raised include irregular programme updates, lack of access to as built records and the electronic version of the programmes and disputed as-built status of the works. However, the use of unrecognised DAM and modified CPM were the most common reasons for disagreement. Furthermore, alteration of the contractual baseline was never accepted as a justification by the relevant decision maker when the baseline programme was a contractual document. Assumptions as to the baseline logic were only accepted if the baseline did not provide logic. This suggest that disagreements relating to the as-built programme, withholding of relevant records and programmes, and the selection of DAM were the most significant issues. Moreover, if contemporaneous records were withheld the delay analysis was theoretical because it relied on assumptions rather than facts and was rejected by the decision maker.

## DISCUSSION AND CONCLUSIONS

Based on twelve cases, the key reasons for disagreement in delay disputes were identified and categorised. The primary data indicates that there are two main areas (records and analysis) including five categories: baseline programme, programme updates, contemporaneous records, delay analysis method (including CPM) and causation analysis. The analysis of those categories indicates that there are four issues, namely availability, validity, disclosure and analysis of information.

*Availability of information*

Although it is accepted that the arguments presented by Gibbs *et al.,* (2013: 48) that uncertainty of outcome can be driven by the insufficiency and/or poor quality of information upon which the analysis relies, the data here indicates that baseline programme and as-built records, although sometimes incomplete, were always available to one of the parties. These cases also reveal a frequent problem, when such information was not available to both parties, specifically increased uncertainty because information such as as-built records and the electronic versions of the programmes are necessary to produce accurate delay assessments. It is the interplay between availability, validity, disclosure and analysis of information that can be exploited by one of the parties to create uncertainty of outcome. Similarly, information asymmetry encourages opportunistic behaviour which in turn creates

problems. Consequently, the driving factor does not appear to be the lack of records but their disclosure and/or subjective analysis.

*Validity of information*
It is, of course, possible that the validity of information can be addressed with technology that can (i) generate accurate records, (ii) automate key aspects of delay analysis and (iii) share the data among all parties. Advances in technology such as the introduction of sensors (Akinci and Anumba, 2008), 3D scanners (El-Omari and Moselhi, 2008), blockchain (Li, Greenwood and Kassem, 2019) and drones (Li and Liu, 2019) present an opportunity for accurate contemporaneous collection and sharing of construction project progress.

*Disclosure of information*
Currently, the information holder may decide to refuse to make information available and/or to prefer one source over another even if contractual obligations to act in mutual spirit of trust and cooperation (or good faith) exist. The evidence suggests that such practices are inefficient and ineffective for dealing with time-related disputes. Consequently, to reduce (or avoid) delay disputes, availability of information should be supplemented by the introduction of contractual delay protocols and/or radical changes to the concept of 'ownership' of information. It is contended that such changes are necessary to reduce (i) the uncertainty that is currently caused by information asymmetry associated with the administration of construction and engineering contracts and (ii) the opportunistic behaviour in the context of time-related disputes, hence increasing contractual certainty.

*Analysis of information*
Contractual certainty can also be improved by agreeing to use a contractual protocol for delay analysis and/or change the ownership of programmes, records and the analysis. Some of the case studies indicate that the former is a potential solution. For example, the use of contractually stipulated DAM appears to narrow the scope of the disputes significantly if such method is synchronised with the contract. The SCL Disruption and Delay Protocol (2017) suggests that it is the context that should influence the decision on the selection of a DAM (not the other way round) and accordingly recommends six methods. It is commonly accepted that the parties can identify and rely upon the most suitable delay analysis method(s) at the outset of a project (SCL, 2002; 2017 and AACE, 2011). Indeed, it has been suggested that recommending a 'best of the rest' method for delay analysis should be best practice, specifically Windows or TSA (Parry, 2015). The courts also indicate (i) support for retrospective approach even with contracts that favour prospective assessment of delay and costs like NEC3, specifically if the prospective approach lacks substantiation, and (ii) refusal to hand over records is in the breach of the well-known NEC obligation to act in mutual spirit of trust and cooperation. Another issue with prospective methods is that it is difficult to accurately measure mitigation and the contractor often has a contractual duty to mitigate delays (Northern Ireland Housing Executive v Healthy Buildings (Ireland) Limited, 2014). This suggests that prospective delay analysis should only be used where and when it is unfeasible to use a retrospective method i.e., to reach agreements in principle that EOT is due, or in a timely and substantiated manner with contracts that favour prospective assessment.

## CONCLUSION

The evidence presented here shows that behavioural economics is at the core of time-related disputes as delay experts (and/or their clients) are often criticised for (i)

withholding available information, (ii) neglecting to revise expert opinion when such information is presented during dispute resolution proceedings, (iii) inconsistent reasoning for selection of DAM, (iv) modification of recognised DAM to suit their analysis, (v) selective use of programmes in the CPM analysis and (vi) changing the start/completion dates of activities to suit the CPM analysis. Both the data and the literature indicate that the primary reasons for disagreement are availability, validity, disclosure and analysis of information. The evaluation of the issues and potential solutions presented here indicates that certainty of outcome in delay disputes can be improved by (i) the exploitation of technology and contractual delay protocols and/or (ii) changing the ownership of relevant information.

## LIMITATIONS AND FURTHER RESEARCH

There are certain limitations to drawing conclusions from these findings. Although significant the sample is relatively small and requires further cases. It should also be noted that even though the sources are reliable, and the standard industry terminology was used to summarise the primary issues, it is recommended that further research is carried out, including investigation of the relative importance of each factor, creation and testing of a requirements model and scenario analysis to determine the applicability of such a model. This research is currently underway, and it is intended to present these results in future published work.

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# PUBLIC PROCUREMENT OF ENGINEERING SERVICES: GOVERNANCE AND CONTROL MECHANISMS

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Prior research has emphasized the importance of the early phases in construction projects. However, procuring engineering services for early phases is considered complex due to the high uncertainties and the information asymmetry favouring the service provider. This study explores public procurement of engineering services in the Swedish infrastructure sector, focusing on governance and control mechanisms. The purpose is to investigate the choice of governance and control mechanisms in engineering contracts from two perspectives, the public client's and the service providers. The findings are based on interviews with managers from the Swedish Transport Administration as well as from different engineering consulting companies. Findings indicate that the respondents from both sides seem to describe other choices and combinations of reward system and performance evaluation, compared to previous studies. This could be explained by the fact that the engineering contracts are less formalized than construction contracts in Sweden. This study shows that there are situations when clients have an information advantage in relation to their service suppliers and in-depth knowledge of the tasks procured, which affects the development of procurement strategies.

Keywords: engineering services; governance mechanisms; public procurement

## INTRODUCTION

Architectural and engineering competences are considered essential, in order for the public sector to be able to build roads, facilities etc. to a high quality, (Sporrong and Kadefors, 2014). In spite of this, academic research on procurement of engineering services is scarce (Lines and Shalwani, 2019). Engineering services are considered complex (von Nordenflycht, 2010), in particular early phases of design, due to the highly iterative processes (Ballard, 2000). In addition, engineering services include knowledge-intensive and problem-solving tasks delivered by experts, indicating that clients typically face a strong asymmetry of information favouring the service provider (von Nordenflycht, 2010).

In the construction context, Transaction Cost Economics (TCE) has been widely applied in studying client-contractor relationships and procurement of contractors (e.g., Eriksson, 2010), whereas there is a lack of studies on procurement of engineering services applying a TCE perspective. According to TCE, opportunism and information asymmetry are key premises in the inter-organizational exchange, and

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it is argued that parties have to safeguard against that by applying legal contracts (Williamson, 1975) and appropriate control mechanisms (Ouchi, 1979). Hence, it is important to let the transaction characteristics tailor the procurement strategies and the control mechanisms (Eriksson, 2010).

Due to the scarcity of research on procurement of engineering services, there is arguably a lack of knowledge on how transaction characteristics affect the choice of governance and control mechanisms when procuring engineering services. Thus, this study explores public procurement of engineering services in the Swedish infrastructure sector, focusing on governance and control mechanisms. The purpose is to investigate the choice of governance and control mechanisms in engineering contracts from two perspectives, the public client's and the service providers.

## LITERATURE REVIEW

### Service Specification

Engineering services are usually of advisory and/or problem-solving nature (von Nordenflycht, 2010). The engineering consulting companies (ECC) providing these services are usually using non-standardized production processes, heavily relying on specific individuals to solve complex problems (ibid). In addition, the engineering process is typically iterative (Ballard, 2000), containing a lot of interactions with the client (van der Valk and Rozemeijer, 2009) making trust an important factor for the quality (Uusitalo *et al.,* 2021).

Therefore, procuring services can be perceived difficult in several ways. Wynstra *et al.,* (2018) argue that the uncertainty for the client is high, both in regard to specifications in the tender documents, but also when it comes to evaluation. In addition, it is considered difficult since the client might not have the knowledge needed to write specifications (van der Valk and Rozemeijer, 2009). Therefore, information asymmetry and in-depth knowledge of the tasks are argued being important aspects in both writing service specifications and evaluating the performance. In addition, complex tasks add to the information asymmetry between the parties (Anderson and Dekker, 2005).

### Governance and Control Mechanisms

Governance mechanisms refer to ways of influencing the exchange partner and to establish coordination as well as order in the relationship (Hennart, 1993), whereas control mechanisms show how to obtain it (Eriksson, 2006). The framework is based on three main governance mechanisms; price, authority and trust (Williamson, 1985), combined with three control mechanisms, output, process and social control (Ouchi, 1979) and the main focus is on the main factors of organizational control, namely, how to specify, reward and evaluate the performance (Eisenhardt, 1985).

The transaction characteristics should tailor the governance and control mechanisms (Eriksson, 2010). More specifically, the levels of asset specificity (resulting mainly from complexity and customization), uncertainty and frequency in the transaction are the main factors determining the governance mechanisms (Williamson, 1985), whereas knowledge of the transformation process and output measurability are the factors influencing the choice of control mechanisms (Ouchi, 1979). In the control of complex tasks, knowledge of the transformation process should refer to the client's in-depth technical knowledge of the tasks (Kirsch *et al.,* 2010).

*Price/Output control*
The governance mechanism price is suitable for standardized transactions and usually associated with market relationships and output control (Hennart, 1993). Output control is a formal control mechanism, where the client specifies "what" goals of the client the controlled party should accomplish (Tiwana, 2010). The service provider is typically rewarded for the output in a fixed price contract (Eriksson, 2006). Fixed price contracts are usually used for rather simple tasks and requires the client to clearly specify the output, making changes costly and potentially conflict filled (Bajari and Tadelis, 2001). In output control the service provider is evaluated through monitoring of the finished delivery (Hennart, 1993). In-depth knowledge of the tasks makes both specifying and evaluating more efficient for the client (Tiwana and Keil, 2007). Output control is suggested when output measurability is high (Kirsch, 1996), which is usually the case when asset specificity is low (Das and Teng, 2001).

*Authority/Process control*
The governance mechanism authority is related to process control (Hennart, 1993), which is another formal control mechanism, usually specifying "how" the controlled party can accomplish the goals of the client (Tiwana, 2010). The service provider is typically rewarded for the costs related to the time worked in a cost-plus contract (Eriksson, 2006). Cost-plus contracts are usually used for complex tasks and requires less precisely specifications from the client (compared to fixed price), making changes flexible (Bajari and Tadelis, 2001). In process control the service provider is evaluated through the client's monitoring of the ongoing performance (Eriksson, 2006). In the process control of complex tasks, the client needs to have in-depth knowledge of the specific tasks when specifying and evaluating (Kirsch, 1996). However, the in-depth knowledge could be seen as detrimental in the evaluation, since the client is more likely to impose detailed and inflexible control. In addition, it is difficult for a knowledgeable client not to use process control in the evaluation (Tiwana and Keil, 2007). Process control is suitable when the asset specificity is high (Das and Teng, 2001) and the client has in-depth knowledge of the tasks (Kirsch, 1996).

*Trust/Social control*
The governance mechanism trust is related to social control (Das and Teng, 2001). Whereas formal control relies on information, social control is an informal control mechanism relying on shared values between the contract parties (Tiwana, 2010). In addition, social control makes use of consensus problem solving approaches, striving towards common goals (Das and Teng, 2001). The service provider is typically rewarded for the costs occurred, combined with some kind of incentives. Typically, in a contract focusing on social control joint specifications are used, hence developed in collaboration between the parties (Eriksson, 2006). In social control, the service provider is evaluated based on the shared values of the parties and self-control (Das and Teng, 2001). When it is not possible to measure the results, due to high levels of asset specificity, and the buyer does not have in-depth knowledge of the tasks, social control is suitable (Das and Teng, 2001). In fact, in transactions of knowledge-intensive tasks social control might be the only control option, since the client lacks the knowledge needed to carry out formal control (Kirsch *et al.,* 2010).

*Construction context*
In the construction context, design-build (DB) contracts are an example of price/output control, design-bid-build (DBB) contracts are an example of authority (process control, whereas early contractor involvement (ECI) contracts are an example

of trust/social control. The risk and responsibilities between the parties are regulated in the specification and the reward system (Eriksson and Laan, 2007).

# METHOD

## Research Methodology and Empirical Context

We adopted an explorative as well as abductive qualitative approach. An abductive approach is suitable when the researcher aims to discover new concepts and refine existing theories (Dubois and Gadde, 2002). Within qualitative research, interviews are considered one of the main ways to collect data usually aiming for "rich account" since the interviews are loosely structured meetings (Alvesson, 2011).

The empirical context is the Swedish infrastructure sector in general, and the Swedish Transport Administration (STA) in particular. The STA is the governmental agency responsible for the long-term planning, also managing the construction and maintenance works on the road and railway infrastructure. This study focuses on the engineering service contracts of physical planning and design. The STA procure the entire physical planning and design process from ECCs, whereas the STA focuses on specifying and evaluating these contracts. These contracts are finished before the DB, DBB or ECI contract with a contractor is signed.

In Sweden, ECCs within the field of building and civil engineering plan and design buildings and infrastructure for both public and private clients. The annually turnover within this field has been growing almost each year since the early 1990s (Innovationsföretagen, 2019).

## Collection of Data

In order to gain a comprehensive and strategic view of the physical planning and design contracts, 14 managers from the client and different ECCs were selected for the interviews, see Table 1.

*Table 1: Interviews*

| Side | Organization | Type of interview | Name in the text |
|---|---|---|---|
| Client | Investments | Physical meeting | Client manager A |
| Client | Investments | Skype with video | Client manager B |
| Client | Major projects | Skype with video | Client manager C |
| Client | Investments | Skype with video | Client manager D |
| Client | Investments | Skype with video | Client manager E |
| Client | Purchasing and Logistics | Skype with video | Client manager F |
| Client | Major projects | Skype with video | Client manager G |
| Client | Purchasing and Logistics | Skype without video | Client manager H |
| ECC | Larger | Skype with video | Engineering manager I |
| ECC | Larger | Skype with video | Engineering manager J |
| ECC | Smaller | Skype without video | Engineering manager K |
| ECC | Larger | Skype with video | Engineering manager L |
| ECC | Larger | Skype with video | Engineering manager M |
| ECC | Smaller | Skype with video | Engineering manager N |

The managers from the STA are regional managers, unit managers and program managers that work in three different business areas: Major Projects, Investment, and Purchasing and Logistic. The managers from the ECCs were chosen to represent both those considered being Tier A (larger) and Tier B (smaller) suppliers to the STA.

These managers have titles such as division manager, business area manager and development manager. In regard to ethics, the respondents are all anonymous and the STA approved the final version of the paper.

All the interviews were semi-structured to enable engagement from both the researcher and the respondent and lasted for 45-90 minutes. The questions were based on the framework, thus included transaction characteristics, specification, reward system and performance evaluation. Due to Covid-19, most of the interviews were carried out on Skype. The interviews were all recorded, in consent with the respondents, and transcribed. In addition, notes were taken to capture reflections.

### Data Analysis

The transcribed interviews, including the notes, were attached to the different categories (price/output control, authority/process control and trust/social control) in the framework. After that, within these categories themes where formed based on the empirics, hence aspects emphasized by the respondents. The findings are presented under each of these themes (knowledge of the transformation process, transaction characteristics, specification and reward system, and performance evaluation) in the next section. The themes were analysed using the theoretical framework.

## FINDINGS

### Knowledge of the Transformation Process and Information Asymmetry

All the engineering managers perceive the STA as a professional and knowledgeable client. Engineering manager J says "one part of the professionalism is all the skilled [technical] specialists within the STA that are able to guide" during the contract. The engineering managers also argue that the STA is experienced in procuring and managing engineering service contracts. One of the engineering managers explains that with the STA they usually discuss the solutions and functions, whereas less knowledgeable clients focus more on costs. In addition, the engineering managers say that the tender documents (including the specifications) and the tendering procedures at the STA are more clear, well written and worked through, compared to other clients. This indicate that the STA knows what they want from the ECCs.

The client managers also view their internal project organizations as knowledgeable and informed about their projects, for example in relation to uncertainties, complexities and possible solutions as well as the consultants' transformation process. Usually, the client's internal project organization has been working with project preparations during several months, sometimes years, in order to write the specification and build project specific knowledge. This preparation work results in a situation where the STA "usually has an initial advantage" (Client manager C), in relation to the engineering consultant who just won the contract. The same manager says that some of the information cannot be written in the specification, since it is considered sensitive. Another client manager also reflects on the preparation work at the STA by saying: "in some cases we tend to do a bit too much ourselves, before we procure the consultants" (Client Manager B). The manager means that it limits the flexibility of the engineering consultants later on.

### Transaction characteristics

All respondents argue that the characteristics of physical planning contain more uncertainties compared to the design phase, since no one knows what to build and where. In the design phase the knowledge is more comprehensive, and the

uncertainties are reduced through the investigations that have been carried out. According to Client manager A physical planning is about “defining what you should do” whereas in design it is already “defined what should be done”.

**Specification and Reward System**

All respondents argue that cost-plus compensation (hourly prize per consultant) is the most suitable reward system in the physical planning contracts. That is due to the many uncertainties and the problem-solving characteristics of that phase. In addition, most of the respondents argue that in a fixed price contract the client needs to clearly describe the scope in the specifications, which is seldom possible in such an early phase. However, some of the client managers argue that cost-plus contracts also come with disadvantages. They are a lot more demanding to evaluate, in terms of resources and time needed, compared to a fixed-price contract.

Even though all the respondents argue that fixed price is not suitable in the physical planning contracts, they also say that STA recently procured several contracts in that way. Some engineering managers are frustrated about this, arguing that a contract consisting of a lot of uncertainties and less calculable specifications rewarded on fixed price is inappropriate, since a lot of risks are transferred to them. As a consequence, some argue that in a fixed price contract they will make as little effort as possible, which also often lead to conflicts. "Often you shift the focus from finding the best technical solution, to argue about money" (Engineering manager F).

Respondents from both parties claim that it is possible to use fixed price in the design phase, since the uncertainties have been reduced and the scope has become clearer, thus making precise specifications possible. Some also mention the possibility of a contract including both phases but divided into two stages, where the first stage is compensated on cost-plus, and the second stage is a fixed price contract including incentives. According to the respondents, the most important factors when choosing reward system are the client´s ability to write clear and calculable specifications.

Several of the respondents argue that in the period right after the contract is signed, it is of great importance to aim for consensus between the parties, in regard to the specifications and the expectations on the performance. Client manager C says that it is difficult when the specifications contain a lot of "gaps" so that "the engineering consultants need to make interpretations and then we have another interpretation", which often lead to conflicts. Therefore, Client manager G stresses that it is important for the parties to get the same view of the contract "what's included and what isn't?"

**Performance Evaluation**

There are several respondents from both parties saying that the project organization at the STA in general and the technical specialists at the STA in particular, have difficulties in providing the engineering consultants enough flexibility to work on holistic solutions. Instead, the technical specialists often want to get involved and decide upon a specific solution, within their field of knowledge. As a consequence, one of the engineering managers explains that they are getting different - sometimes also contradictory - input from different technical specialists at the STA, making the consultant organization “going back and forth, based on opinions” (Engineering manager E). The same respondent further explains that they should deliver a solution on an overall level, but often they spend time in detailed discussions with different technical specialists at the STA. Client manager G agrees by saying that "our technical specialists are usually very good, and they would like to tell how it should be

done". However, there are also engineering managers that find it positive that the STA is having knowledge, experience and are able to guide the engineering consultants.

Respondents from both sides argue that the expectations and specifications on what the ECCs are supposed to deliver, in terms of quality, level of flexibility and level of detail, are sometimes unclear. One of the client managers says that sometimes the STA even changes or finishes the delivered documents, when they are perceived inaccurate, since the client thinks it is faster than letting the ECC do it themselves.

## DISCUSSION

In regard to information asymmetry, there are several factors indicating that the expected imbalance, favouring the service provider (van der Valk and Rozemeijer, 2009), is not describing the current situation in the relationship between the STA and the ECCs. On the contrary, the STA seems to have an information advantage initially in the contracts. This means that information asymmetry being one of the basic premises of the TCE (Williamson, 1975), does not fully apply to these contracts, especially not in the specification stage and initially after the contract is signed. Since information asymmetry is connected to uncertainty (Greenwood *et al.,* 2005) and complexity (Anderson and Dekker, 2005), it can be argued that a reversed information asymmetry contributes to lower asset specificity from the perspective of the client. Even though procurement of engineering services is considered complex and uncertain (Greenwood *et al.,* 2005), an informed client is able to utilize the entire toolbox, choosing between all three governance mechanisms. In addition, since the formal control mechanisms rely on specification by the client (Bajari and Tadelis, 2001), instead of joint specification (Eriksson, 2006), an informed client is able to base their choice of governance mechanisms on the transaction characteristics, not being forced due to lack of information.

In general, the STA is seen as knowledgeable in writing the specifications and in the performance evaluation, which indicates that the STA is having in-depth knowledge of the tasks (Kirsch *et al.,* 2010). Even though engineering services are considered knowledge-intensive and complex (von Nordenflycht, 2010) and many clients are unable to use neither process nor output control (Kirsch *et al.,* 2010), a client that has in-depth knowledge is able to utilize the entire toolbox, choosing between all three control mechanisms. Hence, the ability of the client is possibly influencing the in-depth knowledge, not just the characteristics of the service procured.

In accordance with Kirsch (1996) and Das and Teng (2001), since the STA has knowledge of the transformation process and the asset specificity is considered high, they should rely more on authority/process control, rather than price/output control when specifying, rewarding and evaluating the physical planning contracts. Despite that, the STA seems to combine performance evaluation using process control with rewarding on fixed price (output control), which is not in accordance with previous studies (e.g., Bajari and Tadelis, 2001; Eriksson, 2006).

In the physical planning phase in Sweden, the asset specificity in terms of complexity and uncertainty is considered high, thus the service is difficult to specify. In accordance with Bajari and Tadelis (2001), the respondents from both parties argue for cost-plus contracts being most suitable, thus emphasising authority rather than price governance (Eriksson, 2006). Despite that, several of the respondents express that the STA use fixed-price contracts quite frequently. This might be explained by

the fact that cost-plus contracts are perceived more demanding in the performance evaluation, compared to fixed-price contracts. The information advantage and the in-depth knowledge might also influence the STA to underestimate the uncertainties and complexities, thus they favour price instead of authority governance.

According to previous studies, fixed-price contracts should be combined with evaluation of the output, whereas cost-plus contracts should be combined with ongoing evaluation (Eriksson, 2006). Despite that, ongoing evaluation (process control) is perceived to be frequently used by the STA in these contracts, regardless of reward system. In accordance with Tiwana and Keil (2007), this might be explained by the fact that the STA has in-depth knowledge of the tasks, and therefore it is difficult not to control the process of the engineering consultants in detail.

This study also indicates that a client that is able to utilize the entire toolbox of governance and control mechanisms, thus is not forced to use social control, face a challenge of specification. Since price/output control and authority/process control rely on specifications by the client (Bajari and Tadelis, 2001), instead of joint specifications (Eriksson, 2006), the client has to transfer the information of the complex service to the service provider, via the specifications. This challenge was stressed by some of the respondents by saying that besides the uncertainties related to the transaction characteristics, the specifications and the formulations also add on to the uncertainties for both parties, since it is possible to make different interpretations. In addition, the standard conditions of contract for construction works and engineering services in Sweden differs, meaning that the specifications, reward system and performance evaluation could be considered more clearly defined in the first mentioned. Therefore, it can be expected that there is no straightforward way of describing and combining specifications, reward system and performance evaluation when procuring engineering services. This might be the reason why the respondents emphasize the importance of clear and calculable specifications. For example, traditionally in a DB contract the client uses functional specifications, fixed price and evaluates the functional outcome, whereas in a DBB contract the client uses detailed specifications, reimbursement payments and ongoing evaluation using a bill of quantities (Eriksson, 2006). However, in an engineering service contract, interaction and an ongoing coordination process between the client and the service provider are considered a key factor (van der Valk and Rozemeijer, 2009). This indicates that since a complex service is challenging to specify, trust seem to be of great importance in these contracts, regardless of governance and control mechanisms chosen.

## CONCLUSIONS

This study shows that there are situations when clients have an initial information advantage in relation to their service providers, which affects the development of procurement strategies, in terms of how to specify, reward and evaluate. When a client has an information advantage initially and in-depth knowledge of what is procured, it is equipped with more tools in the governance and control mechanism toolbox, even though the client procures complex services such as engineering services. Hence, in addition to let the transaction characteristics influence the procurement strategies, information asymmetry and in-depth knowledge are factors potentially influencing the governance and control mechanisms chosen by the client.

In addition, we conclude that one reason behind choosing different combinations of reward system and performance evaluations, could be connected to the fact that the engineering service contracts in Sweden are less formalized than construction

contracts, leaving a high degree of flexibility to the client. This flexibility increases the potential gaps in the specifications, and thus the need for interpretation. Therefore, the uncertainties for both parties are rather high, which potentially lead to conflicts during the contract period. Therefore, regardless of the governance and control mechanisms chosen in the engineering service contracts, an initial phase of consensus decision making is emphasised to compensate for the lack of formalization, thus there is a great focus on trust in these transactions.

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# Offsite Constuction

# ANALYSIS OF SKILL SHORTAGES IN PREFABRICATED RESIDENTIAL CONSTRUCTION: A CASE FOR NEW ZEALAND

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In New Zealand, the demand for affordable housing and concerns about the performance of residential buildings provide a strong case for using prefabrication technologies. However, the New Zealand construction sector suffers from severe labour and skill shortages, preventing widespread adoption. The overarching aim of this study is to identify the major constraints affecting the uptake of prefabrication in New Zealand residential construction, and the barriers to meeting essential skill requirements for prefabrication. To achieve this, an online questionnaire was administered to construction stakeholders within the residential construction sector; this semi-structured survey contained closed- and open-ended questions. It found four major barriers to prefabrication uptake: a lack of research and development; a scarcity of skilled workers; a lack of previous work experience; and complexity and fragmentation in New Zealand's prefabricated construction supply chain. The industry must work on training and recruiting workers with skills relevant to the design, manufacture and installation of prefabricated elements, to promote prefabrication in New Zealand residential construction.

Keywords: New Zealand; prefabrication; residential construction; skills shortage

## INTRODUCTION

In recent years, the global construction industry has suffered from continuous increases in wages and materials costs (Statistic Sweden, 2019; StatsNZ, 2019). Industry experts are beginning to explore new technologies to enhance construction productivity and efficiency ratios, to reduce building timeframes and costs, and to improve availability and comfort. One prominent technique is prefabrication (Leu and Hwang, 2002). Prefabricated buildings have tangible benefits in terms of time, quality, and cost. Mitchel (2017) discovered that prefabrication can decrease the cost of building by up to 15%, increase productivity by 10% and reduce construction time by up to 60%. Prefabrication also enhances the health and safety of construction workers and improves construction quality (Li *et al.,* 2011). Although prefabrication

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offers a wide variety of advantages, the industry remains unconvinced by the new technology.

The United States of America (USA) was one of the first countries to adopt prefabrication (Shahzad, 2016), considering it the best innovative solution for its construction industry (Azman, Ahamad, Majid and Hanafi, 2010). Organisations like Modular Building Institutes (MBI) actively promote prefabrication in the USA through publications and research. MBI believe by promoting prefabrication, the construction industry can increase productivity, deliver better quality outputs and lower project costs. However, its industry still faces issues such as costly labour and materials, poor quality and an overuse of resources (Shahzad, 2016). MBI (2010) found a lack of skilled labour related to prefabrication. Similarly, the UK Commission for Employment and Skills says its prefabrication sector suffers from skills shortages that prevent its development (McGinnis, 2015). In recent years, the UK market for prefabricated construction has shown positive signs of becoming more attractive for developers and owners (PBC today, 2020). In Australia, prefabricated construction was among eight visions identified by Hampson and Brandon (2004) to increase the construction industry's contribution to the national economy by 2020. Navaratnam *et al.,* (2019) believe prefabrication could increase its market share in Australia; but, as in other countries, there are barriers limiting its potential. Most relate to a lack of knowledge about tools and the flexibility of prefabrication systems, as well as limited public information about the sustainability aspects of prefabrication.

There is low use of innovative technologies in New Zealand construction as practitioners prefer traditional construction methods (Clark-Reynolds and Pelosi, 2016). The industry has been characterised by a lack of productivity due to a skills shortage limiting the uptake of new technologies. To promote productivity, prefabrication technology was introduced to New Zealand in the 19th century. Prefabrication was considered cheap, fragile and temporary (BRANZ, 2013). In recent years, organisations such as PrefabNZ have introduced international standards to improve performance, but the use of prefabrication is still relatively low. In residential construction, prefabrication has not been sufficiently introduced or examined as a solution for increasing housing supply (Samarasinghe, 2021). This study aims to increase the uptake of prefabrication technology, particularly in the residential construction sector in New Zealand. It attempts to encourage the upskilling of industry practitioners around prefabrication as a solution for productivity improvement and, eventually, the nationwide housing affordability crisis. It explores barriers to prefabrication, and the essential skills required for its promotion. It hopes to enhance understanding of prefabrication as a way to mitigate, or even eliminate, the country's housing crisis.

## LITERATURE REVIEW

The New Zealand construction industry has grown steadily in recent years, contributing about $15 billion to Gross Domestic Product (GDP) in 2019 (Statista, 2020). In the same year, there were 37,538 consented dwellings -14% higher than in 2018 (StatsNZ, 2020). The value of newly approved dwellings in 2019 was about $14 billion, an increase of 14% on the previous year (Ninness, 2020). This remarkable upsurge in the number and value of approved residences reflects the growth in residential construction. With the pressing need for new housing construction, the New Zealand Government has promised to quickly build thousands of affordable houses, despite the pressure of existing skills shortages in the construction sector.

Similarly, the UK Government also intends to build 300,000 dwellings by the year 2025. Both governments rely on a new generation of prefabricated homes to fulfil their promises, however, they lack skilled workers to design, manufacture and install prefabricated building components. Mirus *et al.,* (2018) emphasise that although prefabrication has potential for success in New Zealand, it requires government legislation, financial support, a new educational approach for the workforce and mitigation of current risks in the prefabricated construction supply chain.

*Prefabrication in New Zealand construction*

Prefabrication is a construction technique whereby building components, and even entire buildings, are manufactured in controlled manufacturing plants (Smith, 2010). In New Zealand, about 17 % of commercial and residential construction is built using prefabricated parts (Construction Industry Council, 2012). Past research has examined the potential of better applications prefabrication in the New Zealand construction sector (Samarasinghe and Wood, 2021; Shahzad, 2016; Page and Norman, 2014; Scofield, Wilkinson, Potangaroa and Rotimi, 2009). Page and Norman (2014) found prefabrication is mainly used in wall and roof framing in New Zealand, and worth about $2.95 billion per year. Using prefabrication for other building components or whole buildings would increase that value to $5 billion per year (Shahzad, 2016). The New Zealand construction industry is characterised by low productivity and a reluctance to take up new technologies (Samarasinghe, 2020), yet sustainability and efficiency in construction are main concerns for the Government (Scofield *et al.,* 2009). A study conducted by Chen and Samarasinghe (2020) found construction contractors still show a strong resistance to adopting prefabrication.

According to Hunt (2016), an increase of 1% in construction labour productivity could lead to a growth of $139 million in GDP. Prefabrication offers higher labour productivity as it involves minimum on-site work. In the long term, limited natural resources, population growth and environmental threats could push the construction industry towards prefabrication. This could decrease waste by 40%, reduce carbon dioxide emissions by 35% and cut energy consumption by 55% (Moradibistouni and Gjerde, 2017). Although prefabrication has benefited significantly from cutting-edge technologies such as Computer Aided Designs (CAD) and Computer Aided Manufacturing (CAM), its adoption in New Zealand is still below target (Burgess *et al.,* 2013).

The application of prefabrication in New Zealand goes back to the early 19th century where prefabricated panel housing components imported from the United Kingdom and the United States were installed in houses (Scofield *et al.,* 2009). Currently, the New Zealand prefabrication industry comprises of companies that manufacture building components, panels, pods and complete buildings. A study conducted by Prefab (2018) reported that prefabrication is mainly used in manufacturing concrete products, prefabricated wooden buildings and prefabricated metal buildings. A healthy uptake requires an understanding of industry concepts and technologies, a cooperative approach between supply chain stakeholders and full support from government agencies (Samarasinghe and Wood, 2021). Better connections with potential clients and more accessible technical information could improve prefabrication acceptance (PrefabNZ, 2014).

*Skills shortages in the prefabricated construction industry*

BRANZ (2014) states a lack of adequately skilled people has negatively affected prefabrication uptake. Recent studies by Masood *et al.,* (2021) and Sooriyamudalige

*et al.,* (2020) highlighted skill shortages in off-site products, such as modular construction and panelised construction. Therefore, even if demand for prefabricated components is high, production efficiency remains low. The prefabrication industry needs upgraded technical skills to support the huge demand (BRANZ, 2014). Bell (2011) pointed out that research and design are vital in prefabrication. Chen and Samarasinghe (2020) acknowledged that most training programmes provided by construction firms relate to traditional construction, with poor adoption of new techniques. They noted that emerging construction technologies require talented people to operate them; a shortage of such people makes contractors unenthusiastic about embracing prefabrication.

Skill shortages in traditional construction have been analysed in depth by past researchers (Ho, 2016; McGrath-Champ, Rosewarne and Rittau, 2011; Lobo and Wilkinson, 2008; McGuinness and Bennett, 2006; Mackenzie, Kilpatrick and Akintoye, 2000). The tangible advantages of shifting towards prefabricated residential construction have been debated both globally and locally. However, the skills and knowledge required for transition in New Zealand have not been addressed. A prefabricated construction transformation requires transferring on-site work to manufacturing factories, involving significant stakeholder relationship management. The importance of interpersonal relationship management skills has been stated by Ginigaddara, Perera, Feng and Rahnamayiezekavat (2019). The prefabricated construction industry is an emerging one in New Zealand, and the skills required are constantly changing; therefore, education providers find it difficult to provide systematic prefabrication training. As the industry expands, young practitioners with a higher acceptance of digitisation will be better suited to developing new skills related to prefabrication (Ginigaddara, Perera, Feng and Rahnamayiezekavat, 2019).

## DATA COLLECTION AND ANALYSIS

The study collected both secondary and primary data in the context of residential construction in New Zealand. Secondary data were collected through an intensive literature review of journals, research articles, reports and official websites. This exposed several concepts, such as technology acceptance, constraints, lack of skills in the supply chain and suggestions for possible future uptake of prefabrication. Primary data were collected through an online survey (semi-structured) using Qualtrics. An online survey seems to be an efficient way of gathering a considerable amount of data, with the minimum human efforts and mistakes (Regmi *et al.,* 2016). Ethics approval was granted by the Ethics Committee of the Auckland University of Technology before primary data collection began, which was in line with (Mertens, 2018).

The pilot survey was administered to multiple construction industry practitioners. Pilot study was conducted as a means of justifying the reliability and validity of the research. In addition, it gives the researchers an indication of the probable outcomes of their studies (Van Teijlingen *et al.,* 2001). While 20 questionnaires were provided, only 14 were returned. The requirement of having at least 12 participants in a pilot survey is fulfilled in this study (Moore *et al.,* 2011). The survey (n=14) was completed by prefabricated product manufacturers, suppliers, engineers, architects, head-contractors and sub-contractors practising residential construction in New Zealand. The online survey had five key sections, including demographic information, skill shortages in prefabrication, barriers to the use of off-site technology and possible measures for increasing prefabrication use. Other topics within the questionnaire fall outside the scope of the current paper. Response options were

provided on a Likert scale of 1 to 5, where 1 represented strongly disagree and 5 represented strongly agree. The mean score of each response was generated through descriptive statistical analysis in Qualtrics. Responses with mean values of 2.5 and above were considered.

## RESULTS AND DISCUSSION

*Demographic data*

Survey participants indicated their age, years of experience in the construction industry, business type, highest qualification, location and the type of prefabrication projects they had worked in. Participant profiles were generated from this demographic data. The survey results reflected feedback from engineers (50%), consultants (22%), architects (7%) and contractors (7%), as well as professionals (14%) representing organisations like Suppliers, New Zealand Institute of Architects, Association of Consulting Engineers New Zealand, New Zealand Institute of Quantity Surveyors, New Zealand Institute of Building and PrefabNZ. Most participants (43%) had 11-15 years' experience in the industry; 29% had 6-10 years' experience; 14% had over 25 years' experience; and 14% between 16-20 years.

*Major barriers limiting the use of prefabrication technology*

Participants were presented with four main barriers identified from literature and indicated their agreement on a five-point scale (5 being strongly agree and 1 being strongly disagree). These barriers are shown in Table 1.

*Table 1: Descriptive Statistics - major constraints impacting prefabrication uptake*

| Rank | Frequency (N) | Mean (M) | Standard deviation (S) |
|---|---|---|---|
| Lack of research and development (R&D) | 14 | 4.43 | 1.20 |
| Lack of prefabrication-related skills in New Zealand | 14 | 4.07 | 1.06 |
| Lack of previous experience with prefabrication technologies | 14 | 3.79 | 0.97 |
| The complexity of the prefabricated construction supply chain | 14 | 3.29 | 0.86 |

The most statistically significant barrier was a lack of research and development (N=14, M=4.43, S=1.20), an area identified by Bell (2011) as a key factor for enhancing the prefabrication construction method. The second constraint related to a lack of specific skills in prefabrication (N=14, M=4.07, S=1.06). This is compatible with a study by Gibson (2019), that indicated skills shortages in the prefabricated construction supply chain are among the most critical factors for implementation. The third barrier was a lack of experience with prefabrication technologies (N=14, M=3.79, S=0.97); participants noted this lack of accumulated knowledge has a notable effect on the sector, preventing greater use of prefabrication. The final constraint was the complexity and fragmented nature of the prefabricated construction supply chain (N=14, M=3.29, S=0.86). Similarly, Doran and Giannakis (2011) stated that better integration is required in the supply chain to compete with traditional on-site methods.

*Skills issues in prefabrication*

This section sought to understand skill issues in prefabrication supply chain. The study found four statistically significant skills issues affecting prefabrication in New Zealand residential construction. Table 2 displays these.

The most statistically significant issue was recruiting prefabrication-specific skilled workers (N=14, M=4.00, S=1.04). Recruiting skilled workers is considerably difficult, particularly in prefabrication. The next statistically significant issue was

recruiting labour with multiple skills (N=14, M=3.79, S=0.97). Laubier *et al.,* (2019) discussed difficulties associated with sourcing labour from overseas as a solution for prefabrication skills shortages. In contrast, about half of the research participants agreed that recruiting overseas workers (N=14, M=3.21, S=0.850) could help overcome the residential construction skill shortage.

*Table 2: Descriptive Statistics - skills issues in prefabricated construction*

| Rank | Frequency (N) | Mean (M) | Standard deviation (S) |
|---|---|---|---|
| Recruiting prefabrication-specific skilled workers | 14 | 4.00 | 1.04 |
| Recruiting labour with multiple skills | 14 | 3.79 | 0.97 |
| Recruiting overseas labour | 14 | 3.21 | 0.85 |
| The adequacy of training placements in the industry | 14 | 2.29 | 0.95 |

Participants were asked about the adequacy of industry investment in training permanent staff to acquire new skills. Most responses were between strongly disagree and disagree; therefore, the adequacy of training placements in the industry (N=14, M=2.29, S=0.95) is unsatisfactory. As a solution, Professor Ngo (as cited in Climo, 2018) suggests workers from other fields train to join the construction industry, to alleviate the skill shortage.

*Measures to increase the prefabrication uptake*

In terms of ways to increase the uptake of prefabrication, the study found four possible measures (see Table 3) to boost prefabrication in residential construction. Participants delivered feedback on five possible methods.

*Table 3: Descriptive Statistics - measures to increase prefabrication uptake*

| Rank | Frequency (N) | Mean (M) | Standard deviation (S) |
|---|---|---|---|
| Use modern technologies to provide better upfront planning in the residential prefabrication sector | 14 | 4.50 | 1.23 |
| Maintain a high level of collaboration between the different industry stakeholders to benefit the prefabrication sector | 14 | 4.29 | 1.14 |
| Provide sufficient training placements to enhance industry acceptance of prefabrication | 14 | 4.00 | 1.04 |
| Implement BIM and lifecycle assessment (LCA) to positively impact on the prefabrication sector | 14 | 4.00 | 1.04 |

The result with the highest statistical significance (N=14, M=4.50, S=1.23) showed most participants strongly believed the prefabrication industry would benefit from integrating modern, cutting-edge technologies in planning and workflow. The second-highest measure (N=14, M=4.29, S=1.14) revealed participants felt a higher level of collaboration between industry stakeholders would benefit the prefabrication sector and soften reluctance to change. The third measure (N=14, M=4.00, S=1.04) was adequate training placement. Providing sufficient prefabrication training reduces rework due to human error; the cost of rectifying defects is estimated at 6% of the total cost of construction (Johnsson and Meiling, 2009). The same outcome was received (N=14, M=4.00, S=1.04) for the need to implement BIM and LCA to increase prefabrication uptake.

## CONCLUSIONS

A global surge in population and housing demand has created skill shortages in the residential construction sector, encouraging researchers to investigate skill shortage issues and potential solutions. This study aimed to identify the main constraints affecting the uptake of prefabrication in New Zealand residential construction, and to explore issues around the essential skills required to promote prefabrication. It also sought to determine measures to increase prefabrication uptake. The study found four major barriers: a lack of research and development in prefabrication; a lack of prefabrication-specific skills in New Zealand; construction practitioners' lack of previous experience in prefabrication; and the complexity and fragmented nature of the prefabricated construction supply chain.

Other findings showed the industry must recruit workers with skills specific to the design, manufacture and installation of prefabricated elements. These skills are crucial, allowing workers to actively move between off-site and on-site construction environments. Upskilling within the industry would make prefabrication more attractive for those reluctant to participate. Modern technologies allow for better upfront planning in residential prefabrication; similarly, BIM and LCA are important for positive change in the prefabrication sector. It is recommended that industry stakeholders work together to increase the awareness of prefabrication benefits among traditional construction practitioners. Key stakeholders, including the Government, must also provide sufficient training placements to enhance industry acceptance of prefabrication. This research is limited by the number of study participants; nevertheless, it will assist future studies analysing aspects of prefabricated residential construction.

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# DYNAMIC SUPPLY CHAIN VULNERABILITY ANALYSIS OF HONG KONG-ZHUHAI-MACAO BRIDGE CONSTRUCTION: A TOPIC MODELLING APPROACH

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The Hong Kong-Zhuhai-Macao Bridge (HZMB) was a challenging milestone construction project that boosted the Hong Kong construction industry participants to new heights of recognition. While industry-boosting long-term benefits arose from knowledge gained in managing specialist prefabrication processes and complex supply chains (SCs), these advances also necessarily imposed challenges, rendering the project highly vulnerable to disruptions. Therefore, higher resilience was essential to withstand higher Supply Chain Vulnerabilities (SCV) through enhanced capabilities, for which identifying dynamic SCV becomes critical. To address this, the study employed the Topic Over Time modelling approach to detect critical SCV using 1,748 unstructured official documents on the HZMB from 2003 to 2018 (project design to handover). The popularity trend analysis that was thereby conducted, enabled identifying the six most critical vulnerabilities and categorizing them among each project phase. Finally, an ex-post vulnerability evaluation map was developed by considering the vulnerabilities' popularity trend and their relevance towards the project and SC phases. Using these findings, industry practitioners could improve their ex-ante decision-making, targeting value-enhanced-resilient SCs in future prefabricated infrastructure development projects. Further, the text-mining research approach unveils an effective mechanism for researchers to extract dynamic empirical clues from a large unstructured set of documents in construction SCs.

Keywords: supply chain; vulnerabilities; prefabricated; resilience; Hong Kong

## INTRODUCTION

The Hong Kong-Zhuhai-Macao Bridge (HZMB) is the longest bridge-cum-tunnel sea crossing in the world (55km) and a milestone cross-regional major transportation infrastructure project. It was constructed recently and is now in operation. This mega-project was a critical part of China's 13th Five-Year Plan, aiming to promote the economic development of the entire Pearl River Delta by developing an economic hub (Li, 2019). This massive, advanced infrastructure development boosted the Hong Kong (HK) construction industry to new heights of recognition, including an award from the UK Institution of Civil Engineers for its achievements in project

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management and contribution to enhancing regional transportation networks. The HZMB is located at the Pearl River entrance, crosses the Chinese Lingding Bay, and connects three metropolises: Hong Kong, Zhuhai, and Macao. The design and construction of the HZMB included three navigable bridges, one immersed tunnel and two artificial islands (Hu *et al.,* 2015).

However, this project faced more serious challenges than previously encountered due to the vagaries of the weather and the marine environment at the construction site (Hu *et al.,* 2015). Hence, towing and installing activities became more difficult. The other challenging tasks included preventing serious leakages due to excessive and uneven settlement of cross-joints and avoiding settlements along the tunnel alignment due to discontinuous geotechnical conditions (Hu *et al.,* 2015). The bad weather condition around Lingding Bay itself caused serious disruptions (Zeng *et al.,* 2018). The environmental authorities kept close oversight of this HZMB construction, as the site was in a White Dolphin Protection Zone (Li, 2019). The site was also on a busy traffic shipping route at the Pearl River mouth with 4,000 vessels shuttling back and forth daily (Ming, 2017). Therefore, it had to allow for and not delay nor disrupt heavy traffic during any on-site construction processes.

At the same time, the project's quality requirements and specifications were very high (Zeng *et al.,* 2018). For instance, the targeted service life of the HZMB was 120 years; hence had higher expectations than most common infrastructure development projects in China (Zeng *et al.,* 2018). Reducing on-site works through prefabricated construction methods helped in complying with these requirements and withstanding project environment-specific disruptions. These included prefabricated piers, pile caps, girders, steel box, and immersed tube tunnels (Zeng *et al.,* 2018; Zhou *et al.,* 2018) produced in factories and delivered for on-site assembly through maritime routes. With this arrangement, all the main tunnel elements were prefabricated under standardised management systems. Hence, labour, material and time on site were significantly reduced, and greater efficiency, safety and quality were achieved (Lu, 2020). For instance, it required 210 days to finish the two artificial islands, which was two years faster than in traditional construction (Lu, 2020). However, these innovative construction methods, advanced technology and equipment injected a new set of challenges, adding further complexities and vulnerabilities to the project Supply Chain (SC) (Hu *et al.,* 2015). Around one billion RMB worth of immersed tubes were prefabricated, and their factory manufacture required three billion RMB worth of specific equipment (Ming, 2017). Further, the installation of these elements was a complicated and time-consuming task as the elements were very heavy, e.g., 420,000 tons of box girders (Lu, 2020), while the installation of those heavy elements was affected by the meteorological and hydrological conditions on site (Zhou *et al.,* 2018). Under these circumstances, the project overran its timeline, and the actual budget [RMB 127 billion] exceeded the allocation of RMB 72.7 billion (Li, 2019).

The foregoing challenges demanded closer attention to effective vulnerability management mechanisms (Li, 2019). Traditional risk management strategies were inadequate in withstanding the Supply Chain Vulnerabilities (SCV) as observed in this project. Indeed, such fragmented prefabricated SCs call for advanced risk management mechanisms to cope efficiently with project vulnerabilities (Ekanayake *et al.,* 2021). Deploying stronger and appropriate capability measures would have boosted resilience by more effective withstanding of SCV (Pettit *et al.,* 2013). Besides, more resilient practices would have boosted project performance by reducing time and cost-overruns. Proper identification of dynamics of SCV is the first step in

enhancing resilience, hence project performance by proper withstanding of the identified SCV (Ekanayake *et al.,* 2021). In the first study on resilience-enhancing practices in prefabricated construction SCs, Ekanayake *et al. (*2021) identified the critical SCV associated with prefabricated construction in HK through an expert opinion survey. Accordingly, the prefabricated SCs were significantly vulnerable towards extensive skilled labour requirement, outsourcing decision, transportation of prefabricated units, on-site safety, complex on-site logistics, and 'tolerance' based issues, affecting the overall quality and delivery. Further, Ekanayake *et al. (*2021) identified 26 critical SCV under five groupings of economic, technological, procedural, organisational, and production-based.

However, the outcomes of the above-cited study were not tested using a specific case study; hence the authors have suggested case study based real-time justifications for verifying the results (Ekanayake *et al.,* 2021). This HZMB case study-specific research addresses this need. This particular case was chosen considering because: (a) mega-infrastructure development projects contribute significantly to construction output in HK (Xue *et al.,* 2020); (b) prefabricated construction is increasingly prominent in HK infrastructure development projects (Lu, 2020); and (c) projects (such as HZMB) are significantly vulnerable to SC disruptions (Lu, 2020). The HZMB case study, therefore, addresses the identified lack of attention to critical resilient practices in prefabrication based-infrastructure development projects. Hence, the current research questions were developed to explore, (a) the critical SCV associated with HZMB construction, and (b) their dynamics (changing pattern/nature of the SCV throughout each construction phase), so as to provide a basis for initiating resilient practices.

As indicated, this previous study of Ekanayake *et al. (*2021) was based on the static analysis; hence it lacks the evidence to support the dynamics of SCV throughout the project phases. Further, survey and interview data are subjective and depend on respondents' quality (Yin, 2017). Using a large quantitative dataset of official documents on prefabricated projects would address this limitation by facilitating objective and convincing empirical data analysis (Xue *et al.,* 2020). However, the literature remains silent on using such large, unstructured quantitative datasets in the SCV analysis and/or even in prefabricated construction research, thereby suggesting an option of effective text-mining based empirical studies in SC resilience and the prefabricated construction research domains.

'Topic modelling' is a robust tool that detects the core commonalities among a pool of texts. It has received greater prominence under the text mining research approach over recent years (Xue *et al.,* 2020). Among other topic modelling techniques such as Latent Dirichlet Allocation (LDA), PLSA and probabilistic theory, Topic Over Time (TOT) modelling is considered to be a more effective technique (Xue *et al.,* 2020). TOT is the dynamic topic modelling technique that explores both the content of core concepts and the dynamic concept patterns associated with a large set of texts (Wang and McCallum, 2006). Therefore, TOT modelling was considered appropriate to analyse SCV using the project documents of this HZMB prefabricated infrastructure development project while mining the critical SCV and presenting their dynamics over time [over the project phases of planning, construction, and handover].

Under these circumstances, this study aimed to develop an ex-post SCV evaluation map by introducing TOT modelling as a novel method for SCV analysis, using a large set of unstructured project documents of the HZMB project. First, TOT modelling

was used to analyse the official project documents of the HZMB throughout the entire project duration. As a result, the critical SCV and their annual trend could be explored under each project stage of planning, construction and handover using the project timeline. Finally, the results were appropriately mapped with SC phases, and the ex-post SCV evaluation map was developed. It is proposed as an SCV management guide for project professionals. The forthcoming sections of this paper present the research methodology, results and ensuing discussions, practical research implications and the conclusions, including research limitations and suggested ways forward.

# RESEARCH METHODS

## Data Collection

The research flow of this study is presented in Fig 1. The relevant data for this study was collected from the Hong Kong Legislative Council's official website. This website is accessible to the public, while the data maintained by the government is highly reliable. Therefore, all the project documents related to HZMB were downloaded from this open-source library using the search terms "Hong Kong-Zhuhai-Macao Bridge" and "HZMB". This yielded 1748 official documents on the HZMB construction spanning between 2003 to 2018, under the planning, construction and handover phases of the project.

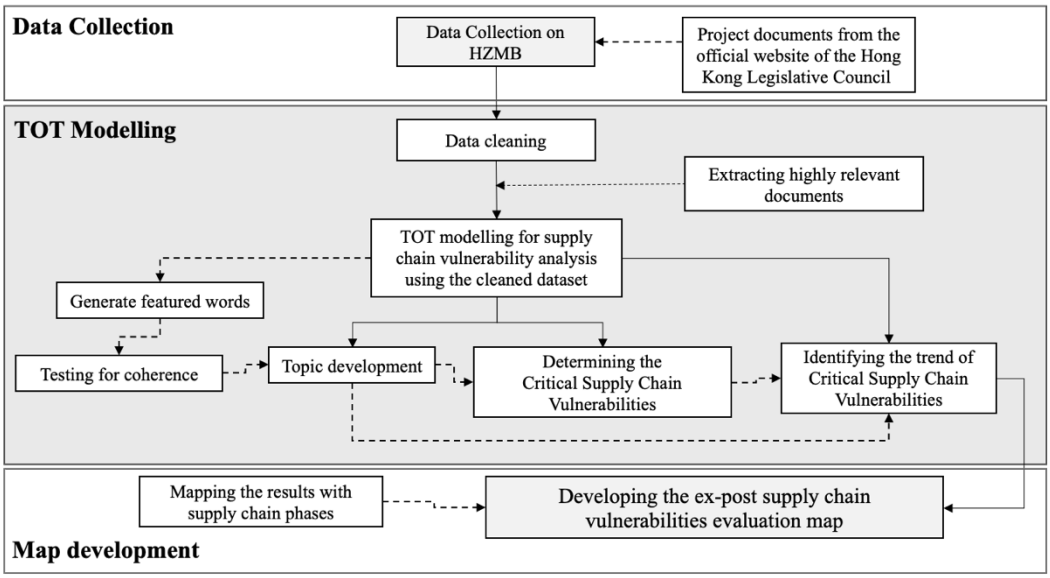


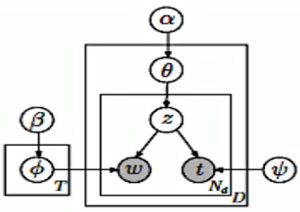

*Fig 1: Research flow of this study*

## TOT Modelling

The collected data set was then screened through a data cleaning process by extracting the contents from the raw data files using keywords related to SCV, prefabricated construction and the HZMB. During this cleaning process, the authors used the SCV terms extracted from Ekanayake *et al. (*2021) as they were verified for prefabricated construction in HK. This approach ensured screening and selecting the highly relevant texts for this study. Thereafter, TOT modelling was employed as described below.

TOT modelling is an advance over the traditional basic text mining technique of the Latent Dirichlet Allocation model (LDA) (Xue *et al.,* 2020). The TOT model not only captures the low-dimensional data structures but also detects the structure's changes over time (Wang and McCallum, 2006). Further, meaningful results would only be

generated by considering both word co-occurrences and the documents' timestamps (Wang and McCallum, 2006). Given these advances of TOT modelling over other text mining techniques, TOT models were considered effective in exploring texts and their distribution over timestamps associated with SCV analysis; hence, the decision was to use TOT modelling in this study. Fig 2 illustrates the TOT model used in Gibbs sampling for parameter estimation (Wang and McCallum, 2006), and also used in this current study. Accordingly, the cleaned data set of the HZMB project was then subjected to the mathematical modelling process [using the algorithm depicted in Fig 2] to generate the dynamic impact models (TOT graphs) of SCV. During this mathematical modelling process, timestamps were generated for all the word tokens, while all the word timestamps in a document were considered similar to the document's timestamp (Wang and McCallum, 2006). Further, fixed symmetric Dirichlet distributions of α = 50/T and β = 0.1 were used as the hyperparameters of α and β (Xue *et al.,* 2020) considering the simplicity of the model (Wang and McCallum, 2006). Data processing using the TF-IDF filtering was done before running the model to enhance the texts' quality while removing frequent but meaningless texts. Then, the model was run to generate the results.




| Symbol | Description |
|---|---|
| $T$ | Number of topics |
| $D$ | Number of documents |
| $V$ | Number of unique words |
| $N_d$ | Number of word tokens in document $d$ |
| $\theta_d$ | The multinomial distribution of topics specific to the document $d$ |
| $\phi_z$ | The multinomial distribution of words specific to the topic $z$ |
| $\psi_z$ | The beta distribution of time specific to topic $z$ |
| $Z_{di}$ | The topic associated with the $i$th token in the document $d$ |
| $\omega_{di}$ | The $i$th token in the document $d$ |
| $t_{di}$ | The timestamp associated with the $i$th token in the document $d$ |

*Fig 2: TOT model in Gibbs sampling [Source: (Wang and McCallum, 2006)]*

This modelling process led to six extracted topics, including 15 feature words with high relevant probabilities in each [Fig 3]. The extracted topics were then tested for their coherence following the method suggested by Xue *et al. (*2020). Therefore, the following formula was employed to calculate the coherence of each topic z considering the allied feature words list of $V^{(z)}$; where, D(V) represents the number of documents that feature word V appears; D(Vm, Vl) represents the number of documents that contain both feature words of Vm , Vl. Since the model passed the coherence test, then the dynamic impact models (TOT graphs) of SCV were visualised through the model, as shown in Fig 3. Finally, the ex-post SCV evaluation map was produced by mapping the impact of SCV with SC phases.

$$C(Z;V^{(z)}) = \sum_{m=2}^{15} \sum_{l=1}^{m-1} log \frac{D(v_m^{(z)}, v_l^{(z)}) + 1}{D(v_l^{(z)})}$$

# RESULTS AND DISCUSSION

## Critical SCV Associated with the HZMB Construction and Their Trend

Fig 3 presents the topics identified, feature words, topic concepts assigned by the authors, considering the common themes underlying the topics (Xue *et al.,* 2020) and their coherence values. Accordingly, the six-topic TOT model was regarded as the best valid model that interprets the project documents and evaluates critical SCV. Following the method suggested by Mimno *et al. (*2011), the TOT model was validated for its coherence and representativeness of the topics. In this TOT model, the topic concepts present the common underlying theme of each topic, which aligns with the associated feature words. Hence, the developed six topic concepts are cross-border related disruptions, disruptions due to outsourcing, communication issues,

safety concerns during transport and assembly, other disruptions associated with transportation, and economic and social disruptions. These topics were considered as the critical SCV faced during the HZMB construction. Comparing the study findings with the only comparable study: that of Ekanayake *et al. (*2021), even, in this project, cross-border, transportation, safety, communication and outsourcing issues were significant. However, the dynamics of their occurrence and the nature of the disruptions are not exactly the same as discussed below. Indeed, the HZMB project faced economic and social disruptions, indicating some differences from the more general data and findings in Ekanayake *et al. (*2021). This is because this project is a strategic cross-border mega infrastructure construction project beset by several environmental, financial, and social challenges.

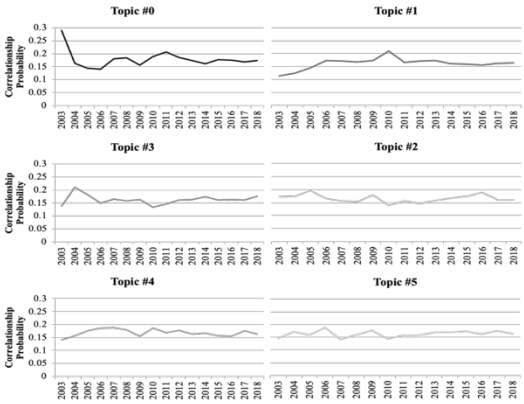
Therefore, drilling deeper here, Fig 3 depicts the dynamic impact of these critical SCV throughout the project duration of the HZMB from 2003 to 2018. In the HZMB project, the planning phase was between 2003-2009, the construction phase was between 2010-2017, and the project was handed over in 2018. Delving specifically into the dynamic impacts of identified SCV, the project had encountered all the critical SCV during the planning phase [Fig 3]. Prefabricated construction has generally proven more beneficial than conventional construction, given the many advantages of mass production of standardised components (Goodier *et al.,* 2019). However, in mega-infrastructure development projects such as the HZMB, manufacturing of the prefabricated components is expensive, and the production cycle is much longer (Zeng *et al.,* 2018). Economies of scale were, therefore, unavailable when using customised and non-standardised elements such as immersed tubes and steel box girders (Lu, 2020). Moreover, much time was spent on planning and design. However, the project was highly disrupted by outsourcing issues in the construction phase. The cross-border related issues were also high in the construction phase because the construction phase involved the transportation of prefabricated components across customs and immigration-controlled borders. When reaching the handover phase, transportation vulnerabilities, economic and social disruptions, and communication issues were reduced because of additional efforts to reap the imminent societal benefits from the project.

Cross-border related disruptions [#0] were considered high in the planning stage since many approvals were needed from all three jurisdictions at the beginning. Mainly, because of this, the project overran its timeline until 2010 (Hu *et al.,* 2018). Further, two temporary governmental committees from the central government and three local governments were established at various levels and locations to better manage such disruptions (Hu *et al.,* 2018). Several problems still arose from many policy conflicts and uncertainties, as each jurisdiction had its own specific policies (Li, 2019).

Disruptions due to outsourcing [#1] were severe vulnerabilities on the project, as many contractors and sub-contractors were involved and responsible for different construction activities. For instance, three major suppliers were selected for the manufacturing of steel box girders. However, they initially failed to comply with product quality, specifications and production capacity requirements (Zeng *et al.,* 2018). Given the high unit price of customised prefabricated units, the suppliers were reluctant to invest in capacity improvements. Therefore, the HZMB authority had to spend much time and money to improve the suppliers' production capacities and quality through technology support programs, training, and preferential price allocation (Zeng *et al.,* 2018). To avoid quality issues, the HZMB authority had to hire an independent consultant group for the 'first-article inspection' and 'full quality

inspection', which incurred more cost and time (Zeng *et al.,* 2018). Further, the outsourcing required special equipment and machinery both in manufacturing and assembly (Ming, 2017). Also, transportation arrangements arising from offsite construction demanded expensive methods by adding more vulnerabilities (Lu, 2020).

Communication problems [#2] were similarly observed throughout each phase due to the fragmented SC (Li, 2019). Multi-stakeholder involvement in such a complex mega infrastructure project required a collaborative platform for communication and timely decision making (Zhou *et al.,* 2018). The complicated environment around the HZMB site also triggered safety issues during transport and assembly [#3] (Li, 2019). Airport height restrictions, frequent typhoons, crisscross navigation, and high environmental standards were also significant (Yau and Lok-kei, 2018). Innovative prefabricated roof modules were used to tackle airport height restrictions. Pre-installed building services in these modules were also needed to reduce safety risks during the assembly at heights (Yau and Lok-kei, 2018). Single lifting and horizontal assembly of modules were chosen to improve safety (Lu, 2020), although it was time-consuming.




| Topic | Concept | Feature words | Average coherence |
|---|---|---|---|
| #0 | cross-border related disruptions | crossboundari; trade; border; implement; corridor; port; increas; oper; move; pollut; region; help; delay; opportun; commenc | -68.1530 |
| #1 | disruptions due to outsourcing | enhanc; pollut; commiss; employ; million; traffic;urg; polici; estim; demand; progress; truck; apart; complet; commenc | -69.5776 |
| #2 | communication issues | facilit; logist; amend; servic; link; progress; govern; option; current; territori; worker; close; develop; construct; comment | -80.3106 |
| #3 | safety concerns during transport and assembly | Safety; cargo; crossboundari; measur; environ; west; execut; road; manpow; lantau; expediti; passeng; congest; transport; employ | -77.5507 |
| #4 | transportation associated other disruptions | transport; exist; airport; tuenmun; believ; trade; promot; comment; time; implement; freight; meet; termin; cross; tourism | -71.2842 |
| #5 | economic and social disruptions | econom; western; local; plan; impact; labour; consult; assess; region; soon; method; enhanc; resid; district; improv | -70.3662 |

*Fig 3: TOT model of supply chain vulnerabilities*

Owing to unpredictable weather patterns, high and strong waves, component control during floating, towing and installing became more vulnerable (Hu *et al.,* 2015). On the other hand, disruptions due to marine traffic added considerable delays despite the requested special pontoons for transportation [#4] (Hu *et al.,* 2015). To prevent worker falling, mechanical collision and other safety accidents, advanced safety protection apparatuses and sensors were required (Zhou *et al.,* 2018). On-site assembly was carried out in an optimal time window by adjusting the production plans as the process was significantly affected by the environmental vulnerabilities (Zeng *et al.,* 2018). The long span [about 153m] and heavy [350t] element installation caused safety issues too (Lu, 2020). Besides, huge floating cranes with a lifting capacity of over 4000t were required for the assembly. Furthermore, prefabricated units and piers had to be divided into sections due to transportation difficulties (Lu, 2020); hence re-assembled again on-site.

In terms of economic and social disruptions [#5], the HZMB had to deal with significant direct and indirect influence from the community and the environmental authorities (Li, 2019). Besides, some political groups' involvement added uncertainties to the project implementation (Li, 2019). As the site was located at the core of the White Dolphin Protection Zone, relevant authorities raised significant queries and concerns during the initial project phases until the project passed the environmental impact assessment by using novel methods that caused less disturbance

to the environment (Li, 2019). On the other hand, economic disruptions were observed throughout the project due to the use of advanced technology, the requirements of skilled and trained labour, as needed for advanced and specific machinery, laser cutting tools, robots, specifically designed pontoons and assembly cranes, with longer production and assembly cycles than expected (Lu, 2020). These economic implications also led to budget overruns.

**The Ex-Post SCV Evaluation Map and Its Practical Implications**

The six topics and their popularity trend outputs generated from the TOT modelling were mapped with the prefabricated SC phases of manufacturing, logistics and on-site assembly to develop the ex-post SCV evaluation map [Fig 4]. The vulnerabilities were positioned under each construction phase [Fig 4], according to their dynamic impact levels in each phase, as derived from Fig 3. According to Fig 4, considering the vulnerability dynamics, the on-site assembly was the most vulnerable SC phase in the HZMB development. The logistics phase was also associated with significant vulnerabilities, as there were specific disturbances due to prefabricated elements' transportation. The outcomes depicted in the map provide a managerial guide to the industry professionals. The industry practitioners would benefit from prior knowledge of potential SCV and their dynamic impact on each project and SC phase, so they may prioritise how to address SCV better through appropriate capability development in each SC phase.

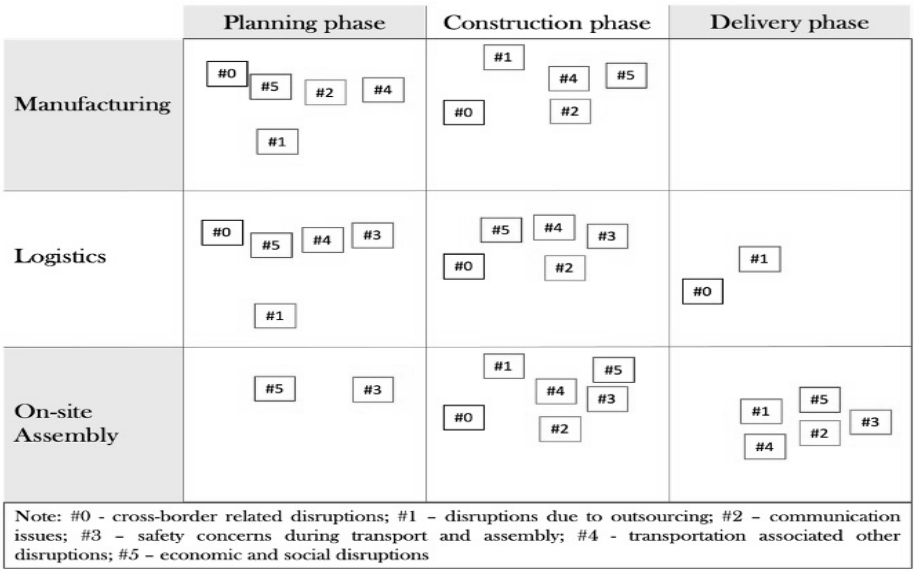



*Fig 4: The ex-post SCV evaluation map*

Although this is an ex-post mapping here, ex-ante decision making is also possible with this tool. The findings could then be applied in the early risk management stage of prefabricated infrastructure development projects. Significantly, the results are already validated through previously published case-study findings (Ming, 2017; Li, 2019; Lu, 2020), i.e., when comparing model predictions with actual outcomes. Therefore, this study's strengths include its representative case choice, reliable information source and a large set of text documents. Indeed, no two projects are ever the same, so as in all case studies, there will not be another identical HZMB project in future. But the findings could be necessarily generalised and adapted by comparing the prefabricated SC specific vulnerabilities in many similar mega-infrastructure development projects.

This is the first known study that developed an SCV evaluation map using the TOT modelling approach. Also, this is the first study that attempted to evaluate SCV associated with infrastructure projects targeting resilience. Hence, the novel research method employed, and the key research outcomes generated in this study significantly contribute to the construction and SC resilience research domains. The research methodology can be applied to other jurisdictions and projects based on the availability of a reliable, large set of project documents. This methodology could also be extended to explore the project-specific SC capabilities, which are the counter balancers of SCV and help develop essential capacities to achieve resilience.

## CONCLUSIONS

This study employed the TOT modelling approach to detect critical SCV faced by the mega-prefabricated infrastructure development project of HZMB. Six critical topics of vulnerabilities were identified and described as resulting from the popularity trend analysis of texts. A decision-making map was also developed by considering the popularity trend of vulnerabilities and their relevance to the project and SC phases to visualise the dynamic vulnerability impact on the HZMB construction. The identified critical SCV of HZMB included cross-border, safety, transportation, outsourcing, communication, economic and social disruptions. Deviating from the literature findings, economic and social disruptions were more critical and specific in the HZMB project, given its complexity and special challenges. Also, comparing with previous related studies, being the first study that explored the dynamic vulnerability impact in prefabricated construction SCs, this study revealed the dynamic impact of SCV during each project and SC phase.

Accordingly, the decision-making map was developed based on both theoretical knowledge and its practical feasibility and potential usefulness. Therefore, industry practitioners would benefit from such collective prior knowledge of SCV and their dynamic impact on each project phase, to prioritise addressing them adequately through appropriate capability development, targeting value-enhanced-resilient SCs in future prefabricated infrastructure development projects. The map was generated as an ex-post model; hence, it may be considered a necessary research limitation in the first attempt. However, this ex-post map could be adapted to suit any special contextual differences in future prefabricated mega-projects; and then help encourage and facilitate proactive decision-making in future ex-ante scenarios. Finally, and more significantly, the text-mining approach adopted in this study unveils and applies novel vulnerability analysis methods while pointing academia to an effective mechanism to extract empirical clues from a large unstructured set of documents in the construction domain in general. As a way forward in further research, the developed SCV evaluation map could be strengthened using several other case studies and/or more empirical data. Further, the map could be necessarily generalised for other project contexts following this robust topic modelling approach. Indeed, the TOT model could be further verified for its consistency with sentiment analysis in the text mining to derive more advanced research implications.

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# Planning, Productivity and Quality

# CREATING COLLABORATION: THE USE OF COLLABORATIVE SPACE IN LARGE-SCALE INFRASTRUCTURE DEVELOPMENT

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Collaborative project delivery models (CPDMs) have been introduced in the construction sector in order to renew and improve the productivity, quality and performance of the field. The procurement phase of utilising CPDM is well researched, but less is known about their implementation. The importance of a shared project space for collaboration and especially knowledge sharing is discussed often in literature, but there is less focus on the relevance of space for forming a collaborative network. A relevant question is the role of collaborative project space in large-scale infrastructure projects, a context where CPDM recently has gained popularity. This area is especially topical with the rise of distance work related to the COVID-19 pandemic, as the idea of a collaborative project space is based mainly on working in the same physical space. The research applies a project network lens and focuses on collaborative space consisting of physical, social and virtual space to study the implications of shared project space for network and tie formation in large-scale infrastructure projects. In order to investigate this matter, we studied a project utilising a CPDM and a collaborative space ("big room"). We found that participation and engagement in a shared space impacts network formation and collaboration between actors. Collaborative space in the form of physical, social and virtual spaces, facilitates a shared understanding and informal social ties and thus shapes the project network. The paper gives insight into the relevance of shared space to CPDM and project network literature. However, when one of these spaces becomes unavailable as in the case of COVID-19, this has implications for the project network and the development of social ties.

Keywords: collaborative; virtual space; infrastructure; project management

## INTRODUCTION

Collaborative project delivery models (CPDM) have recently been introduced in infrastructure construction in order to manage major projects involving multiple organisations and stakeholders (Lahdenperä 2012, Bygballe and Swärd 2019, Eriksson *et al.,* 2019). These models build on early inclusion of key actors, joint decision-making and sharing of resources (Lahdenperä 2012), which are based on relationships enabling trust-building and the willingness to share risks, resources and responsibilities. The nature of the project network determines the level of collaboration within the project (af Hällström 2021). A key facilitator of the project

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network creation in a CPDM is the collaborative space which is seen as a key facilitator of social relationships and thus enabling collaboration (Lahdenperä 2012, Walker and Lloyd-Walker 2015).

Collaboration is based on shared rules, norms and structures between autonomous stakeholders (Wood and Gray 1991). The understanding of shared rules, norms and structures is, however, evolving with the project itself as individuals interact in the project network and the collaborative space. Although forays have been made into both the concept of project space in relation to collaboration in general (Bosch-Sijtsema and Tjell 2017) and the management of the collaborative space in construction projects (Kokkonen and Vaagaasar 2018) in particular, there is still a lack of insight into the relevance of collaborative spaces in CPDMs specifically, especially with the sudden shift from physical spaces to virtual ones caused by the COVID-19 pandemic.

Our aim is to give insight into the relevance of collaborative spaces in a project network created around a project using a CPDM. We will furthermore discuss the shift in the collaborative space from physical to virtual due to the effect of COVID-19.

## Theory

### *CPDM in the project network*

The use of CPDMs is an answer to increased project complexity, scale and risk (Flyvbjerg 2014) necessitating new management models in the infrastructure construction industry (Bygballe *et al.,* 2010, Hietajärvi 2017). CPDMs focus on early inclusion of all main actors, joint governance processes and sharing knowledge, risks and responsibilities (Lahdenperä 2012).

Such projects also often involve multiple organisations (Flyvbjerg 2014, Sydow and Braun 2018), increasing the amount of interorganisational and interpersonal relationships within the project organisation. The actors in a project network can be viewed as either the organisations contractually connected to the project or as the individuals engaged in the project. As the project network is created around a single project, the actors may be new to each other due to lack of previous interaction.

One view providing insight into the forces impacting these relationships is a social network approach based on a project network. We define the network being created by the actors involved in a single project (Hellgren and Stjernberg 1995) and will discuss it as a project network. This enables us to focus on the ties (relationships) connecting actors to each other and the factors influencing these ties. The infrastructure construction project is the frame of a network that is created around the project. This viewpoint can help us understand the patterns of interaction and relationships formed in a specific context, thus making it possible for us to identify and investigate causalities within the project process (Pryke *et al.,* 2017).

A network is based on the interaction of ties and actors (Borgatti and Halgin 2011). The ties can be either formal, observable and measurable, or informal (Papadonikolaki *et al.,* 2017, Wang *et al.,* 2018). Formal ties relate to the collectively agreed upon aspects of the project's management and organisation and are for example the types of electronic communication and document platforms, meetings or the project organisation, while informal ties encompass e.g., social relationships, awareness, knowledge and ad hoc communication (Papadonikolaki *et al.,* 2017). The collaborative space can thus be classified as a tie: the physical and virtual space are

formal (and measurable), but the social space is rather an informal tie, created in the interactions within the space.

*Collaboration and space*

Collaboration is here defined as the process that "occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain" (Wood and Gray 1991, p. 146). It is thus based on a shared understanding of the project context. Since the actors might lack previous relationships, collaboration is mainly built on the ties of the project network, making the formation of a shared understanding paramount for the project network in order to function properly.

One of the main concepts promoting collaboration in CPDMs is the idea of the collaborative space. Since different CPDMs use different terminology for this concept, we have opted to follow the example of Kokkonen, and Vaagaasar (2018) and use the term 'collaborative space'. According to Walker and Lloyd-Walker (2015, p. 118), "close proximity facilitates ad hoc and chance encounters to improve building relationships and facilitating common understanding" and research shows that collaborative spaces facilitate knowledge sharing (Bosch-Sijtsema and Tjell 2017, Kokkonen and Vaagaasar 2018). In this article we will focus on the so-called 'big room' concept of collaborative space which encompasses not only the physical space but also both formal and informal practices within (Kokkonen, Vaagaasar 2018). The way space is organized shapes how people shape their activities, interaction and gives meaning to experience and a sense of identity (Panayiotou and Kafiris, 2010). This is the main argument for recommending collaborative spaces as a key tool in the implementation of CPDMs (Lahdenperä 2012); since collaborative spaces promote the creation of social ties between individual project participants, they are essential to the concept of CPDMs.

For complex projects distributed over different organizations and disciplines, the physical workspace is not the only space of importance for network creation and collaboration. In recent literature, four types of spaces are discussed as relevant for collaboration (Bosch-Sijtsema *et al.,* 2011; Hautala and Jauhiainen, 2014; Vartiainen and Hyrkkänen 2010): (1) a physical space consisting of the material environment as well as a physical space for geographical proximity. (2) A social or communicative space focuses on formal and informal interaction. (3) A mental or cognitive space comprises mental models of individuals or shared mental models of a team. Finally, (4) a virtual or technology space for interaction and connection via technology means, i.e., via email, video conferencing. The collaborative space of CPDMs can be viewed from all four spaces but in particular the physical, virtual and social space. We look at the collaborative space as a formal state tie (af Hällström, 2021) in the project network in order to connect the concept of collaborative space with the project network.

In the recent developments of COVID-19, especially the virtual space, in addition to the collaborative physical space, has become more important in terms of e.g., shared IT-systems and different virtual solutions. Thus, it becomes interesting to look at the interaction hereof, especially in a time when a majority of work moves to the virtual plane due to requirements of working from home.

## RESEARCH DESIGN

In order to fulfil the objectives of the study, we focused on a case study of a large-scale infrastructure construction project utilising a CPDM, based on a multi-party

contract where the public client, the contractor, and the design engineer (planner) all are part of the same contract. The project is employing a two-step process of project planning and general design (phase 1), followed by detailed design and construction (phase 2). Before phase 2 commenced, the client made a go/no-go decision regarding the continuation of the project. Project planning started with the selection of service providers and preliminary planning in 2016, phase 1 started in 2018 and phase 2 in 2019. The project is estimated to be completed in 2024. The project includes a reward system based on final price, as well as key performance indicators tied to both agreed-upon parameters as well as project performance.

21 interviews were conducted with respondents identified by snowball sampling. All interviews were taped and transcribed. A common interview guide was used for the semi-structured interviews and interviews were conducted with respondents on different levels of the project hierarchy. Interviews were conducted in the three actor segments of client, design engineer and contractor. The collaborative space was observed for 40 hours in total. We also observed meetings of the steering groups. During observations, we focused on both formal and informal social ties. The data was collected at scheduled times following a pre-determined framework of interactions and actions.

The qualitative data was thematically coded and analysed in NVivo, with a focus on the interaction between types of ties in the three concepts of physical, virtual and social space as well as informal and formal ties. The case granted access to a bi-annual survey conducted by the management team. The survey data related to shared space is used descriptively and was analysed in a statistical programme.

## FINDINGS

*Physical and social space*

The collaborative space was described as a big room by the respondents and in the documentation related to the project The room included workstations for approximately 100 employees, meeting rooms, kitchenettes and visualisations on the wall of the project in the form of maps, schematics and schedules, as well as presentations of the participating individuals. The seating layout was arranged according to geographical planning and construction sites. Key actors involved in the project were required to be at the big room for three days a week, but some were there perpetually. There were also people coming to the collaborative space only for meetings or periodic day work. The actors had differing levels of familiarity with the collaborative space. The concept of a “big room” was new for both client and design engineer. The contractor was used to what they called a “project office" due to the project-based nature of the contractor’s work. This, however, is more akin to a “joint office” and not the concept of a “big room”, since the collaborative practices are usually not included in the concept of a project office.

From the survey data, the opinion of the usefulness of the collaborative space was in general high, with the mean being over 7 for all surveys analysed (scale 1-10). The client was the most positive (mean 8,18), followed by the design engineer (mean 7,83) and the contractor (mean 7,27). "This [project] would be nothing if we were all in our own offices" as a contractor said. The space was perceived to “make our everyday easier and bring more value to our work” (client). The collaborative space was moreover seen as an asset and a way to shorten information paths within the project. "It's easy to just go over and ask someone when you have a question," as a contractor said.

There was however a slight difference in attitude related to how much time people spent at the project: people spending less than one day at the project per week viewed the collaborative space the most favourably (mean 8,14). People who spent more time at the project were almost identical in their opinions. People spending 1-3 days at the project were slightly more positive (mean 7,64) than people spending 4-5 days a week (mean 7,59).

The people least at the office were, however, also critical regarding the accessibility of the space, citing the difficulty of finding a seating place and the social groups formed in the project. "The big room people have formed "their own trenches". When you visit the space less often, people don't even greet you" according to a specialist form the design engineer who worked at the project less than one day a week. " For someone who often works in the big room, it's definitely like a second home. For those who visit there less often, it is a bit foreign, cramped and the people are often new" (design engineer). Furthermore, the unfamiliarity with the workspace might also impact people's attitudes towards being at the project: " I visit the Big Room less often, mostly because I don't know where there are vacancies and which ones are someone's own. It's not easy to find a workstation in the Big Room that is free and unused looking" as a design engineer said. Others preferred the resources available at their home offices: "Better peace of mind and a workstation in your own open office / multifunctional space" (design engineer). This had, however, improved over time as one design engineer mentioned that "In my experience, the availability of workstations has been easier this fall. It's a good thing!" and another mentioned how "when you visit the big room 1-3 times a week, there is no permanent place and you do not need it. Some corner is always found. There is a shortage of meeting rooms at times, but recently it has also worked better, as have internet connections and [the document sharing system]. I didn't really come up with anything negative right now. The best thing, of course, is nice colleagues and the fact that help is available immediately upon request". The view on the usefulness of the space increased in general during phase 1 and lowered slightly in phase 2 for all actors.

There were, however, some dissenting voices raised over the collaborative space. "Big room working suits me very well, but I understand very well that not everyone can withstand the general hustle and bustle", as a design engineer said. "My time in the big room goes mainly to attending meetings, even if I'm there 3-4 days a week. For this reason, there is little time to get acquainted with the project materials on the walls. For the same reason, things [matters related to the project] should not be handled spontaneously by talking to people (when always sitting in a meeting)" as a design engineer mentioned, highlighting the need to formalise informal information exchanges in the collaborative space in order to ensure proper communication of pertinent facts to all project actors.

During observations, people interacted mainly with people seated near them in a social capacity, such as having joint coffee breaks or lunch. There was also evidence of people walking over to have unplanned discussions, or "mini meetings" as one respondent called them, related to the project work.

*Virtual space*

The project had a shared document system where all project-related documents were uploaded. They furthermore used applications for social interaction, with subgroups according to their role and organisation. There was for example a group for workplace safety alerts, where the project management team could send information

regarding safety incidents, as well as groups of a more social character for specific blocks or subgroups. The respondents discussed these platforms in terms related to upholding existing structures, not creating new ones.

However, the virtual space was not seen as unproblematic; "There is a lot of information in [the document sharing system], for example, it is difficult to find information independently sometimes, there may not be information about many decisions and then you come across it by accident, looking for something else. I can't give development ideas for this, so the fear on the contrary is that there will be too much information. Communicating essential information to relevant individuals remains somewhat challenging" (client).

Design engineers remarked on problems with IT-access impacting their work, as they needed access to their home organisation servers in order to fulfil their roles. This was a view not shared by contractors; one even mentioned a suspicion of design engineers not doing their work properly and using a bad network connection as an excuse for delays in their work.

### COVID-19

Due to COVID-19, both the client and the design engineer had moved to working from home in 2020, using the shared document systems and social media platforms. Contractors were working with COVID-restrictions on the construction sites. Project participants seem to miss the collaborative space, however: "this [pandemic] has shown how much we need the big room" as a survey respondent put it.

Respondents from both the steering group and design engineers remarked on the benefits of an existing social connection to other project participants when the work moved into a virtual environment, but also noted challenges created by working remotely, without the informal daily meetings enabled by the physical space. They felt that the project work was moving more slowly than in the main object of our study due to the use of virtual collaborative tools and spaces. There was also a decrease in the lack of possibilities for informal meetings, one of the main benefits of a collaborative space as mentioned by respondents, as well as less opportunity for water cooler meetings, common lunches and other social interactions.

The survey respondents from the client answered very positive on the survey performed when COVID-19 started, in contrast to both contractor and design engineer. This warrants further investigation as there was nothing to explain this discrepancy in the survey answers.

## DISCUSSION

*Physical, social and virtual space*

In CPDM literature, the collaborative space has been discussed to support collaboration and knowledge sharing (Walker and Lloyd-Walker 2015, Kokkonen and Vaagaasar 2018), but its relation to forming social relations and networks are not often discussed. From the cases we found that participation and engagement in a collaborative space impacts network formation and collaboration between the network actors (client, design engineer and contractor). The collaborative space is perceived here as a physical, social and virtual space (Bosch-Sijtsema *et al.,* 2011, Vartiainen and Hyrkkänen 2010).

For the physical and social space, the social interactions which strengthen informal social ties were mainly occurring between people seated together (Table 1). This

supports previous research on the importance of the seating arrangements and layout of the collaborative space for shared understanding to emerge, they shape activates and interaction, which is in line with literature (Bosch-Sijtsema and Tjell 2017, Kokkonen and Vaagaasar 2018). The 'big room' upheld formal ties, such as meetings, but the collaborative practices and the physical co-existence eased the creation of informal ties.

The virtual space in the form of shared platforms was seen as essential for the project to progress and people to have equal access to pertinent information and it served as a support for existing formal and informal ties (Table 1). However, concerns raised by the design engineers regarding the quality of IT-infrastructure are relevant to keep in mind, especially with the changes brought by the pandemic. If the IT-infrastructure is insufficient to fulfil project needs, it is almost impossible to create a virtual collaborative space: if it is difficult to access the project resources, there can be no project. This can also impact the social ties in the project as a lack of understanding and communication, coupled with presumptions and prejudices can impact the ties negatively.

There was, however, a difference in attitude towards the collaborative space between different segments of project participants, especially related to the amount of time spent at the collaborative space. The time spent at the project's physical space might affect the view of the collaborative space: the slightly lower opinion regarding the role of the collaborative space as a support for openness and collaboration of those most present at the physical space in their responses, might be related to missing input from the home organisation. This is corroborated by interviews and open answers in the survey. In order to improve collaboration and project delivery further, the question of the optimal amount of time to spend at the project should be explored further.

*COVID-19*

Due to the lack of physical interaction, the role of the virtual space increased. As work for clients and design engineers moved to the home offices, relying on the shared document systems and contractors resumed work on the construction sites, there was little to keep them in the new mentality of collaboration and building relationships. During COVID-19, the lack of a physical collaborative space was a factor in enabling the actors to fall back into traditional patterns.

From literature, a stronger focus on a virtual space has had implications for spontaneous interactions and informal meetings (cf. Bosch-Sijtsema and Tjell 2017, Bosch-Sijtsema *et al.,* 2011) which impacts the maintaining and development of ties in the project network. This was also seen in the responses to the survey, where there was an overall downward trend in the responses once the pandemic hit, and respondents leaving open answers mentioned the importance of the collaborative space for the project to progress. The downward trend could of course be attributed to other causes, such as the starting of phase 2, which changes the project dynamic. As phase 2 had started already in the summer of 2019 and there had been no major changes in the project organisation or management since, the most probable cause is the change brought on by the pandemic and the enforced distance work.

*Collaborative space as a tie in the project network*

The social interactions taking place in the space, coupled with the resources available, strengthened the project network and social ties as people from different organisations interacted. In our comparison case, the space rather strengthened the division between home organisations. The collaborative space can thus be said to shape the project

network by both the physical layout and use of the space, as well as the social connections it enables. The layout and management of the space are therefore of utmost importance, confirming previous findings (Bosch-Sijtsema and Tjell 2017, Kokkonen and Vaagaasar 2018). However, when the physical space becomes unavailable, the importance of the virtual space increases which impacts the possibilities for informal meetings and the development of social ties negatively. The project infrastructure must support a virtual collaborative space, especially in times such as these where the physical facilitators of social space are restricted, reducing impromptu meetings and interactions. For future situations it becomes important to study the different spaces for CPDMs and how project networks could be strengthened when the physical and social spaces are less available.

*Table 1: Network formation in the project space(s)*

| Network formation | Before COVID-19 | During COVID-19 |
|---|---|---|
| Physical space | Big room, formal ties are upheld, and informal ties arise easily | Not available: development of new ties impeded |
| Social space | Big room, informal ties arise easily due to frequent interaction | Lacking: development of informal ties impeded |
| Virtual space | Formal and informal ties are upheld supported by the IT- infrastructure and virtual communication tools | Depending almost fully on the virtual space for interaction: virtual space needed for creating both formal and informal ties |

## CONCLUSIONS

Collaborative space in the form of physical, social and virtual spaces, facilitates a shared understanding and informal social ties and thus shapes the project network. The physical space is important in terms of seating arrangements, the social space in terms of access and availability of social encounters and informal meetings, and the virtual space in terms of infrastructure and providing a platform for online collaboration. However, when one of these spaces becomes unavailable as in the case of COVID-19, this has implications for the project network and the development of social ties. The stronger focus on the virtual space and the lack of a joint social and physical space implied that actors fell back into traditional roles and the collaboration benefits of CPDMs become less visible.

The collaborative space in the form of physical, social and virtual space are very important for network building and tie formation in the project network. The physical space is restricted in terms of seating, the social space in terms of access to social encounters and informal meetings, not present during COVID, and the virtual space in terms of infrastructure and providing a platform for collaboration.

Future research could focus on the space in relation to social networks as well as the effects of constricted social ties in the collaborative space. The research is limited by its geographical context, as well as the case methodology.

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# THE ROLE OF PROSODY AND PERSONALITY TYPE ON EFFECTIVE TEAM FORMATION

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Effective communication has always remained one of the most crucial features of every successful project. Misinterpretation of instructions within large-scale projects can cost millions, not just in reworks, but also through compounded unnecessary delays in re-communicating messages among all teams in the supply chain. This paper discusses prosody and personality types and their roles within communication. Poor team formation has been noted to have a strong correlation with unsuccessful project communication. Prosody has an impact the exchange of information, but it is not widely researched or applied within the wider construction sector. The reviewed literature offers an insight into the effects that prosody and personality types have on communication and team cohesion. A mixed methods methodology is adopted in this study. Interviews with senior project and construction managers were conducted to test the importance of correct team formation. Utilising the Myers-Briggs Type Indicator (MBTI) and investigating the role that prosody must play in interpretation of communication, data from a quantitative pilot study highlights the need to understand the personalities behind the teams in advance in order to deliver a successful project and effective team. Data analysis shows the majority of those surveyed within the engineering discipline have Extraversion (E - 77%) and Judging (J - 77%) characteristics, yet this is the least common type among general population. The research offers discussion on finding unity between team formation and successful project communication.

Keywords: communication; Myers-Briggs; prosody; team-formation

## INTRODUCTION

As a general topic, communication is a vast and widely published source of discussion, not just in the field of construction and engineering, but throughout psychology and the social sciences. Many sources (Dainty, *et al.,* 2006; Martin, *et al.,* 2014; Olanrewaju, *et al.,* 2017; Wu, *et al.,* 2017) single out poor communication as being the root of poor productivity and performance within projects. In general, the majority of the problems in the industry are caused by improper and ineffective communication (Gamil and Rahman, 2017). The wider AEC industry relies on effective delivery of information to function at the optimum level. There are many factors which influence the efficiency and effectiveness of communication and the transfer of knowledge and information within a team. These range from linguistics

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and the prosody effect, silent information (the absence of body sounds), personal constructs and personality types of the individuals involved, to bias and the role that the hierarchy must play on those encompassed within the wider project team. There is also an argument that even those who are not directly involved in conversation or direct contact still receive information, through overhearing and eavesdropping (Nilsen 1957), such as in a larger team on major projects.

This paper aims to develop discussion on the effects of prosody within communication and team formation questioning whether personality types and prosody are appropriately considered when creating effective teams for construction and engineering projects. This research is innovative as the level of understanding and knowledge about prosody and team formation is very limited within the engineering sector. Building on the work of Shen, *et al. (*2007) team formation is reliant on the effectiveness of individuals within the group communicating successfully together, and for this, personality constructs surely must be considered when initially forming the group. Defining communication with certainty is difficult as it has such a variety of contexts and can be considered multidimensional (Dainty, *et al.,* 2006) and intersubjective (Mortensen, 2017) and as Nilsen (1957) outlines that the meaning of the word is at once both clear and unclear. As research continues beyond engineering and into the social sciences, wider terms and forms of the same communication theme are expanded upon; Verbal and non-verbal communication, written, interpersonal and intercultural, mimicry and imitation, technological, didactic etc., the list is endless. Gamil and Rahman (2017) outline that good communication skills are essential to produce effective communication yet if the speaker lacks these, then poor communication may result.

## LITERATURE REVIEW

Within the wider aspect of communication and the transfer of information lies the theory behind imitation and repetition, and how the successful transference of a message or material is in the replication and delivery. This can be classified as Meme Theory. Dawkins first penned this term as 'meme' in 1976 referring to his work on Darwin's theory of evolution and studies on genetics. When something is imitated, it is passed on repeatedly and so can take on a life of its own (Blackmore, 1999) in a similar fashion to relaying information around a construction project. Ideas often mutate and evolve as they pass from one person to another. However, as outlined by Boyd and Richerson (2000), ideas do not pass intact from one to another and breakdowns in the accurate transmission of ideas, messages or instructions can occur because of differences in the personal background or culture of two individuals and can lead one person to create an incorrect assumption of what the other is attempting to convey.

### Personality Type

It is important here to draw attention to the role that personality has on the effectiveness of communication. Within engineering, the need for teamwork and multiple forms of communication are the norm, yet project teams are formed by factors such as experience, role, availability and even location and not necessarily formed on personality strengths. These types of methods, although realistic, are potentially flawed as they do not specifically consider the strengths of the individuals involved and are not designed to get the best out of the team. The Myers-Briggs Type Indicator (MBTI) is a worldwide recognised personality testing tool used to determine the type of personality that an individual possesses. No other psychological testing

instrument has been subjected to as many tests of reliability and validity (Myers and McCauley, 1985) and the work of Kim, *et al. (*2013) demonstrated that the validity of the MBTI model has been widely recognised. Building on the Jung typology test, individuals' personality types are fixed into one of a number of categories (16). These rate from ISFP; Introvert, Sensitive, Feeling and Perceiving, to ENTJ; Extravert, iNtuitive, Thinking/Technical and Judging. Many studies suggest that the natural leaders are those with ENTJ traits, and the ESTJs are the administrators (Kroeger and Thuesen, 1992). The work of Shen *et al.,* (2007) has explored the process of forming engineering teams based on the MBTI instrument, however it is only within a research setting and does not provide any practical application beyond a learning environment. They outline how ISTJ and ESTJ types should not be paired together in the same team as a power struggle may develop, which could hinder the performance of the team as a unit, however, this is never qualified or expanded upon within their paper.

In parallel with the research of MBTI was the emergence of the Five-Factor Model (FFM), sometimes referred to as the 'Big five'. In contrast to the MBTI and its use of metrics to categorise subjects into 4x4 strict 'types', FFM uses five factors and provides a percentage weighting to each category. The categories of personalities are known by the acronym 'OCEAN', standing for Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism. In comparison to MBTI, a person is given a weighting on each 'OCEAN' trait, so someone could be low in extraversion but is not categorised as being an introvert like they would be if the MBTI system was applied. To individuals from outside the discipline of psychology, personality can be defined by such terms as friendly and high strung (McCrae and John, 1992) rather than strictly those categorised within the FFM model.

The methods behind assessing individuals to determine their personality have been widely discussed and critiqued (Digman, 1990; McCrae and Costa, 1987) and a wide series of studies have examined the comprehensiveness of the model by joint analysis with alternative personality systems including MBTI, FFM and the Eysenck and Eysenck (1975) scales. The FFM is not a complete theory of personality (McCrae and John, 1992) and is not without its critics either, such as McAdams (1992) who suggests that it is not a theory of personality at all. McAdams alone has raised six criticisms of the FFM, with one critical question being "How is personality organised within the FFM?". This aligns with the queries of Funder (1983) who states that traits have no bearing on real social behaviour and can be laid to rest. However, the methods and its adoption in forming a general personality have been well adopted and used within the psychology discipline. Digman (1990) has concluded that the FFM has, as a minimum, provided us with a useful set of very broad dimensions that characterise individual differences, aligning with the criticism of Hough (1992) who viewed the description of personality as too coarse.

In order to appreciate how a well performing and efficient team can be created, it is necessary to understand the types of personalities that could form the team's spine. Knowing the traits of individuals within the team is key as there is the possibility that some individuals may be pre-determined for different roles (Madter, *et al.,* 2012). Appreciating that the individual is key, Carnevale and Carnevale (1994) identified the importance of understanding the individual and recommended the use of tools such as the MBTI or FFM. According to Bradley and Hebert (1997), ineffective teams may be the product of inappropriate team composition, and the ideal team should be diversified in the talents and knowledge of each member whilst still maintaining open communication. If each team member is given a role that best suits their skills and

knowledge, or their personality, then the team will perform to its maximum capability. Others (Shen, *et al.,* 2007) also argue that any personality type assessment method applied to understand and appreciate the members of the team is better than any of the alternative random selection methods, and there should be a balance of personality types within the team makeup. Mixing up personality types in the most effective way is a key approach to form a cohesive and well-functioning team. King (1989) wrote that the benefits of a well-functioning and successful team include increased internal motivation, greater task commitment, more resilience to stress and higher levels of performance. This also reflects the work of both Kroeger and Thuesen (1992) and Myers (1980) who both suggest that diversity of psychological types results in a successful group performance. Kroeger and Thuesen (1992) go further and make suggestions that too much diversity between types within a group may restrict the team's performance. They suggest that within the MBTI, the J/P difference is a key issue to the team success or failure, and they also highlight that an influence of too many J's is that they may not consider all the potential alternatives in a rush to stay on schedule (Kroeger and Thuesen in Bradley and Hebert, 1997).

**Prosody**

Within the realms of communication, interpretation of messages is exceptionally important, both in terms of the individual relaying an instruction or message, and those receiving it. How that message is delivered is key to the transfer of the information between the parties. Affecting this is the presence of prosody in the transaction. Prosody is defined as "the branch of knowledge which deals in the forms of metrical composition" or the pronunciation of words and versification (OED, 2018). In terms of communication, it is how the message could be delivered or versed that may cause miscommunication or misinterpretation between the parties involved in the exchange.

Communication and prosody have both been widely researched and analysed and in the past decade there appears to be a growing appreciation for the role of prosody. The way in which we deliver a sentence, the utterances used, the intonation melodies and rhythms all contribute to how that message can be received. These phonetic properties that mark emotional or physical states and individual characteristics are often known as paralinguistic features (Gibbon, 2016). Accents and other prosodic cues can sometimes change the intended meaning of a phrase without inherently meaning to purposefully do so. American English has more intonations on the end of the phrases, in general, than the English accent, and phrases that have a 'continuation rise' at the end, such as in many American and Australian accents, convey the impressions of there being more to come. This rising pitch at the end of a sentence also conveys that the sentence could be a question, which in fact it may not be. Hirschberg's research has shown that there is no single method a given speaker employs to convey a kind of meaning, and states categorically that there is certainly no single method all speakers use to convey meaning (Hirschberg, 2002). This demonstrates that every individual is different and may have a varied way of expressing their instructions and opinions which may not be interpreted as they originally intended. This also aligns with the MBTI studies.

Communication is not simply about transmitting but also receiving, including the knowledge that the transmission was understood in the way intended (Firth-Cozens, 2004). To deal with colleagues in a clear way, the technique of prosodic entrainment, also called alignment, adaptation coordination or priming, is one that could be utilised

in order to work within the variations with accents and sentence delivery. Prosodic entrainment is where one party attempts to replicate or mimic the others manner of speech in an effort to communicate on their level and avoid the wrong prosodic cues in their discourse. It is the phenomenon of conversational partners becoming more like each other in what they say, how they say it and other behavioural phenomena (Levitan, *et al.,* 2012), all to varying degrees of dialogue success. This is a heavily researched area not only for linguistics, but widely across the social sciences and human behavioural studies, yet not very well researched or published within the AEC disciplines. Chartrand and Bargh (1999) dubbed the term 'The Chameleon Effect' and they show that imitation of posture and behaviour led to an increased liking between dialogue participants as well as a smoother interaction. With a link to the Myers-Briggs studies (MBTI), they also discovered that more empathetic individuals exhibited a greater degree of mimicry than others (F/S types). When forming engineering teams this factor could be significant in ensuring clear communication throughout the project. By adopting this approach, it may result in clearer communication approaches and strategies as the recipient understands the phrasing and intonation in the desired way.

*Implicit prosody*

It may be argued that an alternative method of communication would be written instruction, thus alleviating the possibility of prosody 'interfering' with the intended message or communication. However, implicit prosody is the application of prosodic cues while reading. That 'voice in your head' that narrates the sentence that your eyes are focusing on is also forming its own interpretation of the sentence structure and perhaps affecting the message, instruction or communication that has been written. Inner speech mirrors the intonation patterns of external speech (Ashby and Clifton Jr, 2005). The work of Breen (2014) also argues that silent reading and the implied rhythms, phrasings, stresses and melodies can affect readers interpretation of the text. As outlined by Fodor, (2002) implicit prosody noticeably affects syntactic decisions. The idea that conveying a message or instruction in writing may be a clearer way of communicating is a noble one and as the work of Gross, *et al.,* (2013) has shown, prosodic reading has many communicative benefits. However, the simple fact that implicit prosody exists may be enough to scupper this attempt in clarity, as prosody is a universal feature in all languages (Endress and Hauser, 2010). A failing of the work of Gross was that they could not establish "with complete certainty" that a silent voice was in fact perceived by participants. It is however very difficult to manipulate sentence prosody in written text since the prosody of full utterances shows substantial optional variation, and experiments to determine if implicit prosody occurs focus on eye movements when reading. Ashby and Clifton Jr (2005) undertook experiments to determine whether the prosodic property of lexical stresses affected eye movements, as some words have varying fixation times and the eye is sensitive to word recognitions. Their results showed that the eye takes longer to read words with two stressed syllables, indicating that readers do indeed process stresses during silent reading.

Building on the rhythms and melodies of accents in the spoken word, implicit prosody has shown evidence of Auditory Perceptual Simulation (APS) which occurs where readers mentally simulate characteristics of the voices of the speaker who has written the text. The results of Zhou and Christianson (2016) demonstrated that even silent reading speeds were modulated corresponding to the speech rates of the control speakers. On multidisciplinary construction sites with many different cultural and

ethnic groups involved, this phenomenon could be a factor influencing written correspondence. Zhou and Christianson's work shows that readers had more negative attitudes towards the Indian-English speech than that of the American-English and with world-wide influences on major UK infrastructure projects this factor must be recognised.

## METHODS

It is difficult to accept that a single research method is appropriate to all construction management research (Wing, *et al.,* 1998) leading this project to incorporate a mixed method approach, utilising both qualitative interviews and quantitative pilot study data for discussion. As this investigation is focusing on issues incorporating communication and personality types, a more qualitative approach is necessary. The outcomes of the pilot study would be segregated into various categories which may dictate the progression of the main research: (i) Stop - main study not feasible, (ii) Continue - modifications required and (iii) Continue without modifications (Thabane, *et al.,* 2010).

Previous studies around this topic have allowed for a mixed methods approach (MMR) such as the work of Olanrewaju, *et al. (*2017) and Wu, *et al. (*2017) where some elements of the research have been based on a cross-sectional survey questionnaire. The qualitative interview method crosscuts disciplines, fields and subject matters (Denzin and Lincoln, 2000) and is a situated activity that locates the researcher in the 'world' of their research topic.

Developing the knowledge of prosody in combination with existing studies (such as Shen, *et al.,* 2007) on MBTI and team formation may aid in filling the identified knowledge gap.

## DATA COLLECTION

Quantitative data has been gathered from participants within engineering, construction, higher education and architecture sectors between 2019 and 2021. Undergraduate construction management students of were part of the data collected, beside qualitative interviews with management professionals within the wider industry. Participation was voluntary and the results were kept confidential. In this pilot study, no analysis was undertaken to segregate for gender or age, the respondents were simply split into professional and students. There are several studies which examine the MBTI type distribution among the general population (Ball, 2001; Wideman, 2002) and table 1 shows the results of the pilot study data against the general population. From the work of Cohen, *et al*., (2013) the most common personality type within the general population is ISFJ (13.8%).

*Table 1: Pilot study data and general population personality types (MBTI)*

| | ENTJ | ESTJ | ISTJ | ENFJ | INFJ | Other |
|---|---|---|---|---|---|---|
| Professionals (n=20) | 30% | 20% | 0% | 15% | 10% | 25% |
| UG Students (n=37) | 24.3% | 16.2% | 16.2% | 8.1% | 2.7% | 32.5% |
| General Population (Cohen, *et al.,* 2013) | 1.8% | 8.7% | 11.6% | 2.4% | 1.5% | 74% |

As defined in the table, the most common personality type within the construction industry is ENTJ, yet this is one of the least common for the general population. The candidates were all at management level and no trades or labour force were included.

The results of the qualitative interviews all showed a lack of awareness of the MBTI in principle. No application of this personality measuring method was used by any of the candidates when forming their own site or project teams. This was acknowledged as perhaps being a failure on their current practices, alongside the total lack of awareness of prosody and its effects on verbal and written communications and its potential impact within larger project teams. Candidates were senior construction and project managers from both contractors and consultancies.

To progress this research project, further in-depth quantitative analysis will need to be undertaken to break down the findings between gender, age and profession, along with a much larger sample size to allow for greater data frequency and stability.

## DISCUSSION

The gathered data from the pilot study shows an above average saturation of 'E' and 'J' types within the AEC sector compared to general population. There is a visible comparison of personality types between the professionals and students as they are all from the wider engineering discipline. From initial qualitative research (interviews with project and construction managers), personality types are not considered when creating teams at any stage of a project. Some questioned were completely unaware of the MBTI type, yet others had heard of it and taken a test socially. All interviewed had no prior knowledge of FFM or the role that could play in aiding team formation, and when it was explained, no obvious benefit was determined. What is surprising in the current research, from initial qualitative interviews, is the lack of understanding among those in the industry about the theme of prosody or the beneficial role it may have within team formation along with approaches and techniques that could be adopted to benefit clear and explicit communication. Interestingly, prosody was a phenomenon that was not known about by any candidate within the pilot study ("never heard of it"). This could be because of a lack of knowledge about the social sciences among those in engineering or point to a gap in training and education. 'Chinese whispers' was the closest comparison that could be made to highlight how prosody affects communication within a team. Both project leaders and team members should be made aware of how prosody can affect the transmission of instructions and messages within a project team, especially in teams where there are multicultural and multinational individuals all delivering the same project.

MBTI appears to be the most practical and obvious tool for assessing and segregating personalities with a view to aid team formation. It provides an absolute 'type' of individual which can then be used to aid team formation and demographics. Based on the qualitative interviews the FFM does not allow enough clear options to determine a 'type' and it would be more difficult to categorise individuals into labels in order to fulfil their position within a team, in line with the findings of McAdams (1992). The research by Shen, *et al. (*2007) outlines the limitations of having too many similar types within the same group, as a power struggle between 'E' and 'J' types may develop. With such a saturation of these specific traits within the AEC sector, this needs to be explored and tested further. Could a battle for leadership between the same types (ENTJ's) have a detrimental effect on the effectiveness of a team and its internal communication, regardless of prosody? Shen, *et al. (*2007) declared that ISTJ and ESTJ should not be paired together, but could this be avoided considering the abundance of the T and J traits within those surveyed?

The work of Hautala (2006) concluded that there is a relationship between personality and leadership, as measured by the MBTI method. Clearly there is a correlation

between students who will eventually enter the AEC sector and those already within it. The overwhelming majority of participants display both Extravert (E) and Judging (J) characteristics (75% professionals, 71% students), suggesting the possibility of a correlational relationship to be investigated in future research. This is not too surprising considering the nature of the industry, where strengths towards the technical and judging personal characteristics would be an advantage.

Multilingual and multicultural construction and infrastructure sites may benefit from an increased awareness of prosody and the chameleon effect. Would an increased level of mimicry of accents, body language and even posture etc., result in a greater level of effective communication because of an enhanced strengthening of the relationship between the parties? Awareness of how individuals read an instruction and how their 'inner voice' could interpret the message could be an advantage in reducing potential errors in understanding or miscommunication. Understanding this phenomenon and engaging strategies to address it and raise awareness may aid in reducing any communication issues among larger project teams.

## CONCLUSION

Communication is widely accepted to be one of the most important actors required to achieve construction project success. It comes in different forms e.g., explicit or implicit. This paper has presented an initial discussion on the effects of prosody within communication and team formation. As part of a wider research project, the current paper has explored a small sample of participants regarding personality types of team members and prosody. Initial findings show that personality type and prosody both affect communication, yet they are not very well known or understood within the construction industry, thus further supporting the rationale for such a study. Individuals within the AEC sector have a 'higher-than-average' level of 'E' and 'J' characteristics than the general population. Taking this into consideration when forming project teams to work together successfully may be a measure resulting in increased level of efficient communication. The pilot study was successful and is at the 'continue - modifications required' stage, which pushes the research towards more in-depth analysis. Current limitations on the project include small sample sizes but despite this, the initial findings point to gaps in knowledge about prosody within communication and its effects on team formation.

A longitudinal study from team formation to completion of projects can yield further insights. An initial contribution of this research is the initiation of a much-needed dialogue on the further improvement of team formation and communication in construction projects. Traditional team formation is always composed through familiarity and trades/skills, however, there is a possibility to approach this practice using personality types to enhance project success rates. Additional data collection and corresponding critical analysis is currently underway as earlier identified themes are further explored along with identifying any emerging concepts.

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# SITE OVERHEADS: THE LOST DIMENSION OF IMPROVED PRODUCTIVITY?

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Contractors routinely use site resources, such as site accommodation and fences, but not necessarily in an efficient manner. Often only loosely calculated the costs are accounted for as site overheads. The aim of this paper is to scrutinize these types of costs theoretically; empirically and analytically in the context of a Swedish contractor; and to improve the definition and categorization of these costs. Internationally, in practice and literature, there are many definitions including 'overheads' and 'site preliminaries.' In Sweden a frequent term is 'allmänna kostnader' (AK); i.e., 'common cost'; which is used by the case company. The study consisted of a literature and documentation analysis; including waste theory and costing methods; interviews; a survey and a qualitative analysis. This helped understand what costs are included in AK. An official company AK definition proved insufficient as employees used it very differently. Managers categorized resources differently from project to project, making comparison and identification of efficiency improvements difficult. A less ambiguous definition and structure of AK; was developed; focusing on the operating cost on-site; rather than any particular activity or zone. Activity-based costing and digital aids such as EquipmentLoop may improve the understanding of costs and allow more accurate estimation.

Keywords: cost categorization; preliminaries; productivity; site overheads

## INTRODUCTION

Cost overruns in construction projects are routinely referred to and accepted (Flyvbjerg 2008), but while Flyvbjerg (2008) and others focus on external causes of projects becoming too expensive, other more internal causes are prevalent. Project economy and accounting involves a series of norms, routines, budgeting, and allocating costs in categories, i.e., accounts. Much of these norms and routines could be questioned and redesigned to better reflect the actual cost structure. In doing so it might turn out that norms and routines in company accounting are socially negotiated or even individually set. In fact, contractors routinely use site resources in projects such as site accommodation, fences, overall lightning, scaffolding, storage containers and concrete pumps, placing those under general overheads, as non-account specific, which is not necessarily efficient.

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The objective is therefore to scrutinize common costs theoretically, empirically, and analytically. This is done in the context of a Swedish contractor, a company where managers and employees believed that their common costs have been increasing to unacceptable levels compared with competitors. Therefore, they aimed to reduce these costs. This paper takes some first steps in improving the definition of these costs and categorizing resources.

The paper is structured as follows. It opens with a theory section building on a literature analysis also involving waste theory and costing methods. The theory framing was also supported by a documentation analysis of material from the Swedish construction industry, helping understand what types of costs are included in the term Allmänna Kostnader (AK) or common costs. The method section describes the research design. The empirical side consists of a series of interviews and a questionnaire survey, some of which is presented in the findings. The discussion is a qualitative analysis of this material. The paper finally arrives at some recommendations for future work with AK.

## LITERATURE REVIEW

*What are AK?*

Construction contractors have both direct and indirect costs. Direct costs include things such as materials, labor, and installations (Cilensek 1991). Indirect costs are needed to support the construction of an object but are not incurred by the actual construction (Cilensek 1991). AK are a part of these indirect costs, which may also be known as site overheads, preliminaries, or common costs. The distinction between company overheads and project overheads is also important. AK are included in the project overheads, which Plebankiewicz and Leśniak (2013) describe as costs that the contractor incurs on the construction site that are required to complete the work, but do not include the standard direct costs. Put more simply, they are costs expended to manage and administer a project on site (Nabil and El-Riyati 2015).

Flanagan and Jewell (2018) have developed comprehensive directions for the Chartered Institute of Building (CIOB) for how to deal with unquantifiable items - e.g., preliminaries, overheads and profit. These site-specific costs are ones that cannot be directly allocated to individual activities and a required characteristic of them is that they serve more than one activity (Flanagan and Jewell 2018). However, in practice the distinction is not always clear and resources such as scaffolding may only be related to one activity, such as painting a façade, and may instead be included in the preliminaries due to preferred pricing methods. Flanagan and Jewell (2018) therefore define preliminaries as the cost of running the construction site, rather than any particular activity or zone, which exclude costs associated directly with subcontractor's work.

Flanagan and Jewell (2018: xviii) outline site preliminaries as the following, "management and staff, site establishment, temporary services, security, safety and environmental protection, control and protection, common user mechanical plant, common user temporary works, the maintenance of site records, completion and post-completion requirements, cleaning, fees and charges, sites services and insurances, bonds, guarantees and warranties." Just four of these categories make up around 80% of the total cost for site preliminaries, which are site management (26%), mechanical plant (22%), scaffolding (18%) and site accommodation (12%) (Bowen *et al.,* 1996; Flanagan and Jewell 2018). Overall construction site overheads are between 11-19% of a project's total cost (Bowen *et al.,* 1996). They cannot be arbitrarily lowered as

they are an essential element of the construction project, for example safety standards and resources are non-negotiable.

*Why are AK important?*
Over the past decade, the Swedish construction sector has flourished with a steady increase in housing production since 2010 (Josephson and Björkman 2010). However, recent reports have started to show a decline, in part due to the new amortization laws in Sweden and increased land prices, which has refocused attention on resource efficiency and competitivity (Josephson and Björkman 2010; Sveriges Byggindustrier 2020). One common way of increasing competitiveness is to attempt to reduce waste and increase productivity. Josephson and Björkman (2010) found that 10% of resource usage in construction projects is pure waste and that reducing the amount of non-value adding activities may help combat Sweden's high construction costs. These non-value adding activities are wasteful and a reduction of them by following Lean Construction principles leads to improved productivity (Kosekla 2000).

A construction company's competitiveness is often measured by their bid price for a project and as competitivity has increased in the sector this creates pressure for construction companies to cut bids to reach desired profit levels, which results in increased risk for the organization (Chao and Liaw 2017). Managers sometimes try to achieve this by reducing the budget for site overheads as it is one of the most wasteful and fastest growing cost categories (Siskina and Apanaviciene 2009). This occurs due to difficulties and uncertainties estimating project overheads and many contractors do not know nor can define their actual site overhead costs (Siskina and Apanaviciene 2009). The result is significantly lower levels of accuracy achieved compared to estimating direct costs in construction projects, which transfers risk onto the construction company (Chan and Pasquire 2006).

*How is AK calculated?*
In theory is claimed by Chan and Pasquire (2006) that overheads are thoroughly calculated, but in practice it is the estimator's experience, intuition, and professional judgement that largely determine the final sum. It is common that indirect costs are not calculated in detail as it is difficult to do, instead they are estimated as a percentage of direct costs to save time (Chao and Liaw 2017; Nabil and El-Riyati 2015; Plebankiewicz and Leśniak 2013). Estimators use their experience based on criteria such as historical project data, competitive conditions, levels of risk and size and nature of the project when attempting to predict site overheads (Nabil and El-Riyati 2015). In projects where site overheads are calculated in detail, companies often price overhead items twice to ensure that resources are not forgotten about, others deliberately neglect items in order to lower their bid price (Wilmot-Smith 2006).

*Activity Based Costing*
Traditional accounting methods implemented by contractors fail to accurately address site overhead cost allocation in projects, hence also failing to manage them (Al-Hajj and Zaher 2012; Kumar and Mahto 2013). The overhead cost management system should provide accurate costing so that losses and gains related to cost objects can be identified and contribute to a reduction of overall project costs (Kim 2017). Kim (2017: 16) addresses traditional costing as 'one-stage costing' where all products or services consume resources directly and therefore the cost allocation to overheads

becomes based purely on direct hours or direct labor costs, which limits the ability to readily identify the drivers behind them.

Activity Based Costing (ABC) addresses the issues with traditional accounting by instead assigning activity costs to cost objects in proportion to how much of the cost object the activity consumes, which results in more accurate cost information (Kim 2017; Kumar and Mahto 2013). ABC allows organizations to easier identify which activities are wasteful and which activities are adding value and more accurately allocates overhead costs to cost objects (Alsayegh 2020; Kim 2017; Kumar and Mahto 2013). The benefits entailed by ABC over traditional accounting often bring increased profit and increased competitivity (Alsayegh 2020).

## METHOD

Literature surrounding the term 'allmänna kostnader' is scarce as it is primarily a term used by the case study company. A literature and document review of similar terms that are used internationally was conducted, such as 'site overheads', 'general conditions costs' and 'site preliminaries'. Sources were identified predominantly by using online searches in Google Scholar and through a university library. The aim was to gain an understanding of these types of costs, what they are, how they are defined, and which resources are included. The literature study also included a review into activity-based costing in construction as a potential solution to the problems faced by the contractor.

The case study was conducted with a large Swedish contractor mainly working with housing construction. Eleven semi-structured face-to-face interviews ranging from 40 to 120 minutes were conducted with both office and site employees, across three different districts from the case company. The interviews consisted of 21 standard open-ended questions that were tweaked depending on the role of the interviewee (primarily estimators and site managers). These questions were developed by firstly performing a series of preliminary interviews with six key people within the organization. An online questionnaire survey with 18 questions was sent to 95 employees from two districts with a response rate of 52%. The purpose of this was to understand the views of a greater number of workers, whilst gaining a deeper understanding of some of the ambiguities that arose during the interviews.

An abductive reasoning approach was adopted to synthesize and analyze understandings gained from the literature review and case study results by having an iterative process, which guided the authors in identifying important aspects and insights during the research process (Dubois and Gadde 2002).

## FINDINGS

The notion amongst all the interviewees was that AK are present in their everyday work and they are an important aspect of achieving a successful project. AK were often referenced as costs for physical objects (e.g., equipment, material, and machines) or recourses (e.g., services) necessary to conduct the work safely and soundly. However, none of the interviewees seemed to know exactly which objects or costs AK entails. Estimating Manager 2 explained that “you need to use a mix of guessing and thorough calculations when estimating AK.” This ambiguity was prevalent amongst all the interviewees when asked about their experience working with AK. Estimating Managers 1 and 2 explained that the problem starts with inefficiency at the sites when site managers are not always thorough in their choice of work method. Two examples given were the inefficient use of tower cranes and site

accommodation. In some instances, tower cranes are moved around the site when instead a more efficient method would be to return it and hire a mobile crane for the remaining lifts. Renting site accommodation is expensive and despite this, site managers tend to rent the same sized accommodation throughout the whole project even though the occupancy rate changes. Another problem was incoherent cost management in projects as site managers report their costs in their preferred manner. Estimating Manager 1 explained that inconsistency in cost allocation practices makes it difficult to obtain any reliable data for future estimations.

Two of the five interviewed site managers explained that they calculate AK based on the percentage that is given to them from the estimators when starting a project. Although how estimators calculate the percentage and whether it is a high or low percentage is not always understood by the site managers. Site Manager 1 claimed that sometimes estimators calculated AK too high, so they lower the budget by 2%, even though nothing in the project has changed. Site Manager 2 explained that they were previously asked to use scorecards and set a percentage goal for AK themselves in their projects. The same site manager then continued stating the following while explaining what reporting to the superiors looks like, "they sometimes ask us how many percentage points we have lowered AK by, and I just shrug my shoulders. We just filled out the form" (Site Manager 2).

Site Manager 1 said that every project has its prerequisites, and as long they are within the provided percentage limit once the project finishes it does not matter how the costs were allocated. Site Manager 2 said that it is problematic when no defined guidelines exist for AK, consequently making ineffective work methods inevitable. The same site manager continued to explain that everyone has a responsibility in a project. This means that it is not necessary to differentiate between costs as long you are meticulous with all costs related to the project. The Site Supervisor said that it is easy to be lazy about AK and it is often forgotten in the daily work.

Even if all the interviewees did not consider themselves knowledgeable about AK, they knew the concept and perceived it as important. In some of the interviews, employees regarded themselves as knowledgeable about AK but when asked to define and explain it they had difficulties explaining exactly what it is or how it should be managed. Thus, all the interviewees defined AK differently. The same pattern was revealed by the questionnaire respondents as 80% believed that it is important to lower AK and that they could accurately define AK. "To understand AK is crucial if we want to lower project costs and be able to see which projects managed to keep their AK low" (Questionnaire respondent).

Ten out of eleven interviewees stated their definition of AK is based on their own experiences as well as influence from their co-worker's perception of common practice when working with AK. This was shared with the respondents in the questionnaire as 61% answered that their definition derives from estimators or colleagues. Estimating Manager 1 explained that a definition of AK accompanied by a list of "AK-resources" already existed in a PowerPoint within the company. Even though an official AK definition existed, none of the other interviewees used that definition when asked to explain AK. A similar pattern was discovered in the questionnaire when respondents were asked to state which definition they agreed with the most. The results showed that most people agreed with the definition derived from the reviewed literature and not with the one provided by the company.

The survey respondents had a modest view towards reducing costs in projects. They answered that company culture, attitudes of people, inadequate communication, the internal rental company, and other reasons to be obstacles in reducing AK. One of the respondents wrote that communication with estimating managers was a prevalent obstacle for lowering AK.

Amongst the interviewees, Site Manager 2 and 4 expressed a lack of understanding and communication as obstacles. They believed that it was key to involve everyone through allocating responsibility down the hierarchical structure within projects. By making site supervisors aware and responsible for intricate parts of the projects they would become more engaged in understanding costs as it would directly affect their performance. Thus, the delegation of responsibility makes employees thoughtful about cost and work methods. Site Manager 2 did not differentiate between AK and other costs in projects. They saw no reason for the categorization of resources, rather they believed in optimization of every resource. According to them, it is the final cost of the project that matters, period.

One meticulous logistics engineer was notorious for being efficient with AK. By using sophisticated spreadsheets and documentation a bank of historical data was created. This enabled accurate AK predictions in future projects. However, the Logistics Engineer still added 10% to the AK budget as a precautionary measure. The method was not used by the other interviewees as the logistics engineer had adopted this from another district within the company. Finally, at the time of this research, a digital tool was being tested in two pilot projects. The tool "EquipmentLoop" (EL) is an app that site managers and supervisors use to keep track of selected equipment like handheld power tools or scaffolding. They received push notifications when it was time to send equipment back, thus avoiding having unused resources laying around costing money. The app was still under development and future versions will include more equipment, rental services, assigning of resources to a specific person, and price comparison amongst vendors. Nonetheless, EL was praised for creating awareness amongst employees and Site Manager 4 claimed that the costs had been lowered since implementing EL.

## DISCUSSION

The investigation rather clearly showed that the employees used their own definition and categorization which varied among them. However, as one estimating manager accounted for there already existed a PowerPoint presentation, which defined AK and gave a general categorization. Yet, the interviews showed that the interviewees were unaware of it. Employees will likely continue to use their own methods and beliefs, which makes lowering AK a strenuous task. Apparently, the individual employee asserted that a clear personal categorization made their work easier. Without a standard method of working, it is difficult for estimating managers to follow-up costs and update their experience values for future cost predictions. A standard practice would benefit the company in terms of saving money and increasing competitiveness as interviewees revealed different management methods in use.

Many of the interviewees mentioned larger machines when asked how they defined AK. Crane usage management was brought up as a key factor that determined if a project ends up with a high or low AK. Estimating Manager 2 provided an example that describes the importance of managing large machinery by advocating an 80/20 tactic. In other words, position the most expensive crane where you will work 80% of the time and use a mobile crane for the remaining 20%. This indicates that large

machinery is often calculated based on time and the concept of waste becomes a relevant aspect to mitigate costs concerning the mechanical plant (Josephson and Björkman 2013). The examples underline the "rule of thumb" character of the individual categorizations used since managers rely on intuition and professional judgment in the absence of a definition (Chan and Pasquire 2006).

The problem was amplified from the prevailing discrepancy in communication between on-site employees (e.g., site managers and site supervisors) and off-site employees (e.g., estimating managers and estimators). The individual appropriation of categories also involved collapsing other project costs with AK. Two site managers did not like the idea of separating overhead costs from other costs. Instead, they argued that every project has a certain amount of resources that need to be optimized as much as possible. This ambiguity is expected when managers find it troublesome to define their costs (Siskina and Apanaviciene 2009). It was the author's understanding when commencing the study that the main AK issue at the company was cost and resource allocation, but it was found no standard understanding of AK existed. Without an explicit definition for AK managers will continue to allocate resources based on their own preference. Therefore, the findings imply that the first step necessary is for the company to agree upon a definition that is communicated, understood, and accepted. It is proposed that the definition from the CIOB literature is adopted since employees found it most relevant and to form this understanding around the ambitions for more efficient cost accounting at the case company.

*The dynamics of AK*

AK was interpreted as having a link to the general societal economic development. In Sweden in 2017 new amortization demands affected buyers' purchasing power and affected all types of properties. The interviewees suggested caution and claimed that the company were feeling the effects of the change to amortization payments in a negative way. The company's net-profits were approximately 3% for the last 10 years, which leaves little room for manoeuvring if market conditions change. This has led to an increased focus on cost even though as one site manager described, they learn a lot from trial and error. They lack a working manual, and the estimating managers struggle with the inconsistent cost management practices of site managers. The costly practices of learning by trial and error and difficulties conducting follow-up studies due to poor practice indicate significant opportunities for improvement.

According to Josephson and Björkman (2010), 10% of resource usage in a construction project is pure waste and a company's competitiveness is based on how efficiently they manage their resources. Waste is defined as anything that is not contributing value to the customer. Therefore, it should be in both the company's interest and the customer to improve effectivity by managing their resources more efficiently. Swedish construction costs remain high, and a lot can be done to become more effective by reducing the amount of non-value adding activities in projects (Josephson and Björkman 2010).

*Tools and methods for handling AK*

One should maybe expect a well-established set of standard tools and methods but Estimating Manager 2's communication appears general when they said that through experience, they understand the process and solve tasks with a mix of guessing and thorough calculations. It can be derived that detailed calculations of overheads or preliminaries are often unfavoured, instead, they are calculated by taking a percentage of the direct costs, often relying on the experience of the estimating manager to make

reliable calculations. It is a time consuming and inexact task. Chan and Pasquire (2006) support these claims by noting that site overheads are prepared through thorough calculations, but it is the estimating manager's judgement that most strongly impacts the final sum.

During the interviews, there are similar narratives to that of Estimating Manager 2 from both on-site and office roles where the Site Supervisor says things are often missed and the Logistics Engineer describing adding 10% to the AK budget for items forgotten about. The result of this is depicted well by Site Manager 2, who says that with no defined guidelines, ineffective work methods occur frequently. They also criticized AK as a percentage, especially when referring to scorecards as they do not say what is included, which makes them irrelevant.

When submitting a tender, companies are often under pressure to cut their bid price to win the contract. This may mean that companies accept lower profit margins, aim to reduce costs, and accept more risk. Estimating managers use their experience based on historical data, market conditions, risk, size, and nature of the project, etc. to predict the final cost. To try and increase experience levels Site Manager 4 liked to give site supervisors responsibility over smaller project tasks. The manager mentioned that this often resulted in an increased focus on costs as supervisors had to choose between different work methods themselves. Although still being tested at the time of the study, EL was highly regarded amongst the employees with access. They found it helped reduce waste by giving them a better overview of resources, which enabled them to work more efficiently. Others without access were sceptical due to the added costs taken on by the project to use the software. However, in the test projects, it was found that the benefits far outweighed the expense. As previously mentioned, AK efficiency at the company suffers from inconsistent cost accounting practices. EL gave managers a more direct overview of their practices, which also seemed more valuable to them than receiving directions from management. Furthermore, EL could be used to provide the feedback data sought for by the interviewed estimating managers and potentially reduce tensions that exist between office and site roles. It is proposed that EL is rolled out to more construction sites and to study the resulting effects on AK.

It is the authors understanding from the interviews that nothing can replace first-hand experience with AK. Many people felt confident defining AK and in their own work methods. They felt this even though they knew most people worked differently with AK to them and received different definitions from different sources. Employees have their individual understanding of AK but if the company wishes to work more effectively with these costs, they must redefine the term for employees and categorize its elements. Moving away from the current one-stage costing towards ABC may further help this transition towards effectivity by clarifying the importance and drivers behind costs in projects (Kim, 2017; Kumar and Mahto 2013). Costs are allocated based on activities rather than arbitrary constraints such as square meters, which is easier for managers to interpret. Furthermore, the structure of ABC would potentially make information about costs easier to communicate as it prices specific activities instead of projects (Stašová 2019). Thus, revealing a potential for avoiding prevailing ambiguity between site managers and estimating managers. Existing frameworks e.g., Kim (2017) can be used as a reference for implementing ABC.

## CONCLUSIONS

This paper aimed at scrutinizing site overheads / AK theoretically, empirically and analytically. This is done in the context of a company where managers and employees believed that their AK have been increasing to unacceptable levels compared with competitors. Therefore, they aimed at reducing these costs.

The study's main contribution is to highlight the lack of a consistent understanding for site overheads in practice. It was clearly shown that the employees used their own definition and categorization, which varied amongst them even though it was assumed that everyone at the company worked in the same way. There is also no consistent definition in the literature. Therefore, the author's position is that implementing and following through with a standard definition (e.g., CIOB's as company workers connected well with this rather than any currently in use), work method and categorization for AK would increase consistent practices between projects. Furthermore, the divide between office and site roles needs to narrow to be able to use these practices to work more efficiently and more accurately predict AK in projects.

The dynamics of AK were interpreted as having a link to the general societal economic development. AK was scrutinized by the case company due to increased competition but due to inconsistencies shown in combating these rising costs, it is questioned whether the case company is incentivized enough to adapt, as they are currently performing well in the market. The study showed that there is the possibility for a reduction in wasteful non-value adding activities by eliminating practices such as on-site trial and error.

With ineffective work methods and no defined guidelines estimators and site managers relied on personal judgement when working with AK, with margins built-in for resources that are simply forgotten about. The company may wish to standardize AK working practices and inform employees to enable them to work more effectively with these costs. ABC and digital aids such as EquipmentLoop were well received as potential solutions to these problems.

This study is limited to one department of one case company. Future research could use more data, including that from the small-medium sized firms that the case company is struggling to compete with. A more in-depth approach could be taken to the categorization of AK resources as a basis for analysis between projects. Furthermore, the effect of digital tools such as EquipmentLoop on lowering costs could be investigated.

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# LOST AND FOUND IN TRANSLATION: TOP-DOWN DECOUPLING AND BOTTOM-UP RECOUPLING OF STRATEGIES AND PRACTICES IN CONSTRUCTION PRODUCTION

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Researchers have noted an apparent decoupling between construction production strategies formulated at upper management, and their top-down translation into on-site practices. In this paper, we revisit the research question of how and why there is such a decoupling and use that to conceptualise a primarily bottom-up schema of production strategizing, drawing on site managers' perspectives. As such, we conduct a Sweden-specific literature review focusing on (s) lean construction production practice variants, and (b) site managers' dispositions towards production strategy improvements imposed by upper organisational levels - which may not align with hands-on best practices. The findings show that production-oriented lean construction variants aiming at strategy or on-site processes may lack an interface altogether; furthermore, there exists a decoupling between the standardisation logic of the strategic top-down view of production, and site managers' tendency to act in free problem-solving roles. We then use the strategy as process and practice (SAPP) framework to integrate those findings and conceptualise a best practice-informed production strategising schema. This schema favours bottom-up production strategising, but also considers a loop-like collaboration approach - in an effort to integrate the benefits from a top-down production standardisation, with the flexible bottom-up buffer zones allowing for innovations and out-of-box solutions.

Keywords: lean construction; SAPP; site managers; loose coupling; Sweden

## INTRODUCTION

Construction production strategies formulated on the upper management levels are apparently decoupled from their top-down translation into on-site practices, as has been increasingly noted in the relevant literature (e.g., Dubois and Gadde 2002, Löwstedt and Sandberg 2020). This phenomenon can affect the diffusion of concepts aiming at, among others, production efficiency and value maximization - and most explicitly, lean construction (LC) (Kifokeris 2021). As such, the following research question arises: How and why does such decoupling manifest within a specific (national) context (which accounts for the institutional forces making each construction sector distinct)? To tackle this question, we conceptualise a best practice-informed production strategy schema, which draws from the site managers'

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perspective in the Swedish construction sector. For this, we initially review the relevant literature on the site managers' disposition towards production improvements imposed by upper management, which can take the form of production-related practical LC variants. Then, we analyse the potential misalignment of such imposed variants with best practices, through the lens of the strategy as process and practice (SAPP) framework. Finally, we sketch the schema itself, an integral part of which is a loop-like approach of collaboration.

Following this introduction, our theoretical basis and research method will be described. Afterwards, the content and analysis of the literature review, the resulting conceptualisations, and a critical discussion, will follow. The paper concludes with some final remarks, limitations, and recommendations for future work.

# THEORY

## Lean construction (LC)

There is not a universally referable definition of LC, but rather a set of relevant interrelated themes (Koskela 2020). Therefore, we offer an overarching understanding of LC (without claiming that it is exhaustive) by synthesising a collection of fundamental aspects ascribed to reflect LC facets. As such, LC aims at the elimination of waste (i.e., non-value-creating activities), efficient resource use, workflow optimisation, on-time delivery of information and materials to project sites, cost minimisation, and customer value maximisation (Tzortzopoulos *et al.,* 2020). Koskela's (2000) transformation-flow-value framework of production pointed to the transformation of inputs into outputs while materials and information flow through value-adding activities and waste, with end-customer value as the goal. Such transformation can be facilitated with just-in-time (JIT) production flow (Liker 2004), while prefabrication can optimise production efficiency and logistics (Vrijhoef 2020).

In practice, LC can be implemented in variants, which may entail: (a) implementing only certain LC processes and tools, like e.g., target value delivery (Ballard 2020), and/or (b) different levels of integration between aspects of LC and other frameworks and tools, like e.g., BIM (Dave and Sacks 2020). In the Swedish context, Kifokeris (2021) notes, among others, the following production-related variants:

- The production processes variant. It can include a degree of prefabrication, modularisation, standardisation, and mass customisation. Its main LC tenets are vertical integration, making-to-order, pull systems, continuous improvement, JIT, value stream mapping (VSM), Last Planner, increased stakeholder cooperation, and broadening of partnering teams. It requires process mapping, technical analyses, standardised documentation on production processes, and appraising production performance indicators. It can encompass practical integration with BIM, virtual design and construction (VDC), and lean communication platforms.
- The production strategy variant. It entails enterprise resource planning (ERP), production strategy optimisation, value-driven purchasing, a product-offering marketing strategy, and bottom-up organisational changes (e.g., in setting the site management agenda) to accommodate product platforming. Its main lean tenets are vertical integration, continuous improvement, JIT, VSM, increased stakeholder cooperation, and broadening of partnering teams.

While Kifokeris (2021) has identified more practical LC variants, only the above are relevant to the current study.

### Strategy as Process and Practice (SAPP)

Originating from the 'practice turn' in the social sciences, "strategy as practice" (SAP) treats strategy as a socially influential human activity, both within and outside organisations (Whittington 2006; Weiser *et al.,* 2020). Strategy formation is conceptualised as socially accomplished actions, interactions, negotiations and situated practices of multiple actors (Jarzabkowski and Seidl 2008). Strategising is based on practices that affect both strategy processes and outcomes and is embedded in institutional contexts rather than individualistic decision-making (Vaara and Whittington 2012; Weiser *et al.,* 2020). As such, strategic practice can be measured against social processes leading to the realisation of strategy (Whittington 2006), and therefore spans beyond top management and into all organisational levels (Whittington 2006) - such as, for instance, the site management levels in construction. Important in this respect are socially defined modes of action deployed by the strategising actors, such as workshops, meetings (Jarzabkowski and Seidl, 2008), and material artefacts (Whittington 2006; Jarzabkowski *et al.,* 2013).

Synthesising the above, the interrelated SAP themes are practices (strategising methods, tools, and social routines for thinking, acting and using artefacts), praxis (the actual activities of people in practice), and practitioners (the actors of strategy that both perform the praxis and carry the practices) (Vaara and Whittington 2012; Jarzabkowski *et al.,* 2013; Weiser *et al.,* 2020). The strategising practitioners here are not only top managers (Jarzabkowski *et al.,* 2013) but can also be site managers.

SAP was recently augmented into SAPP, by including strategy process as the last "P" - namely, shaping and implementing strategic decisions, and a dynamically evolving strategic content (Burgelman *et al.,* 2018). As such, practices and praxis are reinforced with strategic antecedents (within contexts, actors, sequences) and outcomes (e.g., organisational performance), while actors are strongly connected with bottom-up praxis and practices (e.g., site managers) (Burgelman *et al.,* 2018; Weiser *et al.,* 2020).

This reinforcement of the SAP themes of practice, praxis and practitioners, results in the following six SAPP interrelated themes: Temporality, actors and agency, cognition and emotionality, materiality and tools, structures and systems, and language and meaning (Burgelman *et al.,* 2018). Temporality understands strategising as incurring incrementally over time; actors and agency consider power and politics related to practitioners; cognition and emotionality explore the ways such traits affect strategising; materiality and tools consider the way technological artefacts (e.g. IT) can enable transparency, participation, and inclusion in strategising; structures and systems are temporary instantiations of ongoing strategic processes; and language and meaning draw the attention beyond the analysis of narratives per se, and into longer-term processes and the emergence of strategic ideas (Burgelman *et al.,* 2018).

## METHOD

A systematic literature review was conducted to identify the literature pertaining to the research question, which made use of the concept-centric framework augmented by units of analysis - and could be gauged to resolve when no new relevant concepts could be found (Webster and Watson 2002). The main keywords were "LC practice variants in Sweden", "site managers' work practices", and "production strategy". The emerged units of analysis included, indicatively, "loose coupling". These concepts and units of analysis led to the two main themes combined in this paper, namely LC

production practice variants, and site managers' disposition towards production best practices and top-down imposed improvements (both in Sweden). A targeted but comprehensive search (MacLure 2005) was conducted, enhanced by the references-of-references and "snowballing" techniques (Greenhalgh and Peacock 2005).

Our review spanned the period from the first studies on LC in the Swedish context (1997), until the time of the final revision of this paper (June 2021). 37 search engines featuring engineering and/or managerial content were initially tested. After omitting 28 engines that returned no results or results already included in other engines, the remaining nine (each returning at least one unique result) were utilised: Chalmers Library, Chalmers Open Digital Repository, Taylor and Francis Online, Google Scholar, BASE, Semantic Scholar, WorldWideScience, Mendeley, and Scopus. The searched terms were sought in all parts of each publication, via the use of operators.

The review was conducted iteratively, resulting in a large number of aggregated hits per research engine and year. By refining these initial results, the unique studies pertaining to the aforementioned criteria were singled out. When entire papers were featured in collective works (e.g., "kappa" theses), only the collective works were included here. This process resulted in the final collection and analysis of 13 studies. This iterative review followed the abductive reasoning of qualitative research, where observations and explanations are developed by working cyclically between concepts and data (Bell *et al.,* 2019) - in the current case, data as research content.

## ANALYSIS, RESULTS AND CONCEPTUALISATION

The reviewed research efforts (spanning 16 years of empirical studies) can be discretised into two broad categories, namely the ones focusing more on vertical integration (or its lack thereof), and the ones focusing more on (loose) coupling.

When it comes to vertical integration, Björnfot (2006) draws on anecdotal interview evidence to argue that even when the imposition of the LC variants is justified due to lacking production coordination and task control, there can be resistance from site personnel due to established practices. Unger (2006) points to a certain way of understanding LC in production practice, where it is not upper management, but mainly site managers that decide about such things as construction methods, which subcontractors and suppliers then use. Moreover, even though good examples of top-down imposed LC production strategies can trigger a self-spreading mechanism, it would take long before most site managers are on board (Unger 2006). Höök (2008) documents poor shared perceptions between organisational levels due to the lack of communication and goal sharing, which can lead to site managers not understanding the company's upper management philosophy and impositions. There is also a culture where site employees working in flexible teams take responsibility for their own tasks, thus solving problems directly, but also limiting the diffusion of experience (Höök 2008). In a survey with site managers in Meiling (2010), more than half of the respondents meticulously collected inspection data on construction quality defects, but then revealed that this bottom-up sourced data was rarely used by upper management in continuous improvement processes. Eriksson (2009) notes that site managers often believe they do not have sufficient opportunity to state their opinions, offer improvement ideas and initiate on-site problem-solving within LC. On a complementary note, Gerth *et al.,* (2013) shows that site managers can prefer a bottom-up delegation of responsibility to the corresponding craftsmen performing certain operations, thus limiting a top-down intervention on the control and improvement of production processes. Finally, Löwstedt *et al.,* (2018) highlight a

more social perspective of the vertical integration between organisational strategy and construction production, showing the way bottom-up production perspectives are diffused as best practices also in the parent organization. Therefore, a collective and multi-level professional ideal related to ad-hoc and practical problem solving seems to hinder the operationalisation of top-down strategic initiatives for production improvements (Löwstedt *et al.,* 2018), like the LC production variants.

When it comes to (loose) coupling, Styhre (2012) argues that construction production requires from site managers detailed plans for scheduled activities, but also ad hoc solutions for a never-ending stream of unanticipated problems. The characteristics of this work ("muddling through") reflect the tight couplings between in-project processes, and the loose couplings between the various actors in the broader project network; thus, the work of site managers is generally separated from upper managerial strategising, while having an acute responsibility at the construction frontlines (Styhre 2012). Ivina and Olsson (2020) note a decoupled communication between site and upper management, possibly disturbing the performance of preventive maintenance according to LC production tenets. Jimenez *et al.,* (2020) describe different perceptions of productivity between upper managers and site managers, thus creating a decoupling tension; the former perceive productivity as competitiveness and resource management, while the latter perceive it as how much one can complete and how well one performs in transforming resources into an output in a certain amount of time. Löwstedt and Sandberg (2020) frame the ongoing transformation towards standardisation of construction production processes informed by, among others, LC, as a number of interrelated social dimensions of professional work; as such, the site managers' scepticism and resistance towards top-down production strategising can be ascribed to a collective tendency for free and independent work, characterised by professional identity and expertise. Finally, Sandberg *et al.,* (2021) note the ongoing challenge to tighten the coupling between the parent organisation and the construction production process, through the daily "coupling work" of the site managers. Their findings show that site managers not only constantly couple a stream of production processes tighter to each other, but also to themselves; as such, their work is charged with an emotional capital that seems to explain their active strive to remain "loosely coupled" to the parent organization - altogether resisting top-down initiatives (like the two practical LC production variants) intended to tighten the coupling between operations strategising and construction production (Sandberg *et al.,* 2021).

The results in both focal groups of our literature review show that the observed violation of related tenets of the two LC production practice variants (i.e., production strategy and production processes) - tenets like vertical integration and bottom-up platform accommodation - threatens their practical realisation. Moreover, while there can be a top-down imposition of a blend of the two variants, those can be disintegrated and decoupled with on-site (best) practices, due to the site managers' own disposition towards production improvement, problem solving, work identity and work content, as well as conflicts and tensions with upper management. Moreover, this particular disintegration and loose coupling configuration is not anything the site manager are trying to influence, but rather actively work to sustain by taking on responsibilities and contextualising their production-related work practices; this can be deduced from the empirical evidence in largely all reviewed studies, but even more so in Unger (2006), Höök (2008), Styhre (2012), Gerth *et al.,* (2013), Löwstedt and Sandberg (2020), and Sandberg *et al.,* (2021). Such a disposition from the site managers can be understood as a certain professional identity grounded in a tendency for free and

independent work (Styhre 2012; Löwstedt and Sandberg 2020; Sandberg *et al.,* 2021), which is underlined by the aspects of "identity" (who they are), "expertise" (what they know), and "work" (what they do) (Löwstedt and Sandberg 2020).

Altogether, the empirical evidence found in the reviewed studies seems to confirm that site managers possess a substantial degree of agency and influence over operational strategising in construction companies, regardless of whether the initiatives are directed top-down, or bottom-up (Koch *et al.,* 2015). This can be coupled with the SAPP argument in Burgelman *et al.,* (2018), where top-down/bottom-up strategising and integration are not only a matter of aligning processes, but also considering current work practices. In that sense, transforming production processes through strategising, requires transforming the professional work itself - and therefore, the implementation of the practical LC production variants should not only consider the related LC tenets, but also the corresponding work roles and how they are embedded in the realities unfolding at the construction production levels.

As such, considering the results of our literature review, along with the added dimension of the practical LC variants of production strategy and production processes, as well as the six interrelated themes of the SAPP framework, we propose a bottom-up, best practice-informed production strategising schema depicted in Fig 1. This schema aims to offer a concept of understanding the above-mentioned disintegration and decoupling within the Swedish context, as well as reinforce production by taking on board both top-down standardisation through LC, and the flexible bottom-up buffer zones allowing for innovations and out-of-box solutions.

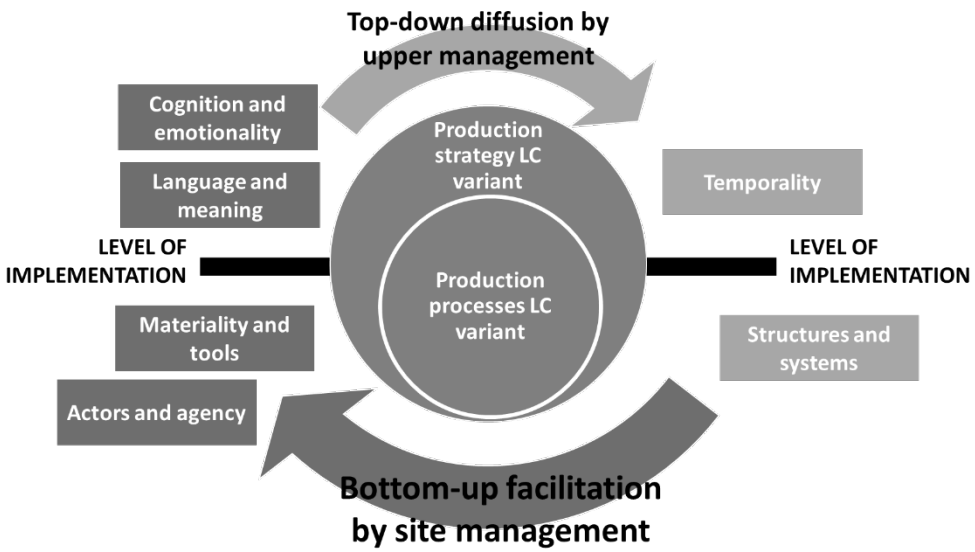


*Fig 1: Bottom-up best practice-informed production strategising schema*

In this schema, the two practical LC production variants are not only blended on the implementation level, but the processes variant is embedded as a constituent in the strategy variant. This points to the fact that, according to SAPP, processes should be practically considered as an integral part of strategizing. Moreover, the LC tenets and entailments of the production processes variant can already be understood as a subset of the ones in the production strategy variant - as also shown in the respective variants' description by Kifokeris (2021) (see Theory). The implementation of these nested LC production variants is informed by a cyclic, iterative process, in which

upper management brings in the diffusion of the variants mainly through the SAPP themes of temporality and structures and systems, while site management facilitates and informs (through performed work and best practices) such an implementation mainly through the SAPP themes of cognition and emotionality, language and meaning, materiality and tools, and actors and agency.

In more detail, for upper management, temporality can be reflected in the longer processes of strategising within the Swedish construction context. Moreover, structures and systems can be connected to the structural and systemic changes impacting the construction companies, and can form ongoing process currently passing through, among others, investments for digital innovation, the expansion IT infrastructure, and institutional shifts brought about by the COVID-19 pandemic crisis. For site management, actors and agency taps into the site managers' role, tendencies and work identities, as well as the resolving of the tensions in the powerplay with upper management; materiality and tools regards the hands-on practical problem solving on site, with what the site managers' themselves have established as best practices and handling; language and meaning, with their attention to the formation of strategic ideas as a longer-term process, revolve around clarifying business, strategy, management, collaboration and communication, via the collection and dissemination of site managers' field data, experiences, and work practices; and cognition and emotionality consider the emotional capital imbued in the site managers' work, as well as their self-image on their identity and expertise.

The darker colouring, bigger arrow size, and larger number of associated SAPP themes (four out of six) pertaining to the site managers' part of the schema, reflects our understanding that on the implementational level, the bottom-up facilitation of the practical LC production variants holds more weight than the top-down diffusion. However, despite this heterogeneity, the depicted cyclic process, as well as the SAPP themes moving from upper to site management and vice versa, also show that bottom-up facilitation cannot operate in a vacuum and without top-down diffusion - but rather, that one constantly feeds into the other. Therefore, the cycle reflects an approach of collaboration in construction management and features a constant feedback loop. According to this approach, decision-making is consensus-based, democratic, and characterised by a flat organisational structure and culture. We therefore argue in favour of both the heterogeneity of our schema, but also for the consensus exemplified by its cyclic collaboration approach. The latter is much less vertical than corresponding approaches in different construction management contexts - even if, curiously, the evidence from the studies in our literature review largely shows that, in practice, such an approach has not always been the case so far, even in the context of the Swedish construction sector.

## DISCUSSION

Practical LC production variants emphasise vertical integration and standardised production processes that span the organisation-project boundaries. However, reviewing the literature on site managers' work, shows a central tension for such multi-level strategising patterns. While it can be claimed that construction projects are inextricably conditioned by the norms, values, strategic plans and routines of the organisations in which they are embedded (Engwall 2003), it is also something in the professional work of the site managers that seems to sustain the "loose couplings" between the organisation and the projects (Sandberg *et al.,* 2021).

As such, a way to reflect upon the SAPP conceptualisation of the previous section is align it with documented related best practices - however, detailed examples of such practices are hard to find. Nonetheless, drawing on the general argument that site managers are devoted to and responsible of delivering the best possible practices in each project, as well as carry this knowledge with them to the next project, it can be understood that there potentially exist loads of information on best practices within the respective companies - and yet there has largely been a failure to collect, compile, and translate this to any usable knowledge or general guidelines for more efficient production strategy and processes (also under the auspices of LC). This missing link may also explain the reliance of construction companies on the individual expertise of site managers (as described in Löwstedt and Sandberg (2020)), even when there are top-down efforts of streamlining production through LC (and even other concepts and frameworks). There is a lot of pressure on site managers and their responsibility to deliver, and it seems that site managers themselves only accept this as long as they are allowed to manage production in their own way. Site managers are deeply invested in best practices, overview, and responsibility on the individual project level. Our review highlights that if top managers want to standardise production processes, they have to consider the redistribution of responsibility for production performance up their own organisational levels, and not only the consequences of this on professional work.

In our conceptualisation, we considered these problematisations by exemplifying both the cycle of a collaborative, consensus-based approach in production decision-making, but also favoured its bottom-up, rather than top-down, aspect. We thus tried to avoid what we consider a "horseshoe theory" trap in the context of our research, which could lead to ascribing equal weights to upper and site management. In practice, upper and site management are not really on the opposite sides of a horseshoe, gravitating to or away from each other with equal force; on the implementational level, the "truth" of production rarely lies in the middle.

## CONCLUSIONS

The site managers' actual work practices can be decoupled from prospective production improvements imposed by upper management (which can take the form of practical production-related lean construction variants). Through a schema utilising the strategy as process and practice (SAPP) framework and analysing such a potential misalignment, we offer a best practice-informed production strategising concept. This schema shows that on the implementational level, LC production processes should be embedded as a subset of LC production strategy. Moreover, the schema is heterogeneous in favour of bottom-up facilitation by site managers (mainly bringing in the themes of cognition and emotionality, language and meaning, materiality and tools, and actors and agency), rather than top-down diffusion by upper management (mainly bringing in the themes of temporality, and structures and systems). However, the cyclic processes of a collaborative, consensus-based approach on decision-making in construction management, is also an important aspect of our schema, showing that the bottom-up and top-down dimensions should be integrated and feed into each other.

A limitation in our study concerns the schema being highly contextualized in the Swedish construction sector; as such, while the methodology followed for the conceptualization is replicable, the schema itself cannot be easily considered generalizable in other contexts. Another limitation is our use of second-hand empirical evidence found in the literature, where the richness of the actual practical

data has already been processed through the lenses of the respective studies. Therefore, our recommendations for future work have mainly to do with the conduct of far-reaching qualitative field studies (e.g. interviews with site managers) in the Swedish and other contexts, in order to capture "raw" data which can then be processed through the theoretical lenses of the LC production variants and the SAPP framework - and in turn update and inform our Sweden-specific schema and/or be respectively used to sketch schemas in other contexts.

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# MATTERS AFFECTING CONSTRUCTION PROJECT-LEVEL PLANNING EFFECTIVENESS: A LITERATURE REVIEW

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Construction project success is often measured based on the adherence to time; cost and quality targets; with Clients and Contractors constantly seeking improvements across these metrics. However, the time predictability of construction projects remains poor; with annually measured 'industry-level' KPIs showing no signs of significant improvement. Access to technological advancements, such as 4D modelling; Artificial Intelligence (AI); and more recently the renewed interest in Off-Site Manufacture (OSM) has indicated opportunities to improve time-predictability; but overall 'industry-level' time performance remains unsatisfactory. As an aspect of time-predictability; insufficient attention is presently focused on exploring 'planning effectiveness'; therefore, the main aim of this work was to review time-predictability and project planning effectiveness at 'project-' and 'activity-' levels via an initial review of subject literature. Following this; a conceptual framework was developed highlighting the key aspects associated with planning effectiveness. These include project environment matters such as complexity and uncertainty; human/cognitive matters such as optimism bias and Parkinson's Law; and the application of available planning techniques or technologies such as Critical Path Method; Last Planner System; Critical Chain Planning; AI and 4D modelling. Whilst 'alternative' planning techniques have shown the potential to improve time-performance; research identifies industry awareness and application of these techniques remains low. As a result of this work, it is considered that planning effectiveness and time predictability can be improved by increasing industry awareness of the constructs identified herein; allowing for the subsequent adoption of available and emerging planning techniques and/or technologies. Subsequent research will explore this; in practice at activity-level; with data obtained from a range of construction schemes to model improvements.

Keywords: planning effectiveness; time predictability; hit-rates; time performance

## INTRODUCTION

When reviewing the immediate success of UK construction projects, recognised industry-level Key Performance Indicators (KPIs) measure performance across several categories, with 'time' being one of the primary categories assessed. Failure to achieve set targets within these KPIs are regarded as degrees of project-failure, with industry efforts focussed on improving performance across all indicators. In

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particular, time-performance is measured against the time-predictability of projects, and despite best efforts, time-predictability in the UK construction industry remains poor. The process of predicting time-targets (i.e., planning a project) can be traced back to the 1800s in modern project management literature, through to the present-day mainstream application of critical path method (CPM) planning and the use of Gantt Charts (bar charts) to communicate intent. In the pursuit to improve time predictability there have been developments in available planning techniques in recent decades, with methods such as critical chain planning (CCP) and Last Planner System (LPS) being utilised in the UK (Winch, 2010), however, current industry-level performance data demonstrates limited improvements. In 2008, to measure time-performance, the Chartered Institute of Building (CIOB) conducted a survey of UK construction projects and identified that as an industry there remained a high demand for robust time-predictability, yet the survey concluded that complex UK construction projects continued to complete, on average, more than six-months behind schedule (CIOB, 2008). Thereafter, despite the collective industry aspiration to improve time predictability, annually reported KPIs recorded only 59% of UK construction projects completed in 2018 achieved completion on-time or early, with a 10-year average between 2009-2018 of 58%, a score that remains unsatisfactorily low (Construction Excellence, 2018). While efforts to improve time-predictability often focus on available or emerging planning techniques and technologies (Gonzalez *et al.,* 2008), it is researched that construction projects encapsulate a variety of complex and uncertain elements, each with the potential to impact time-performance, requiring adequate consideration during project planning (Cohenca *et al.,* 1989; Laufer *et al.,* 1990).

When researching time-predictability at project- and activity-levels, Dawood and Sikka (2009) identified construction activity commencement date reliability as a critical success factor (CSF). They subsequently developed a strategy to analyse programme efficiency based on the number of activities within a programme starting and finishing on time. Activities that achieved their planned start and finish dates were recorded as a 'hit', with overall activity 'hit-rates' used to measure the effectiveness and reliability of the programme. In doing so, Dawood and Sikka (2009) were able to associate the efficiency and effectiveness of a construction programme with time-predictability performance. Later research by Dawood (2010) was able to identify improvements in planning efficiency when using 4D modelling to support the planning process, as opposed to just using 'traditional' planning methods such as CPM planning, achieving an improved activity-level hit-rate of 75% versus the industry-level standard of 58% (Construction Excellence, 2018). To further explore the association between activity 'hit-rates', planning efficiency and time-predictability performance, Gledson *et al. (*2018) undertook subsequent research on four UK construction projects and found a reduced hit-rate score of just 38% on traditionally CPM planned projects, a score which was lower than industry-level KPIs and the activity-level analysis by Dawood (2010). The research by Gledson suggested a continued lack of time-predictability improvements at activity-level across the industry despite the increased access to alternative planning techniques and technological improvements. This research subsequently examines the holistic matters affecting 'planning effectiveness' at project- and activity-level through a systematic-type literature review.

## RESEARCH METHOD

The literature review carried out was structured to establish a common understanding of the project-planning process and how it has evolved into its current application in

the UK construction industry, before exploring constructs impacting planning effectiveness. The research builds upon key theorists in the field of project planning and the wider facet of project 'overruns', recognising commonality between cost and time overruns. The literature review was completed with reference to relevant published textbooks, peer-reviewed journal entries, conference papers and construction industry publications in the field of project management, performance monitoring, critical success factors, project planning, overruns, time-delays and the use of project programmes.

An initial search of peer-reviewed journal entries using keywords "planning", "programme", "overrun", "delay" and "predictability" yielded 3,080 results. No publication date range was set for the initial search. The results were subsequently refined by reviewing article titles and abstracts, with the removal of any obscure results outside the parameters of the research field to obtain a filtered set of 512 entries. After generating the filtered set, recurrent or connected themes were examined, which generated a secondary keyword search for entries associated with the "planning fallacy", "uncertainty", "optimism bias", "Parkinson's Law" and "planning effort", with an additional 622 results. A similar filtering process was applied to the second set of articles, until a set of 107 entries were deemed appropriate, producing a combined result of 619 entries for consideration, as depicted in Fig 1. The peer-reviewed articles were cross-referenced with industry publications and recognised textbooks to ensure sufficient access and consideration of all potential constructs associated with time-predictability and planning effectiveness.

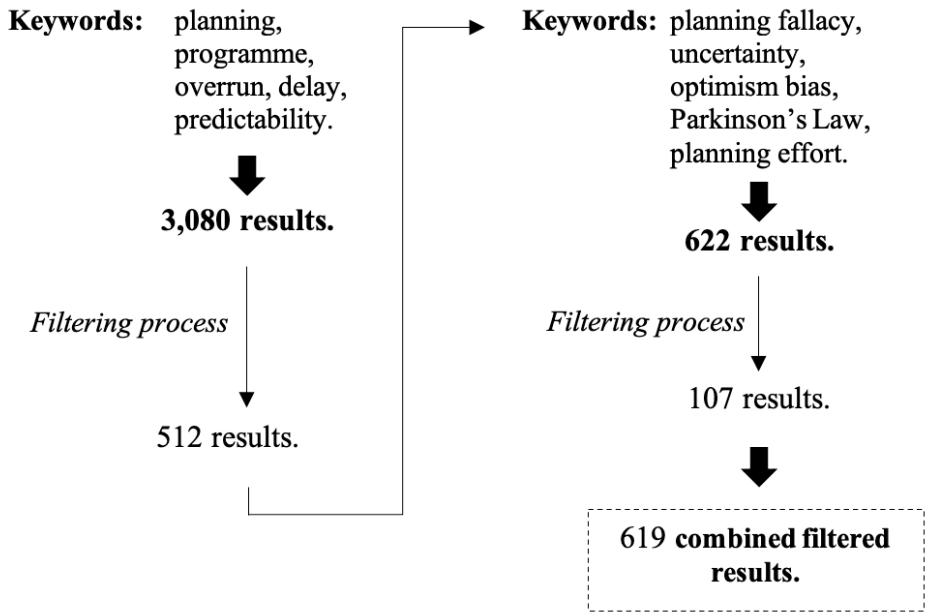


*Fig 1: Literature Review*

The research identified a relatively consistent understanding of the planning 'process'; albeit undertaken in a multitude of different ways, its modern-day placement within project delivery and its association with time-performance. When considering matters affecting planning effectiveness and time-predictability, it identified constructs that can be placed into three high-level classifications of 1) project environmental aspects, 2) human nature/cognitive matters, and 3) available planning techniques, technologies and effort; leading to the summarised findings discussed below and the development of an initial conceptual framework.

# DISCUSSION AND FINDINGS

## The Planning 'Process'

To measure time-predictability, one must set targets from which to measure performance against. The process of establishing time targets is derived from the development of a 'plan' or 'programme', which in the context of construction can be defined as the design and construction of a building or infrastructure project (Baldwin and Bordoli, 2014). When considering the tool for communicating said plans, the Gantt Chart (bar chart) is the commonly recognised method in the industry, which can contain data regarding historic and planned activities (CIOB, 2008). However, project planning goes far-beyond the issuance of graphical representations and is 'a decision-making process performed in advance of action which endeavours to design a desired future and effective ways of bringing it about' (Ackoff, 1970). The planning 'process' must include not only consideration of time, but also consideration of cost, quality, health and safety, design, production and risk (Baldwin and Bordoli, 2014). The method of deriving at the project plan necessitates a planner apply considerable use of heuristics based on judgement and experience-based learning, in an environment laden with uncertainty (Winch and Kelsey, 2005). It is the matters affecting the effectiveness of this planning 'process' which have been the focus of this research.

## Project Environment Factors

Construction projects involve the interaction of a high number of activities, with inter-dependencies, opposing priorities and diverse constraints, emanating in highly complex project environments. Planning comprises of arranging the activities into a robust and accurate schedule, with construction programmes regarded as complex systems. The complexity of construction projects is recognised as a difficult aspect of the project planning process and a recurrent factor contributing to project failure, adversely influencing time-predictability (Gidado, 1996; Flyvbjerg *et al.,* 2003; CIOB, 2008).

Gidado (1996) identifies three factors of task complexity; 'technical complexity' which captures new tasks which are understood in principle, but not yet undertaken; 'analysability' which captures new tasks that are not yet understood and will require increased effort to plan; and 'task difficulty' which captures known tasks that are being completed in new environments. Each complexity factor requires consideration by the planner (or project team) in the preparation of the plan, with the 2008 CIOB survey (CIOB, 2008) reporting 'the more complex the project, the less likely it is that it will be completed either on time or shortly after the completion date'. An aspect contributing to complexity in construction projects alongside the interdependencies of activities, is 'uncertainty'. This includes uncertainty in end-goals / objectives, uncertainty in the method of reaching the goal, uncertainty in the performance of others and uncertainty of potential change (Hagan *et al.,* 2011). Gidado (1996) contextualises uncertainty in the construction environment as incomplete specifications, unfamiliarity with project inputs or the surrounding environment, lack of uniformity of work and the unpredictability of the environment. Related research by Howell *et al. (*1993) identifies that construction projects frequently start with significant uncertainty; however, it is exactly at this time when planners are expected to make project-wide time predictions. Uncertainty in 'how' works are to be undertaken is found to reduce as the final objectives become clearer. In construction this can be associated with uncertainty decreasing as works progress, specifications develop and methods for completing the works become clearer. For project planning,

the first programme iteration is frequently prepared with a high level of uncertainty. Fig 2 below illustrates the correlation between certainty ('how' and 'what') and a typical project timeline, with certainty increasing as the project progresses and time elapses (adapted from Howell *et al.,* 1993).

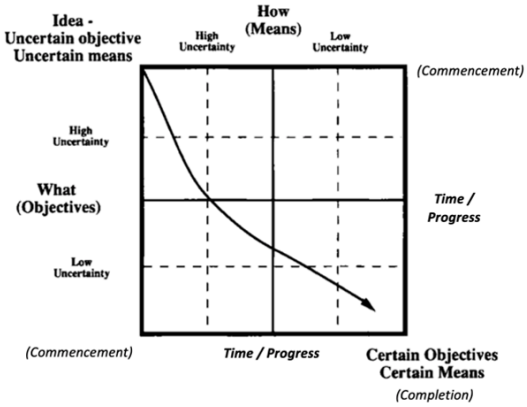


*Fig 2: Certainty: Time/Progress*

To alleviate uncertainty and complexity affecting time-predictions there have been developments in available planning techniques and improved access to technological advancements. In particular, 4D modelling has shown to improve visibility of complex situations allowing for improved time-predictions (Dawood, 2010; Gledson and Greenwood, 2014) and AI has shown to improve the accuracy of estimate predictions by performing simulations of chance, however, uptake of these technologies remains low across the industry.

Aside from technological advancements, the 'rolling wave' planning technique also seeks to address inaccurate time-predictions by adjusting the level of detail included within a programme depending on the proximity to the date and end-goal. As an alternative to estimating entire projects with uncertainty, this method provides detailed planning only as far ahead as known information exists, with high-level planning utilised to populate the balance of the programmed period. The process is repeated during the lifespan of the project at appropriate intervals, with certainty improving at each iteration.

Regardless of the technology applied or method used to assist the planning process, complexity and uncertainty within construction is identified as a long-standing factor influencing time-predictability and must receive adequate attention to avoid setting inaccurate time predictions.

**Human Nature / Cognitive Matters**

Given that project planning is completed in advance of action, and recognising complexity and uncertainty in construction, a planner is faced with the difficult task of estimating activity durations in a programme at the outset of a scheme. Estimations come with risk, and various planning methods are available which seek to assist and improve estimate reliability, such as programme evaluation and review technique (PERT), probabilistic network evaluation technique (PNET), narrow reliability bounds (NRA) and Monte Carlo simulation (MCS) (Dawood, 1998). Despite the range of deterministic and probabilistic critical path network analysis methods available to assist with planning estimations, a significant cause of construction programme overrun can be found in unrealistic baseline plans (Flyvbjerg *et al.,* 2003), that is, the

original estimated activity durations were too ambitious with a bias towards being overly optimistic (i.e., optimism bias).

Optimism bias can result in insufficient 'float' being allocated within a construction programme, leading to failure to achieve activity targets and project time-overrun, a tendency known as the 'planning fallacy' (Kahneman and Tversky, 1979). Estimating the duration of activities, especially considering uncertainty, is one of the most difficult aspects of project planning, balancing the need to ensure the plan is both competitive and realistic (Baldwin and Bordoli, 2014). Recent industry KPI time-performance scores suggest programmes continue to be overly competitive and optimistic, more-so than realistic.

To counteract the planning fallacy, research by Buehler *et al.,* (1997) found a correlation between motivation and prediction accuracy, recognising that if prediction accuracy was the primary motivator over speed (or programme competitiveness), then predictions can become more accurate. Therefore, on the face of it, if there was a collective drive for 'accuracy' over 'speed', then project and activity estimates could improve, and the planning fallacy could be eliminated. However, removing the incentive for speed can result in a deterioration of performance, even when the baseline position is overly optimistic at the outset (Buehler *et al.,* 1995), a behavioural phenomenon best described as Parkinson's Law. Parkinson's Law manifests that work expands to fill the time available, with a relationship between the level of performance and the goals set; the higher the goal (the more competitive the programme), the higher the performance (Gutierrez and Kouvelis, 1991). In the context of construction planning, if too mindful of the planning fallacy (and surrounding risks), one may set a pessimistic goal and the project duration would inevitably grow to fill the extra time made available, taking longer than necessary to deliver the works, ultimately becoming less competitive. Ultimately, human behaviour dictates that if we have longer to complete an activity than necessary, then the level of effort assigned is tailored to complete the task in the time made available. For construction programmes, this can result in accelerated target programmes naturally expanding to fill contracted periods because of reduced effort allocations. Research by Peters *et al. (*1984) reiterates the correlation between targets-set and effort assigned but was mindful to identify that whilst efforts may increase under time pressure targets, this does not guarantee desired results. Increasing effort to meet an ambitious target may improve an otherwise poorer result, but it could still fall short of achieving the set target.

The planning process therefore requires a delicate balance between establishing sufficiently competitive plans to combat activities growing to fill the time made available (Parkinson's Law) and falling foul of setting overly ambitious targets which are unattainable (Planning Fallacy); both of which can affect planning effectiveness and time predictability.

**Planning Techniques**

As noted, when considering construction project planning, the most commonly generated output is the Gantt Chart (Winch and Kelsey, 2005; CIOB 2008; CIOB 2021). The chart is used as the mechanism for communicating the planned intent of future activities and rose to prominence in the 1900s. The use of Gantt charts evolved in the 1950s when it was identified that static charts needed to reflect inter-relationships between activities to cope with ever-growing project complexity, resulting in the development of deterministic critical path method (CPM) planning

techniques (Baldwin and Bordoli, 2014). CPM planning assists planners and project managers determine the 'longest irreducible sequence of events' on a project, calculating the overall programme duration, and became the industry-standard approach to planning in the 1970s. To improve the accuracy and time-performance of deterministic CPM planning, probabilistic techniques evolved, however the industry uptake of these remains low, with deterministic network-linked programmes communicated via Gannt charts continuing to be the industry 'go-to'; recognised as 'traditional planning' (CIOB, 2021). CPM planning has been criticised for its lack of capacity to deal with complexity resulting from uncertainty of information and the dynamic environment of a construction site, its lack of wider-team involvement and the failure to adequately consider resource availability (Shikhrobat *et al.,* 2019). As a consequence, several alternative holistic planning and project control methods have developed, such as critical chain planning (CCP) and Last Planner System (LPS); and more recently, technological advancements have become accessible to support the planning process, such as 4D modelling and the use of AI; recognised as 'modern planning' methods (Al Nasseri *et al.,* 2016).

LPS was developed from 'lean' concepts and takes a collaborative and process-orientated approach to planning, encouraging a wider team-input to take account of constraints, complexity, and uncertainty. The correct application of LPS is intended to force a proactive approach to dealing with the unknown but has been criticised for being time-consuming and requiring unrealistic buy-in from external parties (Al Nasseri *et al.,* 2016). As an alternative, CCP uses a network-based set of activities with dependencies (as with CPM planning), but with levelled resources and an alternative approach to 'buffer management'. CCP 'pools' programme float and has been praised for avoiding some of the human behavioural issues in planning such as 'activity padding', but critics argue the inserted buffers can unnecessarily prolong programmes because of Parkinson's Law (Al Nasseri *et al.,* 2016). CPM, LPS and CCP all seek to address the common concern of uncertainty in project planning and have each shown the potential to improve planning effectiveness when deployed correctly. To further support the planning process, technological advancements have also shown the potential to improve planning effectiveness by improving visibility of complex situations using 4D modelling, determining probabilistic scenarios using AI or increasing control of the project environment by increasing the use of OSM. The application of technological advancements does not require the use of a specific planning technique and in appropriate scenarios have shown to contribute to improved planning efficiency and increased activity 'hit-rates' (Dawood, 2010).

**Planning Effort**

The literature demonstrates that 'traditional' and 'modern' methods of planning can influence planning effectiveness, with each method addressing recognised difficulties in the planning process. Regardless of the chosen technique, research has also found a correlation between planning 'effort' and time-performance. Faniran *et al. (*1994) found that by moving ones focus onto 'planning' (development of construction strategies) as opposed to 'project control' (monitoring progress and actioning deviations), planning effectiveness can improve. The research demonstrated that increasing time spent and effort on the planning process had a direct correlation in reducing time-predictability variance. This hypothesis validates preceding analysis by Cohenca *et al. (*1989) where they identified that planning efforts should be adjusted to suit the complexity and uncertainty of a scheme, with the level of 'effort' applied during the planning process expected to directly impact planning effectiveness.

Overall, the literature demonstrates that available planning methods have evolved since the widespread use of deterministic CPM in the 1950s, with technological advancements providing the capacity to further assist the process, and if deployed appropriately, with sufficient effort assigned, an improved method-selection could provide a route to improved planning effectiveness and time-predictability improvements. The matters identified in the literature as influencing planning effectiveness and time-predictability have been synthesised into a conceptual framework below for application in practice. The framework recognises that each of the concepts researched can influence planning effectiveness, which can be measured in activity 'hit rates'. The techniques, technology and effort assigned can influence the impact of the project environmental and human behavioural matters, with relationships between the concepts.

**Conceptual Framework**

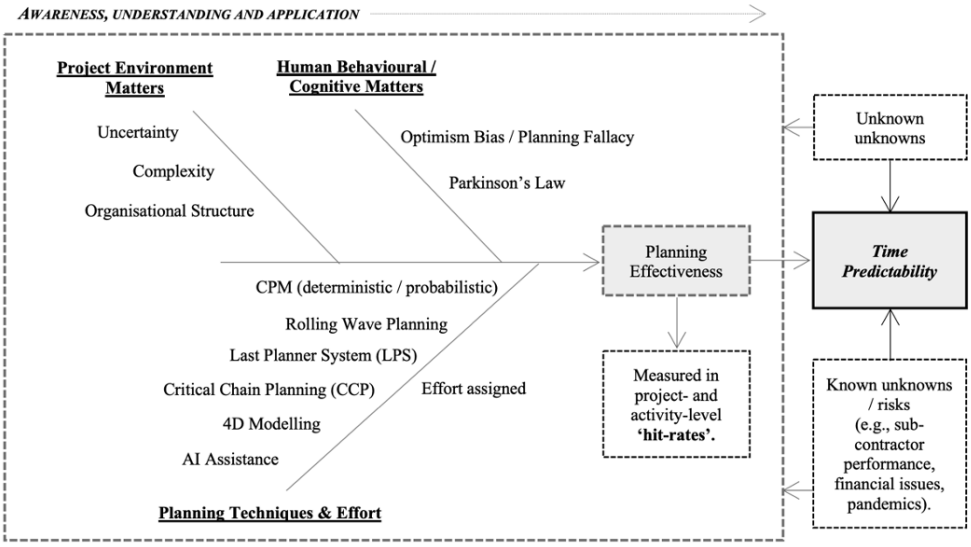


*Fig 3: Conceptual Framework*

# CONCLUSION

It is recognised that construction time performance is measured annually using industry-level KPIs based on the accurate time-predictability of project programmes, with performance failing to exhibit significant improvements. To establish robust time predictions effective planning is necessary, which the literature identifies is influenced by a range of constructs. These include project environment matters, such as the complexity of the project and the uncertainty associated; human behavioural matters such as the planning fallacy and Parkinson's Law; and planning techniques and emerging technologies, such as CPM planning, LPS or 4D modelling, as demonstrated in the conceptual framework. Recognised industry bodies, such as the Project Management Institute, Association for Project Management, and the Lean Institute synthesise similar concepts as influencing time-performance, with common understanding on performance affecting inputs, however, this theoretical awareness fails to translate into industry-wide time performance improvements. Recent industry engagement with senior managers continues to highlight limited awareness of the performance influencing concepts in practice, with efforts often focussed on specific software usage (to produce Gantt charts) and a perceived shortfall in a planner's skillset, as opposed to the application of the wider planning process. Similarly, in the latest planning protocol issued by the CIOB in 2021 (CIOB, 2021), advice continues

to focus on 'how' to plan a project from a technical and technique basis, with no mention of time-predictability or the wider constructs affecting planning effectiveness, demonstrating the need to alter the focus of the industry to align with the concepts identified to realise the potential for time performance improvements.

Collating concepts (i.e., inputs) associated with planning effectives and time-performance is not distinct from surrounding work, however, this research provides an opportunity to analyse the collated concepts in a unique manner by seeking to understand the relationships between the concepts and planning effectiveness at micro-level on recent and current projects. The 'hit-rate' work described by Dawood and Sikka (2009) provides a distinct opportunity to expand activity-level research in practice to analyse how activity-level performance translates to overall time-predictability, and how specific attention to the researched concepts can alter performance.

Accordingly, using the conceptual framework established from this research, a series of research instruments are to be developed to analyse the relationships between the concepts and activity 'hit-rate' performance on recent and live construction projects to seek improvements in planning effectiveness and time-predictability. The research instruments will be developed to explore performance variances after increasing consideration of the concepts, with it hypothesised that activity-level 'hit-rates' can improve with directed focus. The subsequent research has the prospect of increasing activity 'hit-rates', thus improving planning effectiveness, reducing the theory-practice gap in the field of time-performance, with the potential to yield overall improvements in time-predictability.

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# Research and Education

# DEVELOPING TEAMWORK SKILLS: AEC STUDENTS WRITING REFLECTIVE JOURNALS AND USING ACTION RESEARCH

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Construction is a collaborative endeavour. Therefore, AEC students should learn to critically reflect on interpersonal issues and how they act in teams alongside their technical and scientific training. I teach the required skills and knowledge to attain this, within a master's level course in green building design at a German university, which revolves around a training project. Students design a building in interdisciplinary teams. First, I encourage the students to develop a project schedule and assign responsibilities. Subsequently, they use an action research approach to improve their project management skills. They keep a personal reflective journal throughout the project, enabling them to critically reflect on how they perform individually and how they interact as a group. This journal writing helps them to identify problems and subsequently improve their practice by employing action research. Therefore, my account of how to engage AEC students in critical reflection reveals the challenges and opportunities of this process. Students on my course can struggle to identify the value of reflection and hence problematising their practice. They grab the most readily available solution to their organisational problems without more in-depth investigation. Often tight project schedules restrain their willingness to reflect and make it hard to get them engaged. However, after overcoming initial obstacles, they start to write and use their insights to feedback into their action research projects. Conflicts in the teams are particularly challenging for the students but also unique learning opportunities.

Keywords: action research; feedback; reflexivity; teamwork; project teams

## INTRODUCTION

The aim of the paper is to demonstrate how action research and learning journals might help students acquire skills and knowledge to foster learning in their later professional career is. Within a multidisciplinary master's course in green building design, I introduced students to critical reflection or reflexivity. To achieve it, I encouraged students to use action research methods to improve their project management practice and write a learning journal to actively reflect on their practices.

Although a prominent topic in construction management research (e.g.; Kanjanabootra and Corbitt 2016), critical reflection or reflexivity has attracted little attention within the curriculum of architecture engineering and construction (AEC) students. The primary focus within the ACE courses lies in technical knowledge, as is the case with

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the course I teach. The teaching of project management is often side-lined and concentrates on technical features (Nijhuis, Vrijhoef and Kessels 2018). Even so, management in general, but project management in particular, will be a significant part of my students' future jobs. Moreover, management is a profoundly social activity. Hence, soft or interpersonal skills are essential.

## BACKGROUND

The master's course I am involved in runs over three semesters, followed by one semester preparing a master's thesis. I teach two successive modules which deal with project management and teamwork in interdisciplinary teams spanning the first two semesters. The students hold a bachelor's degree in architecture, civil engineering, building equipment, facility management, landscape architecture or other closely related engineering degrees. Some of them have work experience in the construction sector, some work part-time, but there are also students entering the course without any practical experience in the construction sector.

The two courses resembled a student project for each semester, which included designing a student dormitory during the first semester and turning a public library into an office facility during the second semester. The students were assigned to interdisciplinary groups of five or six students, of which at least one student of each group has previously studied architecture, civil engineering and building equipment. The student project was conceptualised to integrate the knowledge of the different disciplines. To succeed, it was important for the groups to consist of at least one member from each of the disciplines mentioned above. As the name Green Building Design suggests, strong emphasis was laid on sustainable design.

Interdisciplinary teamwork is considered a significant part of the curriculum. The students had to design the student project, which included almost all other modules in one or the other way. Therefore, students were required to work in interdisciplinary teams throughout the whole course over three semesters. One of the leading ideas behind the course was to learn from different disciplines. Emmit and Ruikar's assertion reflects this idea: "To be effective […], the construction design manager will also need to understand how designers and engineers work and be able to communicate effectively across a broad spectrum of organisations and levels. This calls for a collaborative approach, excellent interpersonal ('soft') skills, and the ability to make informed decisions on a strategic and operational level" (2013: 6). These "people skills, such as diplomacy, negotiating, coordinating, communicating, integrating, and organising are central to the design management role." (2013: 58)

Within the module, I concentrated on the personal side of management. My colleagues dealt with the technical and engineering skills in other modules or learned them by themselves. As a result, I often had the feeling that they were well equipped to deal with technical issues. Yet, they were unfamiliar with social science methods, not to mention qualitative research and practice approaches.

### Design and Aim of My Module

Project management in higher education often covers only a minor part of the curricula (Nijhuis 2017). So too did the module I taught, and it was assigned an auxiliary or supportive role in the curriculum. Hence, my main aim was to teach competencies and behaviours "that enable managers to develop independently and continuously within their role." (Dainty, Mei and Moore 2004: 883). This enabled them to learn some general competencies of project management and acquire specific

competencies in their jobs (Nijhuis, Vrijhoef and Kessels 2018). Therefore, I used two separate but supplementing concepts: action research/learning (Reason and Bradbury 2008, Revans 2016) and learning journals (Moon 2006).

I asked students to keep a personal reflective journal in which they took notes about their experiences in their teams. I encouraged them to write about thoughts and emotions and about what triggered these thoughts and feelings. Subsequently, I urged them to ask themselves intriguing and uncomfortable questions, why they acted, thought, and felt to lead them towards deeper reflection (Moon 2006). The journal was to help the students observe themselves in action and subsequently sensitise them to their personal interactions and other group members. I actively encouraged them to draw on experiences made outside of the university to understand the patterns of acting and thinking more thoroughly.

The journal also served a second purpose closely related to action research. The observation and reflections helped the students to identify actions to improve their project management. Journal writing was meant to clarify the "objective" of the action, serve as an analysing or "fact-finding" tool, as well as a means to plan actions (Lewin 1946).

**Triggering and Maintaining the Process**

During the first semester, students were given different activities in order to develop a project plan for their design project. The first activity consisted of planning their project work according to Allen's (2015) Natural Planning Model. They had to define the purpose, envision the outcome, brainstorm ideas and action, organise actions, and finally define the next actions (Allen 2015). In a later activity, they had to schedule the different task and actions they had defined before.

These activities helped the students to get their project work running. Here the module fulfilled its supportive or auxiliary role to the main design project. I sought to support the students to achieve their best performance and asked them critical questions to clarify their goals and problematise issues in their teams and their work. During our bi-weekly online meeting, I provided feedback on the activities, and we discussed how to proceed. Often these discussions took longer than planned and took surprising twists and turns because we touched interpersonal issues and problems neither I nor the students had anticipated.

These issues resembled the necessary soft skills I sought to teach students. To develop these interpersonal skills, I repeatedly encouraged students to reflect on their teamwork and question their assumptions critically. The vehicle is the project and their teamwork. To foster their reflection, students were asked to tackle problems within their teamwork using an action research approach. This action research approach was an option for the students to learn a methodology which Dainty, Mei and Moore (2004) call for and which they might use in the future to learn and develop independently.

Action research and journal writing have a particularly good fit. Action research forces the students to take action, into moving things forward, although it also entails observing and reflecting on action. Here AEC students put action in the foreground. However, learning journals encourage the students to recall, record, observe and reflect, which is less action driven. The students are taken out of the heat and put in a calm spot to think about what had happened and what they have done, only to be thrown into new actions later (Heidegger 1927) and to use their earlier reflections.

At the start of the second semester, I asked them to identify problems or themes about teamwork they had stumbled over in the first semester. Therefore, they had to individually consult their learning journals and identify themes and discuss them in their groups. Subsequently, they had to select up to three themes and prepare a brief action research proposal. This proposal was the basis for a student-led learning design during the semester.

I supported the students again through bi-weekly feedback, discussions and planning. In this way, I sought to offer them guidance and help them with thoughts and literature on their investigated topics. For grading, the students had to prepare a personal or a group paper. During the semester, I offered them feedback on a draft version of the paper. Through my feedback, I sought to give them additional food for thought. The draft also enabled me to understand their learning progress better and adapt my teaching in the following meetings.

One particular challenge was studying and teaching remotely. Due to the ongoing COVID-pandemic, we had to meet via online meeting tools such as Jitsi, Microsoft-Teams or Zoom, throughout the period. Students relied almost entirely on synchronous and asynchronous online communication tools. Yet interpersonal skills were more challenging to teach as, according to Ellis, Thorpe and Wood (2003: 139), "softer interpersonal skills were best dealt with in face-to-face class sessions." Although online communication tools have significantly improved since 2003, not meeting in person and enjoying the full range of in-person communication remained an obstacle and was regularly lamented by students. However, whether and how the COVID restrictions affected their learning is beyond this paper's scope.

## METHODS

I collected qualitative material in three ways. Initially, I wrote field notes during and after meeting the students in our bi-weekly online sessions. First, I took brief jottings and developed them later into broader accounts of the events or conversation I participated in.

I also drew on the formative and summative papers the students submitted. I found vivid accounts of their changing thinking in these. I provided feedback on their formative assignments predominantly in the form of questions, hints for further thoughts, and reading suggestions. These papers also provided impressions of the students' difficulties with writing reflectively. I continuously asked the students for feedback on my teaching, predominantly because I sought to improve their learning experience. This feedback also provided me with insights into their learning and their struggles with critical reflection as a side-effect.

Finally, once the second semester was finished, I asked several students to participate in an unstructured interview. Two students participated in one-to-one interviews and another two students took part in a group discussion. These interviews could be best described as guided conversations, where I raised some topics but sought to let the students talk. Occasionally, our conversations drifted away from the interview's initial aim but often offered me exciting takes on the lectures that I had not had before.

## RESULTS AND INTERPRETATION

In the following section, I will report on the process, starting with the first semester of teaching. Subsequently, I will present my findings regarding the learning journals and then focus on the action research. Finally, I will wrap up my interpretations of what

the students learnt over the course and what challenges the students and I faced throughout this process.

**Natural Planning Model**

Allen (2015) suggests that the process of a Natural Planning Model is to define an aim, envision an outcome, brainstorm ideas, organise them, and identify the next actions. Completing these activities helped the students kickstart their work on the project itself and in my module. Very soon, they knew what to do next; they had actions or tasks to be fulfilled and knew who was responsible for the delivery.

I soon noticed that the students mainly focussed on what they should submit as a project file to the tutors and disregarded the fact that the project was a mere vehicle to foster their learning. They prioritised delivering an excellent design to earn them a good grade rather than focussing on the learning experience. I asked one group why they were working on the project. The initial response was to design a sustainable student home. I insisted their "best learning experience" could also be a viable objective of the project. Their intriguing response was something like, "oh, we hadn't thought about the project this way."

One could reference an allegory often used in counselling in which the counselled is metaphorically asked to "go onto the balcony" in a theatre and see themself acting on stage (Ury 1992: 11). Once the counselled has seen themself acting, their acting changes through the new perspective. In some way, this was a game-changer for the students. Once they realised the potential learning for themselves, they had another intrinsic motivation apart from delivering an excellent design and the extrinsic motivation of achieving a good grade.

The approach of these engineering students also demonstrated a way of thinking similar to what Antonacopoulou (2010) addressed to managers: they were focused on immediate problem-solving rather than problematising. In this situation, I probably wore the researcher's hat and problematised their project's possible objective. Yet, it was an exercise to drag the student away from the problem-solving mode. Only later did I learn that problematising, as I often do, caused resistance within the students.

**Journal Writing**

Journal writing was only a familiar task for a very few students who had written diaries before. The majority of students were very unfamiliar with this sort of writing. Additionally, it appeared that most engineering students preferred to capture and communicate their thoughts through drawings and calculations rather than written texts. Hence, they showed some hesitance or resistance to the task. During the meetings, they often admitted to having not written much in their journals. They cited different reasons; for example, 'I didn't have enough time', 'I was too tired after long hours of working', 'I forgot to write' etc.

It may be tempting to call these reasons cheap excuses. One student later even referred to laziness as the root cause of not writing. However, I think this is short-sighted. During the interviews, but also in informal conversation, the students said they did not know what to write. I told them repeatedly to write what moved them during the meetings, what made them feel strongly, what they enjoyed. Essentially, I urged them to write what they wanted and to understand what that meant to them. However, they were not used to writing that freely, and I had severe difficulties overcoming this reluctance.

Motivation to write is a big issue. I am not sure how to tackle it. Coercion through formal assessment is somewhat tricky. Moon (2006) cautions us of the effects when journals are assessed directly. It often leads students not to write freely. They restrict what they write because they fear being judged on their journal writing. For that reason, I told my students that I would not assess the journals directly from the outset. However, some students still continued asking whether I wanted to see their journals, which I, of course, denied.

The whole point of writing the journal is that students are provided with a tool to develop personally. Hence, they must have ownership of it; it must be their private space to think. Therefore, forcing the students to write becomes counterproductive. As a tutor, one can only highlight the benefits and perhaps offer personal examples of journaling to motivate students to follow my advice and example.

Despite the difficulties (and after lengthy discussions), some did start writing. First, they used it to memorise meetings. One student recounted that he wrote notes after meetings and ahead of the next meeting to structure his thoughts much better. Hence, he first adopted quite a technical use of the journal. This observation does not come as a surprise, but it appears to be a way of breaking the deadlock. After a while, most students wrote at least occasionally. Some wrote after the meetings, others once a week, and some even wrote daily. Some wrote and never consulted their previous writing again; others reread the written passages later to learn about shifting perceptions. Some noted that they stepped into the shoes of team members and tried to adopt their perspectives. One engineer attempted to understand the architects in their group better. One student sought to anticipate what it meant to be a parent of a 3-year-old during lockdown.

Despite the positive progress during this phase, I repeatedly emphasised that I would not assess the journals. Still, one set of questions, among many, constantly surfaced: "Is this appropriate to write? Is this worth noting? Am I doing it right?" I answered, "It's fine if it helps you." Students were not satisfied with this answer. It offered them too little advice. They were used to tutors telling them whether they are right or wrong. But I did not, and I could not. They had to learn to see by themselves.

The difficulty is getting the students away from these judgemental questions. Because they wonder about rightness and appropriateness, they often do not write. Yet, the writing from the very beginning can never be wrong. The students need to write to start a more profound thinking process. Even when they got into writing, hindering questions or expectations still remained. Two students mentioned that they wanted to question more, would have liked to go deeper, and felt superficial. They thought this, although they did very well, and their level of reflexivity in writing and thinking exceeded that of most other students.

One of the most significant challenges of critical reflection is that it has no logical endpoint (Moon 2006). The deeper one digs, the more questions one asks, the more challenging and uncomfortable the questions become. Critical reflection or reflexivity is best when it challenges its own roots, when everything starts moving along with the question one asks. This raises the question of when reflection is sufficiently deep. In the case of engineering students it seems enough when they get a sense of 'unstable ground', since it gives them a feeling of what they can expect from critical reflection and what it can offer.

Students commonly reported that this approach - writing a reflective journal which contains feeling and emotions - was something they did not come across during their

engineering studies and was not what they expected from a course in project management. It was utterly new, which added to their reluctance to write. However, once they overcame these obstacles, it turned out to be of considerable value for the students. The example of one student is representative of several accounts. This student reported that he learnt to manage his emotions better. He observed himself being less impulsive than before. He could "go to the balcony" (Ury 1992), and he entered the scene again in a much calmer mood.

Still, through writing, this student reported becoming much more aware of looming problems. Subsequently, he became more proactive in addressing issues that could later turn into conflicts. Hence, here is a development visible from pure reactive problem-solving to early problematising (Antonacopoulou 2010). It shows that this student was able to use "forms of knowledge" which "do indeed complement each other" (Bartunek 2007: 1328)

**Action Research**

After the project commenced and the students had their schedule, tasks, deadlines, and next actions ready, I asked them to identify issues that could be improved. I used the word "problems", and to this day I regret using the word. One student replied "We have no problems, and even if they're so small we solved them immediately. No need to reflect." That was the day I saw my whole concept for the lecture dissolve.

Other students were not as dismissive. However, the reluctance to search for problems prevailed. There was little appetite from them to ask critical questions about their project management practice. They did not immediately see the value in thoroughly investigating actual problems and had even less appetite to search for potential problems. Here again, the mindset of researcher and practitioner clashed (Antonacopoulou 2010, Bartunek 2007). However, after some feedback with the "no-problem" group and many challenging questions, some minor issues surfaced, which helped to keep the module up and running. Some other groups willingly explored their issues, including communication techniques, feedback methods, ways to update meeting minutes, etc. As the project developed, more issues grew in importance and increased the students' appetite to explore them.

Although I hoped they would work on their project, observe, reflect, plan changes to the working routine, execute them, and subsequently learn to work more effectively and efficiently (Kolb 2015). Instead, the students increasingly seemed to drown in their project work. Hence, they were less and less interested in critically examining their project practice. This also highlights a structural problem of action research: it is the circularity that seems counterintuitive to apply to a project - because a project is a one-off situation. Here, the growing demands towards the project's due date increased the pressure on the students and did not allow for the repeated interventions. However, some issues repeat themselves, namely, jour-fixe meetings in teams, repeated feedback, etc.

Such repeating issues were the focus during the second semester. At the beginning of this semester, the students were assigned to new teams. In these new teams, they prepared the action research proposals and started their actions research. They sought to explore issues, for example, giving feedback, sharing information, everyday working routines. The questions were similar to what they had already asked in the first semester. However, this time they were more familiar with the idea of doing action research and reflecting in their journals.

One common issue the students raised in the interviews at the end of the second term was a lack of structure. Some found it very disturbing, even demotivating. One student recounted that if other team members had not kept her on board, she would have completely lost motivation to work in this module, whereas the others in her group enjoyed "the freedom to do what they wanted". This highlights a danger within this mode of student-led learning. Some students appear to need more guidance than others. For these students, a tighter "scaffolding" to support their learning and research process seems to be necessary (Kolb 2015 drawing on Lev Vygostky). I did not realise this problem when it occurred in the student because the rest of the group covered me. I only learnt about it during a later interview. Still, this is a risk one needs to keep in mind. Another student also mentioned the lack of structure. She recalled others complaining about having little clarity about where the action research process should lead. She did reasonably well and could deal with the open-ended design. Others she recounted had more difficulties. Interestingly, although the two students mentioned the lack of structure, their respective teams delivered outstanding results.

Other groups had internal conflicts, including how much each contributed to the teamwork, keeping deadlines, responding to questions, and teammates' demands. These groups discussed their conflict in my feedback session because it was one of the few places, they felt they could raise such issues. In these cases, I sometimes felt overwhelmed with the task of mediating their problems. In retrospect, however, it was a great learning opportunity for me.

Three students from a conflicting group approached me for an extra conversation. They told me that they realised they had to take over the leadership of the team. These three were not satisfied with the work of the other team members. In the end, we concluded that they needed to move things forward. They met for informal meetings between the three of them and thought about distributing the tasks ahead. Through this reflection, they took over an informal leadership role in their team without patronising the other members. Subsequently, tasks were complete on time, and they could successfully submit their design.

Within these conversations, the students understood that a leadership role was required to finish the project. We clarified that this sort of leadership might be needed from them in their future roles. Although they were very reluctant to take on the position in the first place, they gained confidence and saw the value of their leading position. These students even gave the impression that they did not consider themselves as managers. One might argue a great deal of their work is designing, drawing, calculating etc. Yet chances are high that these students will one day supervise builders, contractors, and co-workers; they will communicate and negotiate with clients, partners, contractors and staff on building sites. After leading the group, the students realised that this could be a significant part of their future roles.

A student of another conflict-ridden team only occasionally responded to other team members emails and messages. But once this student replied, he promised to deliver on the tasks given to him. Only weeks later, the others learnt that he had not. The students had a great learning opportunity regarding managing an almost screwed up project, and I was supposed to assist them. At the same time, they faced severe ethical dilemmas as to whether to kick this student off the team or not. At the same time, I encountered another difficulty as a tutor - I saw the students' potential learning from the conflict. However, they reasonably feared terrible grades in other subjects because

of it. They were distracted from the project work and had one team member who did not deliver. Naturally, they spent little effort in doing action research but concentrated on keeping their project running.

This conflict shows that action research is a risky business. Conflicts in the groups can severely undermine this approach. In such cases it is very demanding for the tutor to keep the group motivated and focussed on the action research. However, team members for one group (which went through a severe conflict in the first term) enjoyed working in a new group much more afterwards and did everything to make the group work well. Through the conflict and reflecting on it, they clarified how they wanted a team to work. They spent considerable effort in action research - making teamwork fun for the group and creating a sense of community despite COVID restrictions. They even developed the habit of meeting for breakfast online to experience more closeness.

These reflections clearly show that students - critically analyse their needs, communicate them and search to satisfy them. So, they tried out NVC methods (Rosenberg 2015) and could find a way to improve their lives mutually. It is hard to identify how deep their understanding of critical reflection or reflexivity goes. However, they took their experience, reflected on it, abstracted, planned and acted as Kolb (2015) describes in his experiential learning model.

## CONCLUSIONS

Since project management is often assigned only an auxiliary role in AEC course curricula, action research and journal writing can provide students with essential tools to develop management skills. Writing journals helps them to organise thoughts and to reflect on the project management practice. Hence, they begin to question their actions and thinking. They adopt new perspectives and critically observe themselves. In other words, they acquire tools to begin a personal development process, which might help them to adopt to new roles and task in their future careers. In particular, they realise the social aspect of building which is beyond right-and-wrong-schemes. However, often special effort is needed to motivate them to start and to keep them writing journals. The lack of structure and clear guidance about journal writing (and action research) might be particularly challenging for AEC students used to well-defined goals. Yet once they realise the benefits, it becomes easier for them to maintain the habit of writing.

Using an action research approach within a curriculum around a student team project can yield very insightful outcomes and foster a deep learning experience. Students tackle problems they are concerned with during their project work. They learn a methodology which uses personal experience to gain deeper insights into managing not only construction projects and to kickstart a personal development process. However, conflicts within the student teams can derail the action research. Being witness to students' conflicts and their emotional suffering was very demanding for me as tutor. Sometimes, I felt overwhelmed by the situation they brought into my seminar. Still, I could offer some guidance, or at least an outsider's perspective which helped them to reframe their thinking and move forward. Nevertheless, conflict in teams offers unique opportunities for the students to learn about project management and interpersonal skills.

Keeping learning journals and using action research the students investigated issues relevant to their team's daily work and acquired knowledge and skills they might use in future teams.

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# A CRITICAL ANALYSIS OF COLLABORATIVE AND DISRUPTIVE DIGITAL-DRIVEN BUILT ENVIRONMENT EDUCATION

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The COVID-19 pandemic has driven the teaching and learning provisions more towards virtual platforms, exposing lack of resilience and technology preparedness. This study aims to provide a critical appraisal of existing pedagogical studies on built environment (e.g., Building Information Modelling or BIM) challenging the opportunism and agency theories in response towards remote education provision provoked by the pandemic. The study consists of critical review of two literature samples, namely how the education sector as a whole has been responding to the pandemic, and the digitalisation-based pedagogy in built environment especially how the pedagogy addresses the pandemic. The review of the second literature sample evaluates longitudinally how BIM-based built environment education had evolved. A conceptual framework incorporating multiple factors from the review of the two literature samples is finally proposed. These factors include educational theories (e.g., Bloom's Taxonomy), curriculum development addressing assessment, student experience, collaborative learning, delivery approaches, and teaching methods. This review-based study not only provides an overview of the digital built environment pedagogical work in higher education, but also contests the opportunism response to remote or blended learning and how the post-pandemic era could embrace the remote delivery-platforms to engender a variety of pedagogical principles, for example, cross-disciplinary team-based information sharing, experiential learning, and project-based learning. The findings of this study represent a barometer and roadmap for measuring the resilience of higher education and built environment programmes towards pandemic and technological disruptions.

Keywords: pedagogy; pandemic; digital built environment; remote education

## INTRODUCTION

The global COVID-19 pandemic has caused unprecedented interruption on higher education including the built environment (BE) sector. Prior to COVID-19, there had been some earlier studies addressing how the education sector could respond to any potential pandemic. Saravara (2007) suggested alternative assessment methodologies to be adopted by academic staff in higher education to respond to pandemic, such as

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web-based environment and other pre-planning initiatives. The adoption of remote technologies (e.g., video conferencing and web-based instruction) could also be found in earlier educational studies around different disciplines such as healthcare (Ismail-Allie and Van Ryneveld 2008).

Like most sectors, the BE education sector has been affected by the COVID-19 lockdown and disruption particularly the restrictions on face-to-face teaching. At the same time, emerging Industry 4.0 technologies have also brought innovations in practice and research in BE, such as augmented reality featuring digitalisation and virtual immersion. Existing educational studies in digital-driven BE can be found highlighting virtual learning environment (VLE). For example, Afrooz *et al.,* (2019) experimented the 3D collaborative VLE for built environment courses by introducing online learning. Student feedback was collected to provide lessons learned in immersive virtual learning. Ovtšarenko *et al.,* (2020) proposed the universal electronic courses by utilising virtual technologies integrating building information modelling (BIM) for civil engineering education.

With all these developments, teaching innovation by integrating VLE with BIM-featured engineering pedagogical approaches requires an overview of existing educational programmes. So far, there is a lack of critical analysis of how the BE education sector has been responding to the pandemic. There is also a need to study how BE education could develop its pedagogical resilience against any interruptions by integrating existing pedagogy theories and latest Industry 4.0 platforms. Aiming to address these needs in BE education, this study addresses these research objectives: 1) performing an overview of how the whole educational sector has been handling a pandemic with coping strategies or alternative delivery approaches; and 2) proposing how digital-driven BE could enhance the pedagogical resilience. The study fills the knowledge gap in BE education on its responses to pandemic or other interruptions. The critical analysis from existing educational studies generates key factors in developing a conceptual framework on how BE education could be more standardised or systematic by incorporating digitalisation.

## METHODOLOGY

This study started from an overall literature review of the education sector in responding to pandemic especially the most recent COVID-19. The bibliometric literature search was not limited to higher education but to any teaching and learning related activities. Neither was it limited to any specific discipline. The scope of the review aimed to cover the following themes: alternative educational methods or platforms (e.g., remote learning), student experience, pedagogy management, and assessment of teaching delivery, etc. The initial keyword search was performed in the chosen database of Scopus as shown:

> TITLE-ABS-KEY ("higher education" OR "remote education" OR "teaching and learning" OR "tertiary education" OR pedagogy) AND
>
> TITLE-ABS-KEY (pandemic OR COVID)

Following the bibliometric analysis of educational studies amid pandemic, this study moved a step forward to focus on BE's education sector in terms of how it responded to the pandemic. Further, the study sought the answer to how the existing digital-driven BE had addressed the pandemic. BIM has been identified as an emerging theme in the education of digital BE or general engineering education, as indicated by Chen *et al.,* (2019). Other latest digital technologies or concepts in Industry 4.0 for BE are also highly linked to BIM, for example, immersive technologies (Elghaish *et*

*al.,* 2020), digital twins (Wahbeh *et al.,* 2020), and artificial intelligence (Huang *et al.,* 2021). Therefore, the bibliometric search of references in digital BE education was based on BIM as demonstrated below following the procedure illustrated by Wang *et al.,* (2020):

> TITLE-ABS-KEY (BIM OR "Building Information Modelling" OR "Building Information Modelling") AND TITLE-ABS-KEY ( education OR curriculum OR institution OR teaching OR pedagogy OR students ) AND TITLE-ABS-KEY ( architecture OR engineering OR construction )

The text-mining and data visualisation software tool, VosViewer (van Eck and Waltman 2020) was adopted to assist the literature review. More justifications and procedure to adopt this text-mining tool with in-built algorithms can also be found in Wang *et al.,* (2020) and van Eck and Waltman (2020). Based on the prior text-mining-based review of two different literature samples, researchers conducted critical analysis and provided a conceptual framework for enhancing the resilience of BE education in responding to any future pandemic or other unexpected disruptions to teaching and learning.

## RESULTS AND DISCUSSIONS

### An Overview of Education Sector Responding to Pandemic

Following the initial literature search in Scopus and continuing with a screening of the literature sample, a total of 1,385 references were selected for the text mining-based analytics. The sample of references included journal articles, conference proceedings, review, and book chapters, etc. Although 1,373 references or 99% of references in this sample were published in or after 2020 corresponding to the outbreak of COVID-19, it is worth noticing these earlier published studies addressing potential epidemics or pandemic that could interrupt educational work. For example, White *et al.,* (2010) proposed the remote education approach for any possible pandemic in the future.

The literature sample was imported into VOSViewer for keyword analysis and yielded the keyword map shown in Fig 1. COVID-19, with the largest font and circle sizes, is the most frequently studied keyword because the bibliometric search focused on the pandemic and educational sector. Fig 1 is displayed to indicate what other linked keywords had been emphasised in the existing educational studies.

The distances of linked keywords also indicated the inter-correlation between keywords. For example, gamification can be co-studied with distance education or web-based learning (Guérard-Poirier *et al.,* 2020) in response to COVID-19. Corresponding to the 106 most frequently studied keywords displayed in Fig 1, a further text-mining analysis is summarised in Table 1. These keywords were categorised into ten different clusters according to their co-occurrence or being co-studied in the literature. These major keywords in Table 1 are listed according to the cluster (C) number, together with two other attributes, namely Total Link Strength (TLS) and frequency (F) of appearing in the literature sample. TLS is the quantitative measurement corresponding to Fig 1 in evaluating the link or connection of the given keyword to other keywords.

Essentially, a higher TLS value would indicate a higher influence of the keyword. The ten different clusters of keywords in Table 1 highlight the remote or distant teaching and learning in responding to the pandemic. Keywords used in these studies include mobile learning, E-learning, active learning, computer-based learning, flexible learning, hybrid learning, MOOC, open education, virtual learning, blended learning,

collaborative learning, digital education, online learning, gamification, problem-based learning, student-centred learning, web-based learning, and remote teaching, etc.

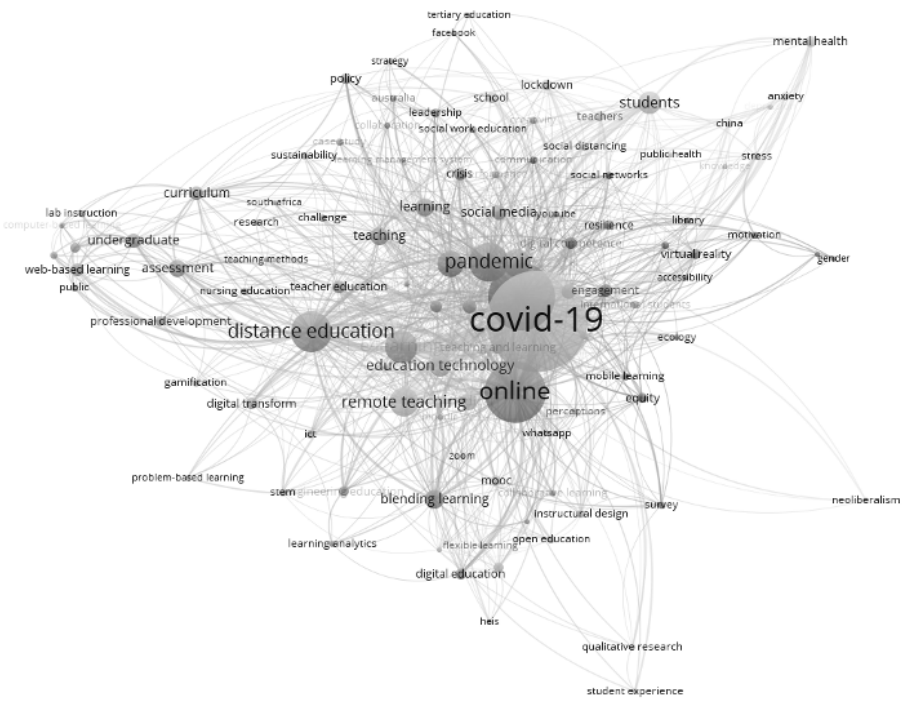


*Fig 1: Data visualisation of existing educational studies coping with pandemic*

TLS values reveal that besides COVID-19 and pandemic, higher education, distance education, and online are the most frequently studied topics with strong linkage to other keywords. It is hence inferred that higher education or university had been the main targeted sector in educational studies amid the pandemic.

Assessment, curriculum, and student feedback are also highly studied keywords in the literature. These educational activities covered different subjects such as engineering, medical, and ecology. The clusters of keywords regarding different disciplines showed that very few educational studies targeted the BE sector. Among the very few studies focusing on BE, Boton (2020) collected student feedback on BIM education in the remote approach during the pandemic. That study served as post-teaching student experience, which was one of the studied keywords according to Table 1. There is still a lack of information of how BE education could be more proactive in designing and delivering the educational work in order to enhance pedagogical resilience.

**Critical Analysis of Education in the Digital Built Environment Sector**

Following the bibliometric search related to digital BE education, a total of 265 references mainly including journal articles and conference proceedings were finalised as the literature sample. Fig 2 and Table 2 are generated following data analytics in VOSViewer. Similar to the prior round of literature review, keywords related to BIM-based digital BE education were also categorised into different clusters according to their closeness of being co-studied in the literature sample. A new measurement item named Average Publication Year is added in Table 2 to show the recency of major keywords being published. These keyword attributes shown in Table 2 allow the longitudinal and cross-sectional comparisons.

The longitudinal analysis according to the average publication year in Table 2 reveals that BIM-related digitalisation education in BE had focused more on modelling

(Ave.Pub.Year at 2011) and visualisation (Ave.Pub.Year at 2013), which could be considered the fundamental functions of BIM.

*Table 1: Data analytics of keywords studied in the literature sample of educational studies*

| Keyword | C | TLS | F | Keyword | C | TLS | F | Keyword | C | TLS | F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Augmented Reality | 1 | 6 | 7 | Active Learning | 3 | 14 | 18 | Education Technology | 6 | 43 | 49 |
| Communication | 1 | 8 | 8 | Australia | 3 | 6 | 6 | Flexible Learning | 6 | 5 | 5 |
| Digital Competence | 1 | 13 | 17 | Collaboration | 3 | 6 | 6 | HEIS | 6 | 5 | 5 |
| Digitalisation | 1 | 23 | 25 | Crisis | 3 | 18 | 20 | Hybrid Learning | 6 | 5 | 5 |
| Engagement | 1 | 19 | 20 | Ecology | 3 | 6 | 6 | Instructional Design | 6 | 10 | 10 |
| Equity | 1 | 13 | 13 | Educational Innovation | 3 | 22 | 22 | MOOC | 6 | 10 | 12 |
| Gender | 1 | 4 | 5 | Experiential Learning | 3 | 3 | 5 | Open Education | 6 | 7 | 9 |
| Higher Education | 1 | 312 | 345 | Leadership | 3 | 11 | 11 | Virtual Classroom | 6 | 7 | 7 |
| Library | 1 | 6 | 6 | Pandemic | 3 | 127 | 132 | Virtual Learning | 6 | 12 | 12 |
| Mobile Learning | 1 | 7 | 8 | Pedagogy | 3 | 57 | 66 | Effectiveness | 7 | 5 | 5 |
| Motivation | 1 | 8 | 8 | Policy | 3 | 13 | 14 | International Students | 7 | 9 | 10 |
| Social Networks | 1 | 8 | 8 | Resilience | 3 | 13 | 13 | Moodle | 7 | 5 | 5 |
| Study Abroad | 1 | 4 | 5 | Social Work Education | 3 | 7 | 8 | Perceptions | 7 | 6 | 6 |
| Survey | 1 | 8 | 8 | Anxiety | 4 | 9 | 10 | Teaching and Learning | 7 | 17 | 19 |
| Virtual Reality | 1 | 10 | 13 | China | 4 | 8 | 8 | Whatsapp | 7 | 6 | 6 |
| YouTube | 1 | 5 | 5 | Covid-19 | 4 | 606 | 708 | Zoom | 7 | 4 | 5 |
| Case Study | 2 | 6 | 7 | Students | 4 | 50 | 52 | Blending Learning | 8 | 36 | 39 |
| Challenge | 2 | 7 | 7 | Stress | 4 | 10 | 10 | Collaborative Learning | 8 | 5 | 6 |
| Creativity | 2 | 7 | 7 | Mental Health | 4 | 16 | 16 | Digital Education | 8 | 13 | 16 |
| E-Learning | 2 | 88 | 96 | School | 4 | 16 | 16 | Engineering Education | 8 | 12 | 12 |
| Education | 2 | 71 | 76 | Social Distancing | 4 | 11 | 11 | Learning Analytics | 8 | 4 | 6 |
| Learning | 2 | 35 | 36 | Teachers | 4 | 12 | 12 | Online | 8 | 262 | 298 |
| Learning Management System | 2 | 4 | 5 | Assessment | 5 | 31 | 32 | Synchronous Learning | 8 | 5 | 5 |
| Nursing Education | 2 | 6 | 7 | Computer-Based Learning | 5 | 5 | 5 | Digital Transform | 9 | 18 | 18 |
| Performance | 2 | 5 | 7 | Curriculum | 5 | 21 | 22 | Gamification | 9 | 5 | 8 |
| Research | 2 | 6 | 6 | Distance Education | 5 | 135 | 145 | ICT | 9 | 9 | 10 |
| Social Media | 2 | 23 | 24 | Media-Based Learning | 5 | 8 | 8 | Problem-Based Learning | 9 | 5 | 5 |
| South Africa | 2 | 4 | 5 | Professional Development | 5 | 12 | 12 | STEM | 9 | 7 | 8 |
| Sustainability | 2 | 7 | 8 | Student-Centred Learning | 5 | 11 | 12 | Medical | 10 | 30 | 32 |
| Teaching | 2 | 33 | 35 | Teacher Education | 5 | 19 | 20 | Qualitative Research | 10 | 6 | 6 |
| Teaching Methods | 2 | 5 | 5 | Undergraduate | 5 | 24 | 25 | Remote Teaching | 10 | 71 | 81 |
| Tertiary Education | 2 | 3 | 5 | Web-Based Learning | 5 | 19 | 20 | Student Experience | 10 | 6 | 6 |

*Key: C denotes the cluster that the keyword belongs to; TLS means the total link strength; F represents frequency, which is the number of times that the keyword is studied from the literature sample.*

Collaboration and integration then became popular topics around 2015 or afterwards, highlighting the importance of cross-disciplinary coordination within BIM, and BIM compatibility with other digital tools. Student learning outcomes and assessment were also widely studied in educational research around 2015 or 2016. More recently, different teaching methods such as collaborative learning, project-based learning, and experiential learning have been more widely studied. In recent years, it is also noticed that other linked digital technologies such as augmented reality and virtual reality (VR) had been incorporated in BIM to enhance digital education of BE. Online learning, as well as skills that refer to digital literacy and competency, have been highlighted in the latest studies.

## A Concept of BE Education Resilience Framework

The text-mining based reviews of the two literature samples reveal the gap between higher education sector and digital-driven BE teaching. From the overall education sector review, few studies could be found focusing on the BE subject. And among the few studies (e.g., Boton 2020) focusing on BE, there is still a lack of proactive approaches to engineer resilience into the pedagogical design and implementation to anticipate, respond, monitor, and learn from a crisis like the COVID-19 pandemic.

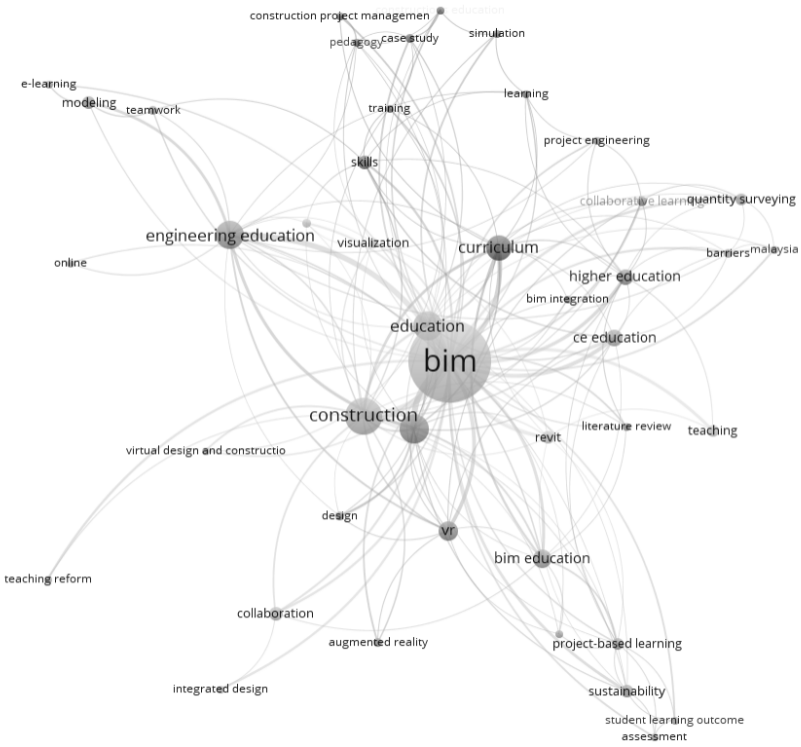


*Fig 2: Data visualisation of existing educational studies in digital built environment*

It is argued that more educational studies in the BE subject are needed to demonstrate how to transform from reactive mechanism to proactive design and delivery of education. The second literature sample targeting digital BE education has been emphasising more on the features of different digital technologies (e.g., BIM) for being embedded in the BE subject. There are numerous studies that illustrated different features for BIM-based digital technologies to be incorporated in various BE disciplines, such as quantity surveying (Xin and Aziz 2020). But few studies on digital BE education were found for specifically responding to the pandemic, nor have they sufficiently demonstrated how BIM or other digital technologies could be embedded in higher education in response to any future pandemic. Nevertheless, the nature of digitalisation has the potential for promoting virtual pedagogy. The question remains as to whether digitalisation education in BE could be standardised for post-pandemic teaching delivery, and whether it is also discipline dependent. Both gaps and opportunities could be found from the review of BIM-featured digital BE education for post-COVID-19 pedagogy. BIM or other digitalisation courses could be delivered in a virtual or blended mode, which serves as a primary means to deliver educational activities amid the pandemic.

By comparing the keywords from the two literature samples as displayed between Fig 1 and Fig 2, as well as between Table 1 and Table 2, several shared topics can be found. For example, these themes could be identified from frequently studied

keywords in the two literature samples: remote or e-learning, digital platform, ICT such as VR, collaborative learning, and learning methods (e.g., experiential learning and problem-based learning). These themes which bridge the two literature samples provide key factors of how digital BE education could adapt itself to be more proactively resilient in the post-COVID era.

*Table 2: Data analytics of keywords studied in the literature sample of digital BE education*

| Keyword | C | TLS | F | Avg. Pub. Year | Keyword | C | TLS | F | Avg. Pub. Year |
|---|---|---|---|---|---|---|---|---|---|
| Case Study | 1 | 4 | 4 | 2018 | BIM | 4 | 151 | 196 | 2017 |
| Construction Project Management | 1 | 3 | 3 | 2016 | Problem-Based Learning | 4 | 4 | 4 | 2016 |
| Construction Education | 1 | 3 | 3 | 2019 | Revit | 4 | 7 | 7 | 2016 |
| Curriculum | 1 | 23 | 24 | 2017 | Visualization | 4 | 4 | 5 | 2013 |
| Learning | 1 | 3 | 3 | 2020 | E-Learning | 5 | 2 | 3 | 2014 |
| Pedagogy | 1 | 3 | 3 | 2015 | Engineering Education | 5 | 29 | 29 | 2016 |
| Simulation | 1 | 3 | 3 | 2017 | Modelling | 5 | 6 | 7 | 2011 |
| Skills | 1 | 7 | 8 | 2020 | Online | 5 | 1 | 3 | 2020 |
| Training | 1 | 3 | 3 | 2018 | Teamwork | 5 | 3 | 4 | 2018 |
| Assessment | 2 | 3 | 3 | 2015 | Collaboration | 6 | 7 | 8 | 2015 |
| BIM Education | 2 | 13 | 14 | 2018 | Construction | 6 | 45 | 47 | 2016 |
| Experiential Learning | 2 | 2 | 3 | 2018 | Education | 6 | 28 | 31 | 2015 |
| Project-Based Learning | 2 | 6 | 6 | 2017 | Integrated Design | 6 | 3 | 3 | 2016 |
| Student Learning Outcome | 2 | 3 | 3 | 2016 | Virtual Design and Construction | 6 | 3 | 3 | 2015 |
| Sustainability | 2 | 7 | 7 | 2015 | Barriers | 7 | 4 | 4 | 2018 |
| BIM Integration | 3 | 2 | 3 | 2016 | Civil Engineering Education | 7 | 12 | 12 | 2019 |
| Collaborative Learning | 3 | 5 | 5 | 2019 | Quantity Surveying | 7 | 5 | 6 | 2018 |
| Higher Education | 3 | 11 | 11 | 2019 | Architectural | 8 | 31 | 32 | 2017 |
| Literature Review | 3 | 3 | 3 | 2019 | Augmented Reality | 8 | 3 | 4 | 2019 |
| Project Engineering | 3 | 3 | 3 | 2019 | VR | 8 | 13 | 15 | 2019 |

*Note: C, TLS, and F denote the same as introduced in Table 1. Avg. Pub. Year is the term to quantify the average publication year of the given keyword, indicating the recentness of the studied keyword.*

These key factors can be summarised in six categories, namely adaptation of educational theories, assessment of teaching and learning, the discipline or the subject, teaching methods, delivery approach, and student experience. These six factors are illustrated in Fig 3, which demonstrates a conceptual framework to bridge digitalisation and BE educational resilience.

The two main themes (i.e., higher educational activities and digital-driven BE education) in Fig 3 correspond to the data analytics from the two literature samples. They inform or enable the ultimate goal driven by this study, which is to develop the resilience of BE education in responding to any future outbreak of pandemic. These factors were generated from the thorough literature review and critical analysis of how digital BE education could map the resilience practices of the general education sector in responding to the pandemic, including adapting educational theories, remote learning as the delivery approach, experimental learning as the teaching method, and research-informed teaching, etc.

These six factors shown in Fig 3 can be considered the synergy generated between the overall higher educational studies responding to a pandemic and the existing digital-driven BE education, specifically: 1) the adaptation of classic educational theories can be found in several existing studies in responding to the pandemic, e.g., Oerther and Peters (2020).

It is advised to design online or blended teaching activities by incorporating the different levels of student learning, involving understanding knowledge, application, analysis, and evaluation as defined in Bloom's Taxonomy (Bloom 1956); 2) curriculum development is one of the key proactive measures to prepare for any disruption such as COVID-19 that may create barriers for physical teaching.

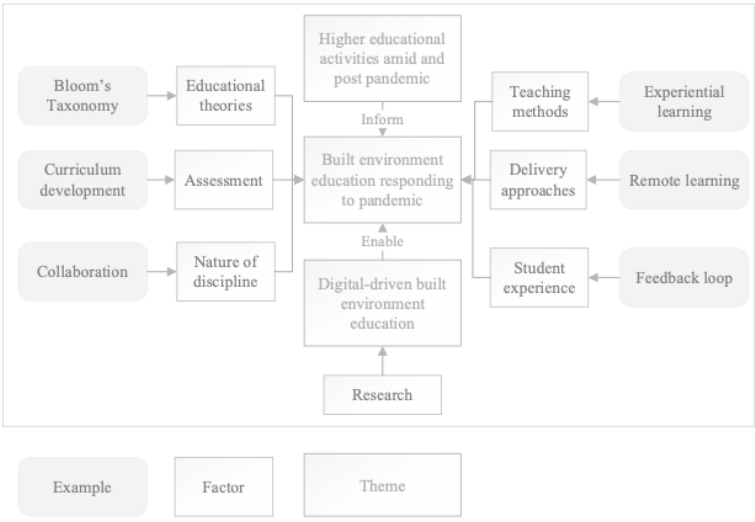


*Fig 3: A conceptual framework for resilient digital-driven built environment education*

For example, flipped classroom as an alternative or mixed with traditional teaching could be designed in a curriculum as inspired from the literature sample (e.g., Revilla-Cuesta *et al.,* 2021); 3) it is worthwhile to investigate the features, or the nature of the discipline as indicated from both literature samples. BE subject is comprised of several disciplines, cross-disciplinary teaching and learning requires a collaborative approach as evidenced from existing studies (e.g., Anderson *et al.,* 2020). It would be a challenge but also an opportunity to develop resilient yet innovative pedagogy in the digital-driven BE education which fits both physical and online deliveries; 4) a variety of teaching methods have been incorporated in educational work from both literature samples. It is not uncommon to integrate different methods of teaching in the higher education. For example, case-based and problem-based learning were designed for remote delivery, as demonstrated in Kalbarczyk *et al.,* (2020); 5) multiple educational studies can be found by adopting remote or online delivery to reduce virus transmission during the pandemic, as evidenced from the literature sample in this study. It is recommended to consider how to balance online and physical education in the post-COVID era; and 6) student feedback forms the loop of continuous development of education resilience. Feedback loop is found as one of the emphases from the literature sample (e.g., Reinhold *et al.,* 2021) crossing different subjects. Whilst addressing the specific features of a studied discipline or subject such as digital BE, the universally learned lessons from other subjects could inform the resilient education of BE.

It is worth noticing that these six factors summarised from reviewing the two literature samples are inter-connected, for example, teaching methods and delivery approach. The current initialised framework will in future lead to further educational studies in the continuous development of digital BE that is more resilient to any interruption. More research methods could be adopted in continuing developing and validating the educational framework, for example, pedagogical case study.

## CONCLUSIONS

This study adopted a literature review approach to investigate how the built environment (BE) education sector had and could better respond to any future interruptions such as pandemic. Two different literature samples were recruited related to the general education sector's responses to pandemic, and the BIM-featured digital BE education respectively. Although the remote-based pedagogical deliveries had been frequently studied in how the education sector had adapted teaching activities amid pandemic, very few references could be found from BE field addressing during-pandemic education delivery. A second literature review focusing on BIM-based digital BE analysed how digitalisation education had evolved since the early 2010s. BIM-related education had evolved from its initial focuses on modelling, visualisation, collaboration, and to more recently, digital skill development and integration with other Industry 4.0 technologies (e.g., VR).

The main contribution of this review-based study lies in that it merged the two literature samples, and initiated a conceptual framework addressing six key elements, namely adaptation of educational theories, assessment of teaching and learning, the discipline or the subject, teaching methods, delivery approach, and student experience. The framework aimed to bridge the existing digitalisation education for BE and its resilience to respond to any future pandemic. These key elements for enhancing digital-driven BE education were generated from the text-mining analytics of the literature samples, for example, remote learning as the delivery approach, and curriculum development addressing assessments. The current conceptual framework would lead to more educational studies in digital BE on how it could rely on its virtual and immersive features to enhance the resilience. Future educational work could emphasise the resilience of BE education, for instance, standardisation of blended pedagogy enabling cross-disciplinary collaborative project-based learning.

## ACKNOWLEDGEMENT

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# Sustainability in the Built Environment

# SUSTAINABLE BUILDING RENOVATION AND INDOOR ENVIRONMENTAL QUALITY

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Indoor environmental quality (IAQ) should be considered for any renovation process. This paper aims at identifying this link pointing out the health effects associated with the renovation process in an educational building. The study focused on four types of spaces: lecture halls, classrooms, laboratories, and staff rooms. This investigated the materials and finishes used during the renovation process for wall painting as well as floor and ceiling finishing. Then further investigation using lab tests were conducted for specimens of wall finishes. This was followed by structured questionnaires with full-time occupants such as staff members and lab engineers, as well as transient occupants such as labours and students to determine symptoms of Sick Building Syndrome. The results showed that wall painting had the greatest impact on IAQ and this corresponds to previous literature. Furthermore, it was found that high VOC was indicated; this was not the result of the material used for wall painting but due to the process undertaken. Also, the surveys enabled determining the short-term and long-term health hazards on different space users and how this varied according to space dimensions and ventilation system. Eventually, the study provides recommendations for proper planning for building occupancy during and after the renovation process.

Keywords: indoor air quality; material selection; renovation practices; sick building

## INTRODUCTION

There is a proven relationship between building construction and Indoor air quality (IAQ). This is particularly true for renovation activities that involve a considerable amount of construction, demolition and finishing e.g., public buildings with intensive occupation density and long stay e.g., educational facilities (Al-Sulaihi *et al.,* 2015). Furthermore, a postulation was made to relate student's health hazards and learning performance with poor IAQ (Al-Sulaihi *et al.,* 2015; Polidori *et al.,* 2013).

Previous research proved that 30 percent of buildings worldwide whether new or renovated receive a high number of long-term health-related complaints. This can be referred to as sick building syndrome (SBS) (EPA and Environments Division, 1991). Building renovation and systems renovation are the main causes for SBS. This is due to their release of a considerably excessive number of pollutants where they act as a potential contributor to unsuitable IAQ. These include high concentrations of Volatile organic compounds (VOCs) and particulate matter (PM) viable and non-viable into the air. Furthermore, the release of excessive pollutants accompanied by inadequate ventilation in the indoor spaces may cause SBS prevalence (Thomas *et al.,* 2019).

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Therefore, this study investigated the relationship between building renovation, IAQ and SBS; taking a case study of a renovated educational building at the British university in Egypt. The research started with a comprehensive literature review about the effect of renovation activities on IAQ. Then, on a case study renovated building, followed a series of steps as shown in Fig 1; 1) observation for the best practices implemented during the renovation process for floors, ceiling and wall finishes in chosen spaces, 2) followed by gas chromatography test investigating the level of VOC emissions caused by wall painting and admixtures and 3) designed questionnaires and interviews to identify the long and short term associated symptoms of SBS. Eventually, the study provides recommendations for proper planning for building occupancy during and after the renovation process.

This study followed 2 approaches presented in Fig 1.

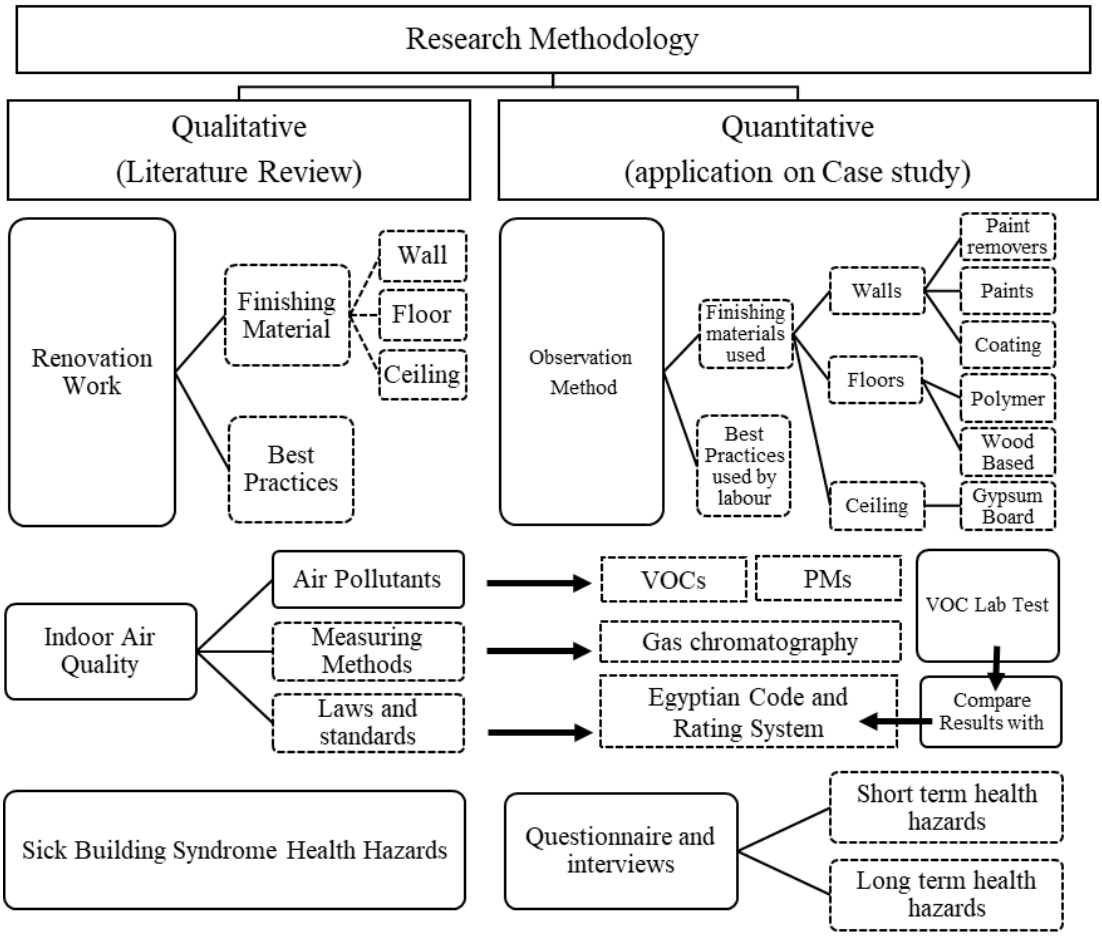


*Fig 1: Research Methodology*

The study started with a thorough investigation to identify the relation between renovation activities, IAQ and SBS. This was determined by analysing the previously published literature in the last three years. Elsevier SciVerse Scopus database was used. Keywords were set to identify scholarly output about renovation work, IAQ and SBS. The subject area was limited to environmental science, material science and engineering. The results showed a number of publications in terms of SBS and its relationship with renovation work and IAQ-as shown in Fig 2 (left). Furthermore, a number of publications investigating the renovation work independently were identified, and then any included work was screened to identify relations to different SBS effects and presented in Fig 2 (right). The analysis of scholarly output about IAQ

of building renovation was divided into three groups with different SBS effects (wall, floor, and ceiling). Moreover, the analysis showed that walls (structure) received the highest focus in this research scope. However, further screening of the results showed that wall renovation in terms of finishing material was neglected. Hence, this research investigated the chemical composition related to wall renovations in term of finishing materials and their effect on human health.

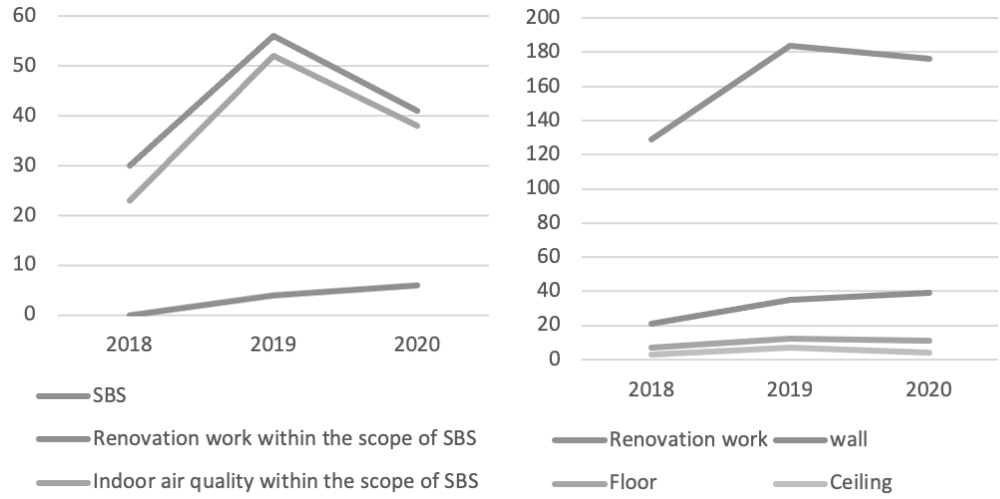


*Fig 2 relevant publications in year and scope*

## LITERATURE REVIEW

*Establishing the relation between IAQ, SBS and the building renovation process*
According to previous studies, IAQ was discussed in relation to space design, different sources and pollution conditions as well as human activities and behaviour. This affects indoor temperature and relative humidity, noise, climate change and carbon dioxide emissions. Moreover, studies showed various frameworks addressing occupants' exposure to the indoor environment using VOC data obtained through passive sampling (Schlink *et al.,* 2016). In general, building renovation is regarded as a sustainable solution with less environmental impact and carbon emissions (Balaban and Puppim de Oliveira, 2017; Kylili *et al.,* 2016). However, renovation activities, as well as the selection of building materials, may pose harmful impacts with regards to IAQ (He *et al.,* 2012). Building materials used for renovation may be categorized into three groups: wall finishes, floor finishes and ceiling finishes.

*Significant air pollutants and health hazards*
Particulate Matter (PM) (referred to as aerosol) indicates the presence of air pollution produced by activities in the atmosphere. It is known to cause significant damage to human health when inhaled. Therefore, the reduction of PM levels in the built environment became an essential need to reduce diseases. PM simulation is considered a complex process due to its physical and chemical characteristics. Whereas, during the renovation activities, high concentrations of PM are released containing harmful elements as sulfate, chloride, lead, nitrate and fungi causing inadequate IAQ and health problems. These health problems were categorized by the world health organization according to the duration of exposure to short and long-term effects. The former includes severe impact on the respiratory system such as lung inflammatory reactions, Cardiovascular malfunction and increased death rates. The latter includes respiratory malfunction, lung damage, increased chronic obstructive

pulmonary disease as well as a reduction in life expectancy owing mostly to cardiopulmonary mortality and chronic respiratory diseases (Pope *et al.,* 2016).

Volatile Organic Compounds (VOCs) are identified as air pollutants found at ground level in the atmosphere containing various compounds. It was stated that "A VOCs Compound is an organic compound with a vapour pressure less than 760 Torr (101.3 KPa) and more than 1 Torr (0.13 KPa) at 20 ºC (Derwent, 2007). Furthermore, the Environmental Protection Agency (EPA) identified the VOCs compounds as any substance containing carbon in the atmosphere except for coal, carbon monoxide and carbon dioxide (EPA, 2017). It has been found that VOC concentrations within newly renovated spaces are higher than those found in a normal state of atmospheric air. It is believed that this affects IAQ causing health problems to occupants. Whereas reported toxicological evidence indicates the unlikelihood of organ intoxication but mucous membranes irritation is expected in the nose and eyes. Moreover, discomfort can be expected due to sensory stimuli. This is believed to be caused by occupants' exposure to indoor air containing xenobiotic and anthropogenic molecules (Mishra *et al.,* 2015).

IAQ measuring methods: IAQ detectors should be used to measure the chemical standards and percentage during the renovation process. This should start at the beginning of any renovation activity to account for materials that include VOCs and PM, i.e., the toxicity of chemical composition and solvent used should be assessed. The measuring methods include VOC charcoal tube, gas chromatography, air samples in canisters, radon detectors, metone particulate matter monitor and Sedimentation Method (Dewulf *et al.,* 2002).

IAQ related laws and standards: information on contaminants identification and tracking can be easily obtained worldwide due to air quality laws. Moreover, IAQ is a major concern in Green Rating systems which makes it an important factor for any sustainable building process; design, construction or renovation (Ismaeel, 2019, 2020). Nonetheless, IAQ data is still minimal in Egypt which results in a lack of information related to indoor air pollutants. This was confirmed by D. Wagdi (2015) who stated that one of the main reasons causing SBS is that most of the pollutants found in the IAQ are not clarified in the standard (Wagdi, 2015).

*IAQ investigation through academic literature*

Previous studies concerning renovation activities and IAQ followed three directions; identifying the levels of PM indoors, determining the average duration needed to regain a safe emission level and material selection for proper IAQ. The former showed a lack of benchmarks and variations in local codes and standards. Furthermore, each study used a selected set of VOCs for the test. Previous studies had various conditions whether it is the location of sampler placement (indoor or outdoor), the approximate distance between the renovation activity and the sampler location, sampling duration and different renovation materials. All results stated that PM constitutes health-hazardous agents as lead, sulfate, nitrate, chloride, ammonium and fungi as Aspergillus s Furthermore, PM levels tend to be higher inside buildings even when minimal renovation activity is taking place (Massolo *et al.,* 2010). Another research direction assessed the duration required to reach the normal emission level after renovation activities take place. The passive sampling method was used followed by Gas chromatography. The results indicated that VOC needed two to eight weeks to degrade after renovation activities whereas normal VOC levels might take up to three months (Derwent, 2007). Another group of studies discussed the effect of

using different materials and finishing during building renovation. Different assessment methods were used e.g., field measurements compared to the international standards for IAQ, life cycle assessment of used material, the impact of insulation on the emission levels, different materials capabilities and how varying the combinations of the materials can lead to different results (Morsi *et al.,* 2020; Ros-Dosdá *et al.,* 2019; Thomas *et al.,* 2019).

*Case Study Application*

The study discussed the renovation activities for the educational building (A) located at the British university in Egypt as regular maintenance after 10 years of operation of the facility. Four different types of spaces were selected: a lecture hall, classroom, laboratory and staff office. This provided a comprehensive view of the effect of renovation activities on occupants' health and wellbeing.

## METHOD

The research method started with an observation method for the best practices followed during the renovation process for the floor, ceiling and wall finishes in the spaces shown in Fig 3. This step recorded the renovation process according to the best practices undertaken by the labours, compared to recommendations from international standards e.g., OSHA standards or the Occupational Safety and. Health Act and EPA guide for better IAQ**.** Then VOC lab tests were performed for 4 different colours of a well-known wall painting product widely used in the Egyptian market. This was done using a gas chromatography test to investigate the level of VOC emissions caused by the wall painting and admixtures. The measurement was done following the normal procedure of testing according to Dewulf, Van Langenhove and Wittmann (2002). This was followed by a final step of designed questionnaires and structured interviews carried from March 2018 to March 2019 to investigate the long term and short-term symptoms of SBS. For the purpose of this study, the former was defined as immediate impact and after 2 weeks, while the latter was defined after 1, 3, 6 and 12 months, respectively. These were carried out on a sample of 150 participants who agreed to commit to this study. It was performed to indicate the short-term health effects experienced by workers, students (limited to the school of architecture; from year 1 to 4) and staff members. Similarly, the survey was repeated for the same participants of students and staff to indicate the long-term effect of occupants' SBS. Their distribution is shown in Table (1) to represent a sample of full time and transient occupants. This investigation aimed at assessing a number of criteria based on the previous literature review. The survey included 4 questions.

1. Investigating the type of symptoms experienced in each of the four defined spaces. Participants should choose one or more from a list determined according to previous literature; aches and pains, chest tightness, cough, difficulty in breathing, dry blocked nose, dry skin and skin rashes, fever, generalized malaise, headache, lethargy and tiredness, sore dry eyes, sore throat, symptoms of an allergy such as fever, watering/itchy eyes and runny nose or wheeze.
2. Indicating the duration taken to start feeling these symptoms.
3. Indicating how long they lasted after leaving the space.
4. Indicated if they have any history of chronic diseases.

The results of the survey were then classified into SBS type 1 or 2 indicating exposure period and duration and highlighting the impact on vulnerable occupants with medical history.

## FINDINGS

*During the observation method*

It was generally noted that labours did not adhere to safety regulations of putting their goggles and facemasks during work.

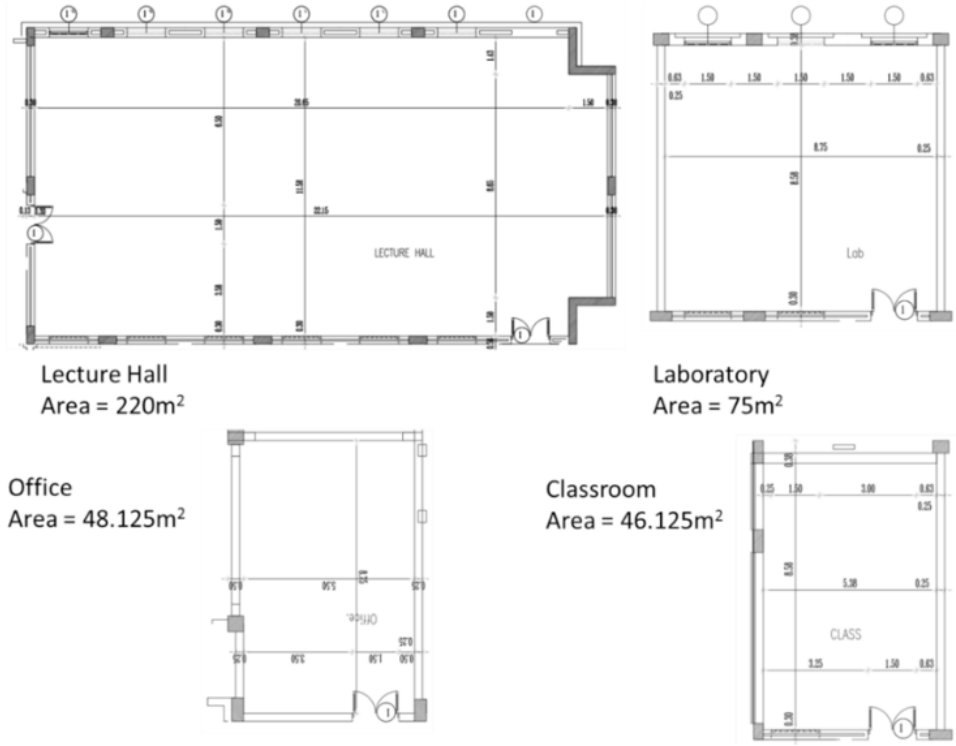


*Fig 3: Selected spaces located on the ground floor of Building (A) at the British University in Egypt*

*Table 1:* The population sample investigating the short-term and long-term symptoms of SBS

| Category of occupants | Short-term | Long-term |
|---|---|---|
| Workers | 12 | 0 |
| Students | 23 | 67 |
| Staff members | 15 | 33 |
| | 50 | 100 |

Further observations for each renovation activity were noted. The floor finish started with a preparation step of the existing surface beneath, removing the old floor carpet, cleaning the surface from any debris and adjusting surface levelling. Then the new vinyl plank flooring was applied on top of the underlayment after cleaning. The vinyl covering was fixed using the adhesives on the back of the planks. Also, wearied false ceiling panels were replaced with new ones following the same modular division of the suspended metal frame. Moreover, wall painting followed a traditional best practice where two-thirds of the paint was diluted with a liquid solvent. It was noted that wall finishing differed for existing and new wall structures. In classrooms, a new wall painting was performed on an old one. It was also noted that an extra amount of paste was added to obtain a smoother surface in some cases. By observation, it was noted that in one hour, workers covered about 7 m2 of an ordinary surface for a single layer of coat.

*Questionnaires and surveys*

The short-term effect was investigated for workers, students and staff members. The major effect was experienced by the former due to working in confined places with poor ventilation, e.g., classrooms, staff rooms, labs and lecture halls. It was noted that all workers didn't use personal equipment and this made them more prone to health effects. Most of them (84%) experienced the same symptoms of nose and eyes mucous membrane irritations, discomfort in the respiratory system, dizziness and asthma. Most students experienced SBS type 1 which developed to type 2 when their stay period exceeded 2 continuous hours in the confined classroom but it is noted that these symptoms developed in a longer 3 to 4 hours in larger spaces such as lecture halls. This affected students' attention and ability to comprehend. On the other hand, staff members suffered from SBS type 1 which developed to type 2 after one week of full-time occupancy. Hence, this caused an increase in sick leaves and absentees. The long-term effect was investigated for students and staff members. Over time, students suffered severe indoor discomfort symptoms which gradually decreased except for those with asthma. This slow rate of decrease was because indoor spaces were not properly aerated. Similarly, staff members suffered some symptoms of SBS but notably less due to maintaining proper natural ventilation in staff rooms. The data analysis showed the percentage of exposed people to SBS during renovation activities in Building A. This was divided as shown in Fig (4) into symptoms appearing in the first month, during the next 3 months and after 6 months of building operation.

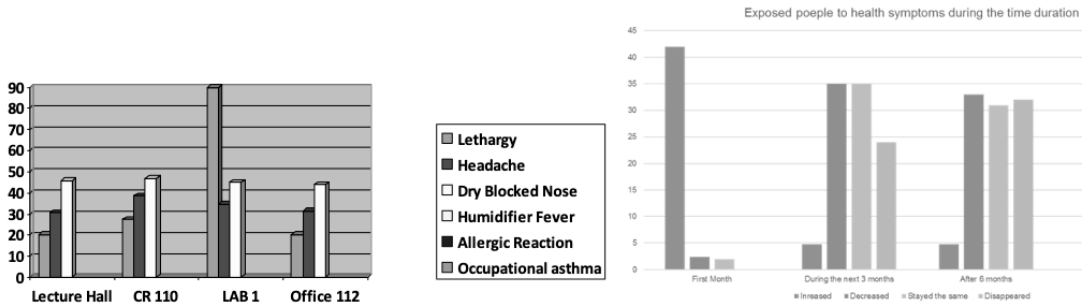


*Fig 4: The results of the online questionnaire*

*The lab test results*

The test results for the used painting product were favourable indicating VOC of 630 PPM, 20.9 % of $O_2$ and 0.00 PPM for both $H_2S$ and Ammonia ($NH_3$) which adhere to the environmental laws in Egypt (Environment, 1994). Nevertheless, the result of a chromatography analysis as presented in Fig 5 indicated a high VOC concentration for one painting product used in the lecture halls located in the ground floor buildings. This occurred during the manual preparation and mixing practices of the liquid mixture paint. The lecture hall used white Paint with a VOC of 5229.4010 ppm. This space had the least percentage of VOC among other spaces. The large space dimension of the lecture hall reduced the perceived impact of the VOC emission level. Hence, during the survey, the majority of the exposed participants indicated that there they experienced the least symptoms of SBS. The laboratory space used the grey wall painting and brown paste of VOC level of 78,217.14 and 814,844.64 ppm, respectively. It was noted that due to the relatively smaller size of the lab space, it demonstrated higher symptom effects as well as the used painting which had higher VOC than used in lecture halls and offices. Also, a considerable number of occupants felt an increase in symptoms. The office space used white wall painting and brown

paste of VOC level of 5,229.4010 ppm. The results showed that the VOC concentration was lower in offices than in labs because the workers used white paint not grey, also less occupancy in that small space reduced the symptoms. Moreover, office spaces were better ventilated which reduced the amount of VOC concentration. Furthermore, the classroom space used grey wall painting and brown paste with VOC level of 78217.14 and 814844.64 ppm, respectively. Hence, the majority of exposed participants indicated that their symptoms increased the most while attending classrooms. This occurred as a result of the poor ventilation and high VOCs concentration.

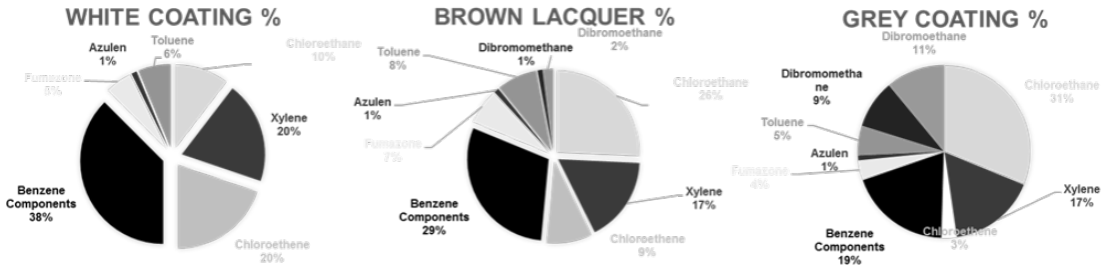


*Fig 5: VOC components result in each coating*

## DISCUSSION

The study pinpointed the importance of adopting sustainable renovation practices, particularly in public buildings. This necessitates accounting for all associated parameters that may compromise the sustainability of the entire renovation process. In the current study the selection of educational institutions which have intensive occupancy rate, pattern and density for all studies spaces which varied in type and dimensions reflected this effect on IAQ. The scope of renovation did not include demolition or new construction of the studied spaces which mitigated several health hazards and minimized environmental impact (Ismaeel and Ali, 2020). It only included new finishing for walls, floors and ceiling. Hence, material selection and construction best practices were the main detrimental to the sustainability of the entire process. Nevertheless, these two factors alone were responsible for several short and long term SBS according to lab tests and occupants' survey responses. Hence, establishing a management and control strategy is a necessity in this regard. This should be performed by revising the material data sheet and regular lab tests for building products. This is in addition to supervision for any manual labour work to ensure it adheres to standards and codes of practices for maintaining IAQ. The novelty of the work is to show with evidence that sometimes-using green materials and products may not be enough to guarantee a sustainable renovation activity if the best practices used still follow the traditional renovation methods. It also shows that IAQ should be monitored and controlled during the entire renovation process or else serious health effects may occur during and after the renovation activities take place. Also, material selection should preferably be investigated during early project stages for proper pollutant source control.

## CONCLUSION

The study pinpointed the importance of adopting a sustainable approach for building renovation in educational facilities and its direct effect on IAQ. This investigated long term and short-term health effects for a number of full time and transient occupants. Hence, sustainable renovation procedures should be undertaken during construction

and before occupancy. This includes a selection of building materials and construction best practices including the wall, floor and ceiling finish both in terms of activities undertaken and materials used. It also requires investigating building materials quality and quantity, and search for market availability for green materials.

The result indicated that IAQ should be planned before any renovation activity takes place. During the construction process, air pollutants including VOCs, particulate matter, ammonia and radon while toluene and xylene, benzene were present in high VOC concentrations. After construction, the concentration of indoor pollutants was high as a result of construction activities then the formaldehyde concentration decreased over time. Ammonia remained high for an average of 12 months. Furthermore, the results confirm the importance of defining the standards and monitoring procedures of indoor air pollutants and the necessity to reduce the presence of harmful emissions in the built environment. This recommends 1) source control referring to material selection in terms of quality, and quantities of materials used and their datasheets, 2) adhering to acceptable emission levels and exposure periods according to international standards and 3) monitoring IAQ during and after construction to ensure workers follow safety regulations and international standards.

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# FROM CONCEPT TO PRACTICE: IMPLEMENTATION OF CIRCULAR BUILDING AS A PROCESS OF TRANSLATION

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The concept of circular building (CB) proposes to transform the current mode of production in the construction sector to mitigate climate changes and reduce fossil consumption. The concept has gained momentum among politicians and academics; however, it is only slowly penetrating the sector. In the paper, we aim at developing our understanding of how this concept is translated into specific organisational settings. Rather than focusing on the actions to support or prevent its dissemination, we focus on how the concept is brought into life as an organisational practice and through which processes and mechanism. Drawing on qualitative data from primarily interviews, we present a case study of two large Scandinavian contractors' efforts to implement CB. The results point at a diversity of positions and choices in translating CB within a specific organisational context. The concept of translation helps us to analyse the shaping of such processes and may consequently contribute to the development of the CB concept by directing attention to how circular ideas and concepts are translated across different contexts.

Keywords: circular building; management concepts; translations

## INTRODUCTION

The built environment is a major contributor to environmental degradation due to its consumption of non-renewable resources. Approaches to reducing, reusing, recycling and rethinking waste and resources in the entire value chain, and to embed the notion of circular economy into all phases of the construction process, play a key role in the green transformation of the industry. In the Circular Economy Action Plan, the European Commission (2020) has drawn up guidelines to promote recycling and reuse of materials. The potential for this is great, as only half of the waste is recycled at EU level. Even in countries that recycle the majority of their waste there is a potential for further developments, as recycling takes place largely through disposal rather than direct reuse. There are several reasons for the scant reuse of materials in the design, production and renovation of buildings. Barriers include uncertainty about the quality

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of reused materials as well as to how to identify, collect and reuse waste. In addition, goal and incentive conflicts among actors discourage pursuit of green targets, and a lack of market standards (Nußholz *et al.,* 2019) for reused material create barriers for turning the concept of circular economy into practice (Ghaffar *et al.,* 2020).

While circularity has gained impetus at societal level as a new normativity endorsed by e.g., political institutions and corporations (Hofmann, 2019), the question, however remains whether companies adopt circularity for greenwashing (Joensuu *et al.,* 2020) or as part of an eco-business logic used not only as marketing also as a business driver (Valenzuela and Böhm, 2017). This directs attention to two interrelated issues of how circularity as a concept is translated and become embedded at an organisational level, and what organisational as well as institutional factors shape this process. In the paper, we thus analyse how circularity is translated into organisational practice in two large contracting companies in Sweden and Denmark. Drawing on translation theory, we discuss differences in the processes and mechanisms through which circularity is shaped and attains status of a particular environmental concept. Drawing on cases in two different countries allows us to account for contextual differences and go beyond understanding circular construction as a singular concept to instead conceive it as a plurality of practices and ideas shaped by local processes and influences.

In the next section, we introduce the concept of Circular Economy (CE) and Circular Building (CB) in Denmark and Sweden. We then explain the theoretical framework used in the analysis, drawing on selected concepts of translation theory. This is well suited for the purpose of understanding how ideas are adapted to local contexts as they diffuse. Next, we present the empirical data and methodological considerations, before proceeding to the parallel analysis and findings of Danish and Swedish experiences. In end, we point to the diversity of positions in the process of translating circularity, and the implications hereof for the diffusion and adaption of circular building as a concept.

## From Circularity to Circular Building: Translations of a Concept

Originating from Industrial Ecology, the concept of Circular Economy focuses on optimising industrial systems to develop a new economic model of production and consumption (Leising *et al.,* 2018). Recently, the concept regained attention due to a series of reports promoting the opportunities of CE to "redefine growth, focusing on positive society-wide benefits" by "gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system" (Ellen MacArthur Foundation, 2015). CE involves a paradigmatic shift from a linear model of consumption to a circular one, maximising the use of materials through the creation of a closed-loop economy (Gallego-Schmid *et al.,* 2020). CE has been mobilised by the EU in its circular economy action plan with specific focus areas for promoting circular principles throughout the lifecycle of buildings. This include (1) enabling reselling of materials by updating the construction product regulation, (2) introducing recycled content requirements, (3) promoting circular design initiative focusing on improving durability and adaptability of buildings, (4) integrating LCA in public procurement, and (5) revising the EU material recovery targets and initiatives to increase sustainable and circular use of excavated soils. In the last taxonomy report, four targets to prioritise economic investments were identified, including new buildings, renovation, individual measures and professional services, and acquisition and ownerships. To do so, the EU policy-framework place businesses and consumers as key actors to drive the transition process and at the same time warn that: "Meeting

eligibility criteria for new constructions, renovations and acquisitions may result in additional costs in comparison to business-as-usual practices" (RICS, 2021).

In Denmark, the notion of CE has been an emerging part of the political agenda recent years. Approaches to reducing, reusing, recycling and rethinking business models (Advisory Board for Cirkulær Økonomi, 2016) have been a driver for the political ambitions to further the green agenda. The recent national strategy for sustainable construction (Regeringen, 2021) only contains one mention of circular economy when highlighting the ambition of reducing the construction sector's carbon emissions with 0.8 million tons by 2030. To achieve this, the strategy highlights the following means: (1) gradual phasing in of limit values for climate footprints from buildings, (2) further development of LCA and LCC, (3) promoting fossil-free construction sites, (4) safe and healthy recycling in construction to promote climate-friendly building materials, (5) reduction of on-site waste, and (6) targeted energy efficiency efforts. These means include both existing and new initiatives with which there are no prior experiences.

Also in Sweden, the concept of CE has been part of the political agenda for the last decennia. The government defines circular economy as a tool to reduce resource use in society and the environmental impacts that follow from it. In relation to CB, more resource-efficient use of the materials in each cycle should increase their lifespan and economic value, while reducing both the extraction of new raw materials and landfill waste (SEPA, 2018). The strategy for the transition to CE focuses on developing CB through (1) sustainable production and product design; (2) sustainable ways of consuming and using materials, products and services; and (3) non-toxic and circular material cycles as driving force for the business sector and other actors with measures to promote innovation and circular business models (Ministry of Environment, 2020).

**Theoretical Frame**

Translation can be defined as 'the process in which ideas and models are adapted to local contexts as they travel across time and space' (Lamb and Currie, 2012) through a combination of institutional pressures and stakeholder initiatives (Hultin *et al.,* 2020). The concept is mobilised to explain how ideas travel and shift from abstract ideas to objectified or enacted practices in a given context. This shift includes the processes of dis- and re-embedding (Czarniawska and Sevón, 2011).

Disembedding describes how an idea, concept or model is moved from its institutional surroundings, and translated into an object such as a text or a picture that is able to travel in time and space (Czarniawska, 2008). As the idea enters a new organisation, it has to be modified to fit its new context and in doing so, it acquires a new meaning. This re-embedding process (Wæraas and Nielsen 2016) allows actors to make sense of a new idea in their own settings. During this process, some aspects of the idea may be kept, while others may be reshaped to align the idea with existing conditions (Sahlin and Wedlin, 2008, Hultin *et al.,* 2020). The attention is then on why and how actors choose particular ideas among the numerous options available (Czarniawska, 2008).

The role of modifying is often the tasks of managers, but their different contexts may give rise to interpretations (Spring and Unterhitzenberger, 2020). Sahlin and Wedlin (2008) furthermore distinguish between what they call programmatic and technical elements of a certain practice. The programmatic elements refer to the ideas, aims and objectives of a certain practice, whereas the technical elements refer to concrete tasks, routines, tools and techniques. They underline that the exclusive adoption of certain

tools may serve as a Trojan horse as a focus on implementation may hide programmatic aspects of the practice yet can transform the organisation radically.

We use this framework to focus on how different elements of CB are translated into organisational practice. Our focus is on the role of different actors, and the processes of re-embedding they take part in. We will accordingly not focus on disembedding, however, in the discussion we will mobilise the distinction between programmatic or normative elements to highlight the status of the measures taken in the two companies.

## METHODS AND DATA

The paper builds on data from two ongoing, individual research projects in Denmark (2021-23) and Sweden (2018-23) that analyse relations between waste management practices and the wider transformation, which the industry is expected to undertake in implementing circular principles. Both projects draw on interpretivist approaches and combine qualitative methods including interviews, site visits, meeting observations, and document analysis (Bell and Bryman 2018).

The material for the Danish study encompasses six interviews. Three with respondents at top management level and three at project /construction management level. Various observations at projects meetings and strategy talks provide insights in the contractor's long and short-term agendas and strategic approaches from different views. The Swedish project, so far, includes 31 interviews with 41 respondents and 12 visits and observations. For the purpose of this paper, we have focused on one large contractor, where five interviews with 11 respondents and two site visits have been conducted.

All interviews have been analysed according to the themes developed in iteration with the features of circularity and the theory. We followed an abductive approach (Dubois and Gadde, 2002). Initial interviews were general in relation to the topic of waste management, while later interviews focused on collecting detailed data in relation to the theoretical framework to ensure a basis for comparison. The cases differ on many dimensions, and it is difficult to generalise the findings. This has however not been the purpose of the paper, as our interest has been in understanding embedded processes of agency, and factors that shape the diffusion of a new concept.

## FINDINGS

The empirical findings are presented in this section focusing on each case company in turn. For each case, we describe 1) how the company communicates its CB efforts, 2) how managers in staff functions work with CB, and 3) how CB is practice at a project level. This will enable us to shed light on three issues from the theoretical framework, namely what meaning is associated with CB in the organisation, what role managers play in modifying CB, and the specific ways in which CB is embedded.

### The Danish Case

The Danish case contractor is a large company with approximately 1.000 employers and construction sites all over Denmark. The company is heavily involved in a series of sustainability initiatives in collaboration with different stakeholders, and a few of these are directly relating to the notion of circularity. Most notably is the development of a resource assessment system that can be used to give an overview of CO2 savings on construction projects. This is initiative is part of an industrial R&D project and has only been tested on select case projects. The company has nevertheless used it for marketing purposes. The contractor has also joined forces

with a company that uses recycled wood for secondary building components. This collaboration is used to gain knowledge about reusability, but also for branding of circular construction methods.

In the organisation, CB is described differently, but there is strong acknowledgment of the need for changing traditional linear construction models to circular a thinking even though it is argued that the system is not in place at industry level. CB is linked to existing process optimisation methods and approaches (e.g., lean construction), which are a cornerstone of the corporate DNA, and respondents draw parallels between these and CB. The argument is that lean has contributed to optimising work processes, and therefore it is natural that also CB is understood an optimisation tool. CB is mobilised in the company through collaboration initiatives and is vocalised through information meeting and in the upcoming company strategy. At present, there is not a formalised CB strategy, nor any guidelines for implementing CB into projects. The initiatives are exclusively based on personal motivation among or stem from client demands e.g., to use certification schemes such as DGNB. Management is nevertheless actively trying to diffuse CB ideas into work practice in different ways. New specialisation areas and employee titles have been introduced in the organisation, with a head of sustainability recently appointed, and LCA and LCC tools are used to calculate material and waste streams, and to make assessments of projects. CB is also used as a competitive tool in an narrative fashion to win construction projects. The approach has been part of the contractor's agenda for a long time. In recent years, and in parallel with an increased focus on CB, the variety of tools used for winning the clients' interest and competitive tenders has widened. The toolset still includes time and cost optimisations, but now has an increased focus on specific green initiatives as e.g., CO2 and waste measuring.

At a project level, CB is finding its way into work processes even though the primary focus is on traditional on-site planning and building methods. According to the construction manager of a large renovation project, CB is rationalised by the specific economic benefits it may give rise to, e.g., in the form of savings from the reuse of floorboards, from demolished parts of the building as patches for floor connections on new balconies. On this project, the use of DGNB is planned. This e.g., requires that all waste is weighted, and fragments monitored. Monitoring has however been lacking in the early stages, meaning that time is spent on collecting reports and documentation to fulfil the DGNB criteria. Besides being a DGNB criterion, waste reports are also used to provide insights into how much and what type of waste is produced. Unsorted waste is expensive to deal with, and the construction manager uses this information as a proof for subcontractors and craftsmen to support proper waste sorting.

**The Swedish Case**

The case concerns one of the largest contactors in Sweden. Even though the CB term has not yet entered their public communication, they advertise their collaboration to achieve the goals of the Fossil-Free Sweden initiative, their implementation of a roadmap for a fossil-free construction industry, and their support to the UN goals for sustainability. During the last years, several initiatives have been launched, focusing on reducing energy consumption for production and operation of buildings, including transports. They propose several green certifications depending on the types of building with a preference for Miljöbyggnad, a Swedish certification standard. They demand quality declaration and traceability of material from their suppliers as well as,

in some cases, the possibility of returning unused products. They also have reduced their material consumption and amount of waste produced on site.

Regarding CB specifically, in 2016 the company introduced an open digital platform for more efficient handling of stone, soil and other secondary fillers at construction sites. Through the service, it was possible to transport material between workplaces instead of ending up in a landfill. After three years of exploitation, the platform was closed down as it was argued that the market was not ready to engage in such initiatives. The company moreover argued to aim at identifying areas where the most effective efforts can be made to reduce the material consumption. They advertise their participation to pilot projects led by research institutes on recycling of selected material such as plastic, pipe, steel, aluminium or gyps in collaboration with other actors of the sector. Regarding renovation, they are involved in a project focusing on the reuse of windows in collaboration with a housing company and a windows maker and take part in a demonstration project aiming at using 80 % recycling product for the renovation of a university facility. The company is involved in inter-sector networks to promote circular economy. To measure the environmental impact of a product, the company advocates for the use of environmental product declarations (EPD), life cycle analyses (LCA) and life cycle costs (LCC). However, according to our interviews with site project managers, the diffusion of these practices is far from generalised, and they struggle to give examples and assess the number of projects, which benefit from these measures. The role of the environmental manager is to focus on informing and implementing the different waves of green demands. She introduces concepts and solutions building on the compilation of various sources such as Swedish and European legislation, Ellen McArthur Foundation, and networks, conference and exchanges with other companies. Our interviewee, as many other of the environmental managers participating in the study, struggles to provide calculations demonstrating the economic advantage of increasing handling, recycling or reuse of material. Without clear economic benefit “it is nearly impossible to convince project managers to engage in new practices”. So, to mobilise project managers, a competition has been launched between departments. Every month, the unit producing the smallest amount of waste receives a prize announced in the whole company. Moreover, the amount of waste produced is also part of the KPI to measure the performance of different departments. Drawing on newsletter and annual meetings, their initiatives, goals, regulations and best practices are shared with the rest of the company.

At the project level, there is no systematic planning of waste management and recycling. According to one production manager, even when the construction aims at being certified, the quantity and management of waste can be down-prioritised without too many consequences. Besides, one of the site managers claims: “we don’t always know what has been promised during the contract, so we are not always informed of such details”. The site project managers tend to focus on what they can decide upon rather than then on the broader aspects of circularity. First, whereas they agree on the importance of reducing amount of material, they see the implementation of circularity principles as a very small aspect of their daily job on site. Second, they do what "the client ask them to and during the production of building, usually there is less rather than more budget". Besides, they also claim that they do not have the power to engage or negotiate with the products suppliers to instigate new cooperation or development towards circularity. The examples they give of their own actions relate to a better consumption of material, the opportunistic possibility to transfer the

surplus of material to other sites, and the increase of waste sorting. They tend to dismiss the storage of recycled products and material for a later use as it is "better [to] discard things now rather than collecting, stocking and discarding them later anyway".

## DISCUSSION

As the two cases have shown, there are both similarities and differences in the how the concept of CB is understood in the two companies, and how it is brought into life as organisational practices. Table 1 summarises the different practices that the companies have undertaken in relation to re-embedding central CE concepts, as presented in the previous section on circularity and circular building, and highlights stated barriers.

*Table 1: Dimensions of CB re-embedded in the two cases*

| Dimensions of CE | Danish case | Swedish case |
|---|---|---|
| Redefine growth | Not mentioned | Not mentioned |
| Decouple economics from finite resource consumption | Not mentioned | Not mentioned |
| Focus on society-wide benefits | Articulated intent to contribute to a transition | By improving current practices |
| Design waste out of the system | Select examples for specific products | Rather recycle existing waste, focus on specific material |
| Promote the concept of circular economy | Changing employer titles<br>Internal dissemination of CE at meetings, etc.<br>By embedding CB in resource assessment tool<br>CB is used narratively as competitive tool | Transforming vocabulary<br>Building legitimacy with external network<br>Branding CE<br>Audit for dismantling buildings and handling materials<br>No changes in goal, value, benefit<br>Projects still assessed under linear economy |
| Enable resale of materials | Only if there are economic benefits<br>Collaboration with re-sale company<br>Storing waste/materials | Stockage of material to be reused |
| Promote circular design initiatives | Lifecycle analyses<br>Offers waste sorting<br>Resource assessment | Show case<br>Standardisation<br>Material certification<br>Building certification<br>LCA<br>Dismantling buildings |
| Revise material recovery target | Not mentioned | Pilot project with suppliers |
| Barriers mentioned | System not in place at an industry level | No market for reuse<br>No recycling market<br>Sector not ready<br>Unsecure risk investment |

As previously stated, re-embedding entails a modification of an idea that allows actors to make sense of it in their own settings. As can be seen, the translation of CB is quite diffuse. Both companies struggle to translate what circularity entails in a specific contracting practice, and the specific tools and methods that are employed are related to established industry standards in both countries most notably in the form of LCA methodologies and certification schemes. In addition, the majority of the efforts can be considered quite piecemeal. Small and incremental changes are implemented. In the absence of CB strategies, the project levels of the two cases opt for practices that fit within existing structures rather than designing new, systemic approaches. In the Swedish case, the modest re-embedding is motivated with reference to a lack of market mechanisms and supporting field structures. This is also the case in Denmark as illustrated by a department director who claims: "It's everyone's responsibility to change the industry […] we need to push the finish line, so we don't get used to something. The norms need to be pushed."

An interesting finding in relation to the Danish case is that attempts at re-embedding CB in existing tools are made. CB is thus translated in relation to lean construction, which is firmly embedded in the company. This means that CB acquires the status of an optimisation approach instead of a radically new economic logic that entails a redefinition of growth and a decoupling of economic activity from the consumption of finite resources, as proposed in the European Action Plan.

Another interesting finding is that there is an absence of ownership to the translation process. The literature often argues that 'managers' perform re-embedding by adopting a given innovation (e.g., Love and Cebon, 2008). Who the managers are, is often not explicated, but normally it is executive managers who are accorded this status. We show how actors at different levels and functional areas of the organisation contribute to the process. This might account for the limited scope and impact of the translation process so far. The question of who 'owns' the transition to the circular economy is relevant to reflect on. Is the lack of ownership and direction a straitjacket or strength in relation to the diffusion and adaption of CB? This question remains to be answered. Nonetheless it is interesting to observe how differently CB is seen at the different levels of the organisation. Not surprisingly, sustainability managers in the Swedish case refer to the foundations of the concept, Ellen MacArthur publications and the broad discourse on sustainability, whereas CB in the Danish case is seen as a strategy for winning bids, a process optimisation method, and a question of waste handling on-site.

Returning to the issue of programmatic and technical elements of a practice, which we introduced in the theory section, we suggest that our findings illustrate that CB is associated more with implementing specific tasks, routines, tools and techniques than with something that fundamentally changes established ways of working or challenges existing systems. The companies re-embed CB in the form of mandated methods even though they knowingly work within the boundaries of a traditional 'linear' model of consumption and question the relevance and impact of the associated practices on the climate. The programmatic element of CB arguably necessitates more fundamental behavioural and structural changes. As argued by the Head of Sustainability in the Danish cases: "I think they [the craftsmen] are focused on working and less on other stuff. We have to articulate it [CB] as a new culture. We have to address that it is something that we need to get good at […] Maybe nudging or technical solutions? It is a balance between sticks and carrots. We need to make it [CB] a part of us, and a part of our practice."

## CONCLUSIONS

In the paper, we have taken the first steps at analysing how the concept of circular building is translated from abstract idea that permeates policies and industry initiatives at transnational and national levels to specific practice in two contracting companies in Denmark and Sweden. The analysis displays certain similarities but also differences between these translation processes. Common for the cases is that the translation is somewhat hesitant. Many of the local translations take the form of an implementation of specific tools or techniques, rather than of programmatic elements, associated with CB. Whether this may be a Trojan horse for a potential transformation of the organisations remains to be seen.

The analysis here is thus still at its preliminary phases, with more data to be collected and more elaborated analyses to be conducted. The Danish material is particularly under-developed, as this research project is still in its very early phases. Moreover, the analytical approaches remain to be elaborated. Future research will attempt to link the specific translations to questions of contextual differences to account for field-level influences on patterns of diffusion. Another unexplored question concerns the role of multiple translators in processes of re-embedding. Following a more conventional ANT-approach (Callon, 1984) this will focus on how the interests of different actors are translated across levels of functional areas of the case organisation. Nevertheless, we hope that the tentative analysis can generate some interesting early insights into how an increasingly important policy area, circular building, is translated from abstract idea into specific organisational practice.

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# TOWARDS ZERO CARBON BUILDING REFURBISHMENT: A NEW CONCEPTUAL FRAMEWORK FOR DECISION SUPPORT TOOLS

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To alleviate the climate change impacts, the construction industry needs to enhance the carbon performance of both new and existing buildings. The purpose of this paper is to examine the current decision support tools for building refurbishment and their applications to zero carbon refurbishment in the early design stages. A critical review was conducted with the final selection of 15 state-of-the-art decision-making tools for building refurbishment, which might be suitable for emerging or modification into zero carbon refurbishment decision support tools. Based on existing evidence, a conceptual framework is proposed for future development of zero carbon refurbishment decision support tools. The study provides perspectives on the lessons-learnt for the future development of zero carbon refurbishment decision support tools such as the application of the carbon budget and Value-Focused Thinking in the goal-setting stage, the inclusion of refurbishment strategies, the involvement of project stakeholders and end-users throughout the refurbishment process and the potential integration of incentive schemes to take up zero carbon approaches. The insights gained from this better support the construction industry to develop and deliver zero carbon refurbishment projects.

Keywords: zero carbon; refurbishment; existing buildings; decision support

## INTRODUCTION

In the light of climate change, the world wrestles with reducing global warming to no more than 1.5 degree and achieve net-zero greenhouse gas emissions by 2050. Having responsibility for more than 40% of international energy use and one-third of global greenhouse gas emissions (Lucon *et al.,* 2014), the building and construction industry can significantly contribute to reducing climate change impacts. To decrease carbon emissions, one response is zero carbon buildings (Xing *et al.,* 2011; Pan and Pan 2020). However, the description of zero carbon buildings is confused. At present, the term encompasses several categories, such as "low energy", "low emissions", "sustainable" and even "green" buildings, leading to the problematic process of adoption and implementation. Thus far, Pan (2014) proposed a model using two fundamental dimensions of zero carbon buildings' concept: (1) specific to general, and (2) carbon/energy to holistic sustainability. Zero carbon building

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includes the reduction of operational and embodied carbon throughout the whole life cycle of the building. To achieve net-zero carbon target by 2050, many existing buildings will need to be upgraded, refurbished or renewed as much of the current existing building stock will still be in use in 2050. This study focuses on refurbishing buildings to reduce the highest level of carbon reduction. The term "refurbishment", which represents a "modification and improvement to an existing building to bring it up to an acceptable condition" (ISO 2010; BS_EN 15978 2011). Vilches *et al. (*2017) define the building refurbishment boundaries according to BS-EN 15978: 2011 and EN 15804:2012. These boundaries are the production of new components, transport of new components, construction as part of the refurbishment process, waste management and end-of-life of the substituted and remaining existing building components. Building refurbishment towards the concept of zero carbon buildings defined above is called "zero carbon refurbishment".

Successful zero carbon refurbishment for existing buildings can be attained if effective decisions are made throughout the refurbishment process. Over the years, researchers have paid attention to the design and development of decision support tools to aid the optimal refurbishment solutions (Jensen and Maslesa 2015; Li and Froese 2017; Gade *et al.,* 2018; Serrano-Jiménez *et al.,* 2021). Several systematic reviews of decision support tools have been undertaken in academic studies (Thuvander *et al.,* 2012; Ferreira *et al.,* 2013). The latest review was conducted by Nielsen *et al. (*2016), which provided a state-of-the-art overview of the development of decision support tools in the pre-design and design stages. The authors have identified 43 decision support tools that are applicable in the pre-design and design phase of renovation projects. This view has shown a constant improvement of decision support tools for building refurbishment from the mid-1990s until 2015. However, most of them were designed for sustainable building renovation. The review was also limited to refurbishment strategies, which characterised distinctive levels of building refurbishment, depending on each urban and socio-economic context from different countries (Li *et al.,* 2017; Penna *et al.,* 2019). Apart from a hierarchical process towards zero carbon refurbishment for buildings established by Xing *et al. (*2011), there is a limited number of simple and holistic decision support tools that can address zero carbon problems for existing buildings. Making decisions about the refurbishment of buildings and the incorporation of net-zero carbon target are more difficult as decision-makers must deal with a combination of zero carbon problems and constraints and limitations. This paper examines the present decision support tools for building refurbishment in the early design stages and determines lessons-learnt for developing zero carbon refurbishment decision support tools.

## METHODOLOGY

A critical literature review has been undertaken to assess, critique, and synthesise the literature on decision support for building refurbishment in a way that facilitates a new conceptual framework for future zero carbon refurbishment decision support tools. The critical literature review search strategy used the keywords: "building refurbishment" OR "building renovation" OR "building retrofit" AND "decision making" OR "decision support" in the title, keywords, and abstract fields via Scopus database to ascertain the relevant literature within the scope of the review. Scopus was chosen for the document search because it is the most present, influential, all-inclusive, and broadly used by academic researchers for peer-reviewed literature (Falagas *et al.,* 2007). Initially, 160 papers including articles, review, book chapters, conference papers published in English from 2016 to 2021 were found. Then, the

mainstream chosen for reviewing included top-ranking journals and conferences in the construction field ranked by Scimago Journal and Country Rank (e.g., Building and Environment), publishing the largest number of papers in the research context. 80 papers were examined and evaluated by reading abstracts to confirm that they were relevant to the research scope, which was limited to the decision making in the early design stages including pre-design and design phases. The final selection included 15 state-of-the-art decision-making tools. The reviewed decision support tools were analysed according to six themes: country, target users, types of buildings, functionality, assessment methods and methodology.

## RESULT

The decision support tools are defined as mechanisms or approaches that can assist decision-makers, such as building clients and other building stakeholders, to make informed decisions related to building projects (Nielsen *et al.,* 2016; Jensen *et al.,* 2018). Literature shows that there is a continuous development of decision support tools in the last five years. The reduced version of the up-to-date decision support tools review, categorised according to target users, types of buildings, and functionality is illustrated in Table 1. Aside from those designed in the US, Canada and China, many decision support tools were developed in Europe. European policies have advocated the refurbishment of the existing building stock towards the sustainable development, as demonstrated in the Directive (EU) 2018/844 (European Commission 2018). There were no decision support tools for building refurbishment in Oceania. The majority of tools were designed to support the decision-making for residential buildings rather than other building types. In the past, most of decision support tools were targeted at decisions and evaluation on individual refurbishment projects whilst the current trend moved from individual buildings into multi-buildings (Gade *et al.,* 2018; He *et al.,* 2019; Salvia *et al.,* 2021). The tools were primarily generating and ranking refurbishment solutions and evaluating the economic benefits during the design stage, targeting a group of building professional users who had experience in building energy and cost modelling. Only Kamari *et al. (*2017) developed a new simplified holistic sustainability decision-making support framework, which could be used by non-professional building users in any stages throughout the refurbishment project life cycle.

In view of assessment methods and methodology, many of the designed tools were focused on sustainability, with at least one or two sustainable dimensions such as environment, economy and society. A combination of Life Cycle Costing and Life Cycle Assessment methods was proposed for measuring two sustainability aspects including economy and environment. Details of the methodology used for the development of decision support tools is demonstrated in Table 2. Considering the environmental dimension, both operational and embodied carbon emissions had been assessed in the process of choosing improvement options (Olsson *et al.,* 2016). Whereas Net Present Value and the Global Cost calculated by analysis were predominantly used to appraise the economic sustainability of various design alternatives (Guardigli *et al.,* 2018; He *et al.,* 2019; Penna *et al.,* 2019). Nonetheless, most of the tools have taken environmental and economic aspects as the main concerns, the social aspect has mostly been overlooked. In fact, Serrano-Jiménez *et al. (*2021) considered both impacts and benefits of the refurbishment applications through a procedure of quantifying and weighting multiple social, technical, and economic variables, whilst Kamari *et al. (*2017) engaged the involvement of multi-stakeholders and end-users through the application of Soft Systems Methodologies

with Value-Focused Thinking. Although scholars have attempted to deal with the social issue by setting social criteria and additional parameters, social issues have remained on the fringe of mainstream practice (Jensen *et al.,* 2018).

*Table 1: Summary of key findings from the review of up-to-date decision-making tools*

| Tools | Types of buildings | Target users | Functionality |
|---|---|---|---|
| BECEREN (Olsson *et al.,* 2016) | Residential buildings | Multi-decision makers | Provide alternative improvement options and renovation measures, evaluate different improvement options |
| (Seddiki *et al.,* 2016) | Masonry buildings | Multi-decision makers | Rank different thermal renovation solutions |
| (Jafari and Valentin 2017) | Residential buildings | Homeowners | Calculate the economic benefits of energy retrofitting, determine the optimum retrofitting budget, select the optimum energy retrofitting strategy |
| (Kamari *et al.,* 2017) | All types of buildings | Relevant stakeholders | Audit, develop and assess building renovation performance. Support decision-making during the project's life cycle |
| SWAHO (Li and Froese 2017) | Residential buildings | Homeowners | Enable trade-offs among renovation actions based on the homeowner's perception of sustainability |
| REDIS (Gade *et al.,* 2018) | School buildings | Danish municipality | Support the building owners in choosing which buildings to renovate within a building portfolio, or which renovation actions to initiate across multiple buildings |
| (Li *et al.,* 2018) | Multi-story residential buildings | Relevant stakeholders | Select low-carbon refurbishment solutions for multi-story residential buildings in high-density subtropical cities |
| (Guardigli *et al.,* 2018) | Public housing stocks | Investors | Assess different renovation strategies, evaluate the economic sustainability of various design alternatives |
| (He *et al.,* 2019) | Multi-buildings | Investors | Optimise energy efficiency retrofit investment in numerous buildings under financing budgetary restraint |
| NovaDM (Kamari *et al.,* 2019) | Large-scale residential buildings and social housing | Designers | A constraint-based renovation design support |
| Klimakit model (Penna *et al.,* 2019) | Social housings | Multi-decision makers | A tool for promoting the energy refurbishment of social housing |
| (Napoli *et al.,* 2020) | Public buildings | Multi-decision makers | Support the decision process of regional or local authorities in the context of a large number of energy retrofitting actions of public buildings |
| PARADIS (Kamari *et al.,* 2021) | Residential buildings | Designers | Support informed decision making for optimal renovation scenario design |
| (Serrano-Jiménez *et al.,* 2021) | Residential buildings | Housing managers | Select feasible and sustainable housing renovation strategies |
| PrioritEE toolbox (Salvia *et al.,* 2021) | Public buildings | Local decision-makers | A web-application Decision Support Tool for comparing and ranking a portfolio of energy interventions |

These findings suggest that refurbishment project goals should be based on construction stakeholders and end-users' perspectives and consider wider aspects such as benefits and impacts of refurbishment projects, aside with sustainable aspects.

*Table 2: Summary of methodology used in developing up-to-date decision-making tools*

| Tools | Methodology |
|---|---|
| BECEREN (Olsson *et al.,* 2016) | Case studies. LCC and LCA approaches |
| (Seddiki *et al.,* 2016) | Delphi, Swing and PROMETHEE methods, and Graphical Analysis for Interactive Aid (GAIA) |
| (Jafari and Valentin 2017) | Building energy simulation: eQuest. LCC formulation |
| (Kamari *et al.,* 2017) | Literature review, individual and focus group interviews, and application of Soft Systems Methodologies (SSM) with Value Focused Thinking (VFT) |
| SWAHO (Li and Froese 2017) | A design science method |
| REDIS (Gade *et al.,* 2018) | A design science method |
| (Li *et al.,* 2018) | Identify sustainable refurbishment solutions, assess emission reductions. develop system process, validate with industry experts |
| (Guardigli *et al.,* 2018) | Evaluate the economic sustainability of various design alternatives with the net present value (NPV) and the global cost (GC) |
| (He *et al.,* 2019) | Use a multi-objective optimization model. Validate the model with 27 buildings of non-governmental organisations |
| NovaDM (Kamari *et al.,* 2019) | The IDEF5 methodology for knowledge engineering and ontology development |
| Klimakit model (Penna *et al.,* 2019) | Literature review, workshops, economic analysis based on Net Present Value (NPV) |
| (Napoli *et al.,* 2020) | Collect database of the building stock, develop of the multi-criteria model, apply ELECTRE TRI-nC method, sort the energy retrofitting actions into categories |
| PARADIS (Kamari *et al.,* 2021) | Building Information Modelling (BIM) based decision support system |
| (Serrano-Jiménez *et al.,* 2021) | Apply an iterative design process based on data and experiences from two case studies |
| PrioritEE toolbox (Salvia *et al.,* 2021) | Literature review, using national database, develop a web-based application, test in five local pilots |

The review has demonstrated new decision support tools, which had additional parameters such as impacts and benefits of the refurbishment suggestions, and/or apply for a specific situation in different nations. This might be because these tools were designed for definite purposes and practical cases. Some tools were not available for use online or with local languages and databases. Thus, even though there were many tools developed in the past with the same functionalities, researchers have intended to create new tools based on existing theoretical foundations, making them more suitable in different contexts. The literature showed that there is a lack of tools to support decision-making processes in the early stages for building refurbishment specifically towards zero carbon target.

## DISCUSSION

The development of zero carbon refurbishment and decision support tools for building refurbishment was critically examined. A new conceptual framework for the future development of zero carbon refurbishment tools is recommended based upon the analysis and is provided in Fig 1. Overall, the development of the conceptual framework for zero carbon refurbishment is based on the theoretical framework of the

refurbishment process in the early stages, including five main parts: (a) Goal setting; (b) Building diagnostics; (c) Refurbishment strategies; (d) Refurbishment actions; (e) Performance evaluation. For zero carbon refurbishment projects, there is a need to examine the carbon measurement and performance, employ the refurbishment strategies towards zero carbon, engage with construction stakeholders and end-users, and consider the incentive schemes in a way that enable maximum the carbon reduction.

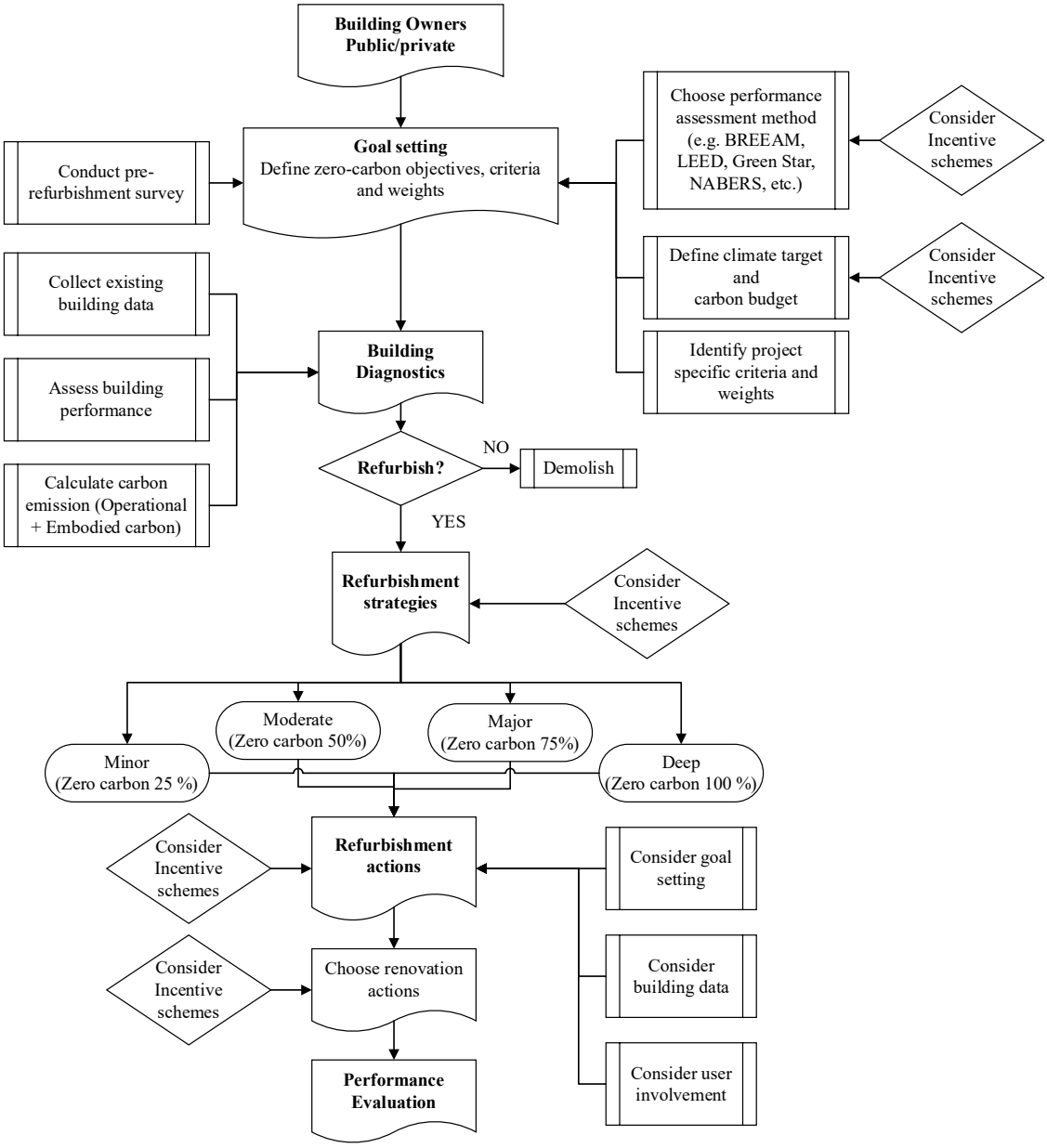


*Fig 1: A conceptual framework for future zero carbon decision support tools*

## Setting the right goal

Setting the right goals is the first step in the refurbishment process (Ferreira *et al.,* 2013; Nielsen *et al.,* 2016). For zero carbon refurbishment project to be successful, a building's life cycle carbon performance must be integrated with other project criteria, particularly clients' requirements and stakeholders' values. The concept of Value-Focused Thinking introduced by Keeney (1992), with the emphasis on the goal-setting aspect of the decision-making process, has been applied in a few recent decision

support tools because it promoted the uptake of sustainable building renovation while satisfying the client's preferences and requirements (Olsson *et al.,* 2016; Kamari *et al.,* 2017; Gade *et al.,* 2018). As such, an implication for the future development of new decision support tools for zero carbon refurbishment projects is using Value-Focused Thinking as a fundamental basis to identify project criteria and weights. Moreover, there is potential for the use of carbon budgets for individual buildings suggested by Chandrakumar *et al. (*2020), to help define the carbon performance goal in decision support tools for zero carbon refurbishment. A meaningful zero carbon refurbishment decision support tool should consider the carbon impact of its building in order to achieve net-zero carbon target by 2050.

**Renovation strategies**

Research on zero-carbon strategies for building refurbishment is limited. In the UK, Xing *et al. (*2011) established a hierarchical process towards zero carbon buildings refurbishment. Nevertheless, this concept may not be applicable in all building types as Dotzler *et al. (*2018) argued that it might be more efficient to refurbish the building services in the first place. Different countries may adopt different renovation strategies, for example, the UK has committed with decarbonising British electricity, and as a result, carbon emissions from electricity have fallen 46% in the three years to June 2016 (Staffell 2017). Recently, partial or over-time refurbishment strategies seem to be a trend in some nations towards sustainable refurbishment (Jensen *et al.,* 2018). For zero carbon refurbishment, long-term strategies also need to be established with regard to partial refurbishment, particularly the carbon budget can be established (e.g., 25%, 50%, 75%, 100% carbon reduction) in the early stages and achieved over time.

**User-centred refurbishment process**

User-involvement in the decision-making process is critical for bridging the "energy performance gap" and improving occupant well-being (Ma *et al.,* 2012). However, in the early phases of a refurbishment project, the involvement of end-users is often ignored before making final decisions (Jensen and Maslesa 2015). Prior to the work of Li *et al. (*2018), which reflected user-habits and methods of assessing emission reduction in the process of selecting refurbishment solutions, the role of end-users was largely unknown. Users should be involved in both goal setting and choosing refurbishment stages, aiming to generate appropriate refurbishment actions. For example, a biomass boiler can be a good selection in the case of low levels of user dependency (Kesidou and Sorrell 2018). Future decision-making tools must be able to consider user-involvement throughout the refurbishment process.

**The potential of integrating incentive schemes in future decision support tools**

One criticism of the literature is that there are many decision-support approaches and tools available while the uptake of high-performance building renovation is very low. For example, despite much of the previous research has aimed at developing more sophisticated Life Cycle Costing models and tools, Gluch *et al. (*2018) claimed that managers' interest in these refinements seems limited. Government incentives, rewards, and tax policies could potentially drive consumer's and developer's decisions towards low-carbon building interventions. Penna *et al. (*2019) has encompassed the public incentives in the decision support tool to reduce the payback period and increase the cost-effectiveness of the refurbishment solutions. A robust energy intervention selection framework could be used to integrate set of government policies

and practices (Perera *et al.,* 2018). Such interventions should be integrated in decision support tools to drive users to make zero-carbon decisions for refurbishment projects.

## CONCLUSIONS

This study set out to examine the current application of decision tools to zero carbon refurbishment for existing buildings. The literature review showed how future zero carbon decision-making tools can be developed to better support building professionals in the process of building refurbishment. The findings provide a new understanding of decision support mechanisms for zero carbon refurbishment projects. The analysis of the climate change target and carbon budget undertaken here, has extended our knowledge of setting the right goal for zero carbon refurbishment projects. The involvement of project stakeholders and end-users in the building refurbishment process is supported by the current findings. When zero carbon targets are considered in the project goal and criteria, there is a need for a balance among stakeholder's values, end-users' interaction and benefits, and other project requirements. Developing acceptable specific refurbishment strategies for the zero-carbon refurbishment project is required, especially partial refurbishment strategies that can be established and achieved over time. The integration of incentives schemes is possible to take up zero-carbon approaches. Tools are created to not only support decision-makers but also encourage them to lead the uptake of zero carbon projects. Overall, this research provides implications for the future development of zero carbon refurbishment decision support tools, better assisting the building sector to develop and deliver zero carbon refurbishment projects. However, being limited to empirical data, the study lacks practical implications for specific building situations. Further experimental investigations are needed to evaluate the proposed framework through the development and implementation of case studies.

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# CIRCULAR BUILDING AND NEW BUSINESS MODELS: WHAT OPPORTUNITY FOR THE CONTRACTORS?

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Social and political forces are advocating the need to shift towards circular economy, defined as a restorative and regenerative economic system where resources are retained and reused and which should replace the current linear economy of take, make and dispose. This is a radical change for the construction sector which has for a long time considered the management of waste as not been part of the tasks of the industry. Demolishing and recycling activities, usually considered as low value work, now received a renewed attention and construction companies are slowly developing new business propositions to include the reuse of waste. Building on the ongoing discussion on green business models, following Teece, we define business model as a 'model' which represents the organisational and financial 'architecture' of a business and includes implicit assumptions about customers, their needs, and the behaviour of revenues, costs, and competitors. Instead of focusing on innovation as an internal process, we understand this development as a dynamic process stretching outside company boundaries. Building on a longitudinal study of construction companies (2017-2020) active in the southwest part of Sweden, we propose to give an insight in how these companies are engaged in developing new business propositions focusing on circular economy, how these propositions have emerged and how they could be transformed in new businesses. The empirical material draws on a qualitative study of 11 companies gathering interviews with 35 practitioners, five sites visits and three observations of meetings and workshop. Our contribution aims at informing how the companies, investing in the dynamic processes of business models, can support innovation in the construction industry and participate to the development of circular economy but also to document what are the main challenges they face in doing so.

Keywords: business model, circular economy, construction and demolition waste

## INTRODUCTION

The recent social and political focus on circular economy is pressing the construction industry to rethink its work process and use of material. In particular, the activities related to the management of Construction and Demolition Waste (CDW) are under scrutiny. To improve the circularity of building material, the life cycle of various products and material is documented to facilitate and encourage the choice of sustainable solutions, and many models are developed to optimise the supply chain and logistic processes. Likewise, demolishing and recycling activities, usually

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considered as low value work, have received a renewed attention and some contractors are now developing competences to include these activities in their portfolio. The European Commission has launched successive initiatives, its first circular economy action plan in 2015, updated in 2020 includes focus areas for construction promoting circular principles throughout the lifecycle of buildings (EC, 2020); the last taxonomy report (EC 2020) identifies four targets to prioritise its economic investment: new buildings, renovation, individual measures and professional services and acquisition and ownerships.

Moving attention from material and technical flows to the creation of a new market, the EU policy identifies businesses and consumers as key actors to drive the transition process and suggests that the additional cost generated by the transition to circular for new constructions, renovations and acquisitions should be supported by the mechanism of the newly created market. "These additional costs can be counterbalanced over time through the expected energy savings and the wider benefits (on health, comfort, lower volume of energy consumption and reduced energy bills, etc.) associated with high-performing buildings" (EC 2020). However, whereas the potential of these new business opportunities has been forecasted by numerous researchers, in practice, it seems so far difficult to transform this potential into profit for the company and most of the construction and property professionals are still struggling to apply genuine circular thinking to their business services and products (Jones and Comfort, 2018). One of the tools to integrate new opportunity and develop new business propositions is the use of business models.

The ultimate purpose of these business models is to increase companies' financial benefit and positioning on the market. These models serve to map the actual core aspects of an organisation and to define possibilities for future developments, in particular the green business models should help to include circular thinking in new business propositions (Lüdeke-Freund *et al.,* 2019).

In this paper, we propose to give an insight how these new business models are taking shape building on the activities of a case company and interviews with 10 other companies operating in the region of Gothenburg. We build on the concept of sustainable business models (SBM) to describe, organise and analyse the processes which have driven toward these changes. The model enables us to decompose the new business models in different components and observe how these components are shaped and organised trough time to create the new propositions.

To do so we draw on the material gathered in an ongoing five-year PhD project with publics and private actors engaged in CDW as well as managers of the companies which have developed business models targeting CDW. We gather their concrete considerations, choices and actions when developing solutions including the circular economy principles. The overall purpose of the paper is to inform about the dynamics and processes which shape the creation of new business models and consequently innovation in the construction sector. While the scope of research on waste management within construction is including the contribution of study of the supply chain, existing work practices, business approach to projects, and technologies to reduce generation of waste, innovative approach to business development is rarely been addressed (Pekuri *et al.,* 2015, Abuzeinab *et al.,* 2018, Berg *et al.,* 2019, Buser and Carlsson, 2020).

## Business Models

The basic assumption of business model is that enterprises can organise and conduct business practice, and that they can create and capture value in doing so. BMs can take many forms, mobilising different components and configurations (see see Saebi and Foss 2015, for a review), but most of the authors agree on a common definition: business models focus on how a company defines a value proposition to address specific customer segments and organise itself and its networks to reach the benefits associated to this defined proposition.

Teece (2010) characterises a BM as a strategic tool "defining the manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit" (p:172). BM describes the organisational and financial 'architecture' of a business and includes implicit assumptions about customers, their needs, and the behaviour of revenues, costs and competitors (ibidem). To be operational it should be sufficiently differentiated to meet customers' needs, difficult to replicate and should lead to competitive advantage (Teece 2010). The use of BM often brings organisational changes for a company however, these may not be limited to the company but request to include a larger group of actors such as company's customers, key stakeholders, and shareholders. (Zott *et al.,* 2011). Common features of Business encompass the dimension below:

*Table 1: Dimensions of business Model (Lüdeke-Freund et al., 2018)*

| Major dimensions | Subcategories |
|---|---|
| Value proposition | Products, services |
| Value delivery | Target customers, value delivery process |
| Value creation | Partners and stakeholders, value creation process |
| Value capture | Revenues, cost |

Value proposition describes the benefits that customers can expect from the company products and services. Value delivery defines the audience of the product or service and how the later are delivered to the customers. Value creation entails the necessary partners to develop the proposition and the process to produce it. Value capture assesses the revenues and costs of the propositions. Building on these dimensions to describe BM is in line with major frameworks such as Osterwalder and Pigneur's "business model canvas" (2009) and widely accepted theoretical definitions (Teece 2010, Lüdeke-Freund *et al.,* 2019). As pointed out by to Baden Fuller and Mangematin (2015) many firms run portfolios of business models: large companies typically have diversified exploiting competencies in different ways across multiple customer groups. This results in different divisions capitalizing on common capabilities to sell products or services one way in one market, and in a different way in another market. The authors underline the lack of information regarding the merits of running these portfolios, and how companies have developed these business models across time and space (2015). They advocate for studying the processes by which managers construct and reconstruct the business models that frame their decisions about their businesses (Demil and Lecocq 2015, Baden Fuller and Mangematin 2015).

## Green Business Models

The attention to sustainability and more recently for circularity has stimulated the development of green business models striving for associating the short-term financial interest of companies to maintain or increase economic prosperity with the longer-term focus of social, environmental and economic sustainability (Schaltegger *et al.,*

2015). However, the incorporation of circular thinking aiming at "decoupling economic activity from the consumption of finite resources and designing waste out of the system" (Ellen MacArthur foundation, 2013) involves a radical paradigmatic change.

This requires a complete reverse of the companies' focus, who thanks to "generations of engineers, operations managers, and business administrators," have concentrate their efforts so far to optimize forward supply chains that conduct resources and goods "from cradle to grave" (Lüdeke-Freund *et al.,* 2019). The authors argue that the companies' fundamental challenge is to rethink their supply chains and use of material and transform the way they create and deliver value (Ibidem page 36). Kirchherr *et al.,* (2017) identify 114 definitions of circular economy and Lüdeke-Freund *et al. (*2019) estimate to 4,445,280 theoretically possible combinations of design options to create circular economy business models.

The shared objective of these countless possibilities is nevertheless to offer a strategic tool to companies seeking to integrate sustainability values and goals in their business. We choose here to build on the categorisation of Bocken *et al.,* (2014) who identify eight sustainable business model archetypes to integrate circular concerns in business purpose and support innovative practices. They aim a categorizing and explaining BM for sustainability providing mechanisms to assist the development of sustainable BM and examples for business to de-risk the green BM innovation process, and finally to contribute to define a clearer research agenda for BM for sustainability (Bocken *et al.,* 2014). The eight archetypes developed are:

- Maximise material and energy efficiency
- Create value from 'waste'
- Substitute with renewables and natural processes
- Deliver functionality, rather than ownership
- Adopt a stewardship role
- Encourage sufficiency
- Re-purpose the business for society/environment
- Develop scale-up solutions

## METHODOLOGY

The present article builds on the findings of an ongoing five-year PhD (2018-2023) project focusing on the adaptation of contractors to the flux of new regulations regarding the handling of waste (Andersson, 2021). Following the sector development during the last three years, the frame of the project has moved from sustainability to circularity demands and from the handling of waste on site to more strategic considerations including the creation of new business propositions. The frame of understanding for the present paper draws on a selective literature review drawing on BMs and green BMs theory focusing on the particularities of the construction sector.

The qualitative study consists of a mixed-methods and employs an interpretive approach to discuss the empirical material (Bryman and Bell 2011). This enables us to gain insights to the specific contexts through quotes, observations, and thick description. The paper builds on a case study of the regional division of one of the biggest contractors in Sweden gathering interviews with 13 project, production and site managers and their environmental manager complemented by visits of three building sites, and observations of two start up meetings where the contractor

introduced a new waste management concept to its sub-contractors. The case study is supplemented with 17 interviews with practitioners including six demolition companies, two environmental managers of two of the larger contractors in Sweden, one large contractor subsidiary and an architect in the Gothenburg region as well as the participation to two workshops and three seminars on the topic of circularity and waste management gathering practitioners of the sector. An overview of the interviewees is presented above in Table 1. The semi-structured interviews enable us to gather the participants experiences and opinions regarding the implementation of circularity principles and practices. The interviews were recorded and transcribed. These sessions were mainly documented with notes and pictures.

*Table 2 - Interviewees' overview*

| Company | Interviews | Interviewees | Positions |
|---|---|---|---|
| 1 of the biggest contractors | 10 | 13 | Project-, production, site-, manager |
| 3 of the biggest contractors | 3 | 3 | Environmental manager |
| Demolitions small - medium contractors | 6 | 10 | Project-, production -site manager |
| | 1 | 1 | Sustainability manager |
| Large contractor - subsidiary | 1 | 2 | Business development manager, |
| Recycling contractor | 2 | 3 | Business developer manager |
| Architect | 1 | 1 | Environmental manager |
| Total | 24 | 33 | |

The document study is based on numerous national and European governmental reports, professional guidelines, certification standards, legal frame and companies' websites. As this study is exploratory, we have followed a rather iterative process between the interviews, observations and the literature (Dubois and Gadde 2002). The material has been organised and analysed according to the emerging themes in a matrix crossing the conventional dimensions of BM and the eight archetypes developed by Bocken *et al.,* (2014).

# FINDINGS

## Value Proposition

The strategies of the three larger contractors in Sweden regarding products development are quite similar. If the following practices are far from being standardised at the level of the project, the companies are nevertheless engaged into experiments to integrate circularity. They have created a handful of pilot projects to demonstrate the feasibility of building out of recycle components like the Epic building in Malmö. They organise stockage of dismantled material such as doors windows for future reuse. They also propose milieu certifications and the use of sustainable material for their new projects. All these propositions which do not necessitate new heavy investments should hopefully answer the need of interested customers, but mostly so far serve as marketing tools.

Our case company have tried to develop new services to customers focusing on the management of waste but without much success. In 2015 they created a subsidiary proposing to collect and handle all types of construction waste for both professional and private customers. However, the scope of these activities is now reduced to the management of excavated masses, asphalt, concrete and soil. If the lack of readiness of the market was flagged as explanation for the downsizing, the numbers of existing competitors and a decrease of turnover for the company are more likely to account for

the decision. In 2016, the company introduced an open digital platform aiming at optimising handling of stone, soil and other secondary fillers at construction sites. The service proposed was the organisation of transport of material between workplaces across projects instead of driving it to landfill. Though having expended to Finland and Norway and counting 16 000 users, the platform was closed after three years of exploitation: “the market was not ready to engage in such initiatives” (company press release). Despite the project being awarded prizes for its contribution to sustainability, the lack of profit and external investments and the decision of the company to re-focus on their core activities drove it to an end.

**Value Delivery**

The target customers are so far mostly public actors such as municipality, administration or university who have specific interest, and funding to push forward the development of circularity but also the responsibility to build according to the coming national regulations. However, pilot projects of circular buildings can also be the results of the contractor's own initiative aiming at selling or renting the facilities to private actors after the completion of the project. In this case, they target "green customers" sensitive to the sustainable, innovative and fashionable aspects of the construction. But as the production of circular solutions is said to be clearly more expensive than the conventional one, the projects managers interviewed avoid including circular features in their design for private clients unless it is explicitly requested. Even though, they witness architects offering the choice between several options including some elements of circularity to their clients such as reuse of doors or windows or upcycling of material and furniture. But according to the project managers, the handling of waste during the project is never a key argument or decision factors for signing a contract. But they do recognise that customers are becoming more attentive to the issue.

Our interviewees rely on green certification of building to provide green value to their customers. Still, they also admit that one can reach the higher level of various milieu certifications without paying much attention to waste and circularity as the milieu standards focus mainly on the energy spent or saved to produce and operate a building. And this even if they are aware of the coming request of delivering life cycle analysis for public procurement. They also noticed that circularity may not "always be sustainable in construction".

If they see the transfer of material surplus from one project to another as coincidental, they value the possibility to reuse their own material such as huts, fences, or formwork timbers from one building site to another. Though it does not seem to be a practice they intend to advertise for their customers as it contributes to increase the profit margin of the project.

**Value Creation**

The development of circular solutions requires the collaboration of a large network of actors for the contractors. The relation to suppliers is expected to transform from a one-way consumers relation to a partnership. For example, our case company is engaged in a renovation project to test a basic process for dismantling and returning windows for circular recycling in collaboration with the product manufacturer and the tenant owner association. The contractor is responsible for the return process in the project and ensures efficient dismantling and return of the used windows. Thereafter, the manufacturer takes over and separates out the types of materials to ensure the recycling of, for example, metals, plastics and glass… Similarly, carpet, floor or

insulation providers propose to take back surplus and even used products, creating a long-term partnership with not only the contractors at the time of the production but also the company responsible of the operation of the building. The few demonstration projects of circular building also draw on a large network of actors to provide not only the material but also the existing, and to be created, competences to design and manage such productions. If this type of pilot projects is not expected to deliver revenues, it nevertheless challenges the traditional tasks and risk divisions between suppliers and contractor and open to new kind of contractual relations. A less risky form of contribution to value creation is the centralisation of material purchase, which enables the company to exercise pressure on their suppliers thanks to the large quantities they order.

The three big contractors are engaged in network of interest with suppliers, products manufacturers, research institutes, and some of their competitors to identify which material would be worth investing in to reduce resources consumption. Led by research institutes these studies aim at assessing the potential of recycling and reuse of material such as plastic, pipe, steel, aluminium or gyps… with sometimes unexpected results like when researchers had experimentally identified the possibility of reusing concrete, providing they could build an oven the size of a warehouse. Our case company has also joined a network of Swedish large companies outside of the construction sector whose task is to lobby for circularity and drive technological development, consumer behaviour and policy forward in four pillars of the circular economy: circular design, sustainable consumption, increased access to and utilization of recycled materials, and circular value chains. So far, the network has concentrated its efforts primarily on the value chains of plastics, textiles and building materials.

However, the interviewees still identified challenges such as lack of trust, loyalty, and transparency between the partners. Since most of companies in the sector tend to choose their partners not only on their competences, but also on their low-price offering. Moreover, they identify the construction unreliable flow of waste, the lack of practical solutions and the juridical issues regarding the quality of recycled material as barriers to be singularly lowered before the type of partnership mentioned above can be implemented as business solutions.

Moreover, the rare initiatives taken towards new value creation are seldom reaching the large majority of projects, which are still following linear work processes. The project managers though sensitive to the issue feel disconnected form the experiences described above.

**Value Capture**

Here we start with the costs as the section on revenues will unfortunately be very short. The notable challenge of these construction companies regarding the management of waste is said to be its high cost, especially the one of demolition waste. The cost variables identified are transportation cost, treatment cost, planning cost, operational cost (sorting on site, quality control of the material), etc. Since, most of the projects of these construction companies focus essentially on cost-driven business models, which builds on minimizing costs as much as possible by utilizing low price value propositions, extensive outsourcing and maximum automation for their projects, it limits drastically their involvement in circularity. Moreover, their collaboration with demolishing and recycling companies is well functioning and the benefit of handling waste already fairly distributed.

But even if we assume that the sector can contribute to produce enough waste to be integrated in the circular loop and contribute to the production of new buildings, our interviewees are still pessimist regarding the potential of CE BM within the actual juridical and economic context. Here, they outlined the challenges related to the low revenue flow of waste, the cost of recycling, the undervalued recycled or upcycled products, and an almost inexistent market for the final product. As summarised by one of the project managers, "why buying something for a higher price to get a lower quality".

However, there is a small niche market for circularity carried by environmentally engaged parts of the public sector and individuals who are ready to invest in such solutions even at a higher cost. Besides, the notion of value should not only be understood in economic terms. Value driven companies are less concerned with the cost implications of a particular business model design, and instead focus on value creation contributing with other benefits to the company such as branding and social recognition. One of the other companies interviewed explained that they hide the higher cost of circular projects by spreading it around in other conventional projects or by adding new services to the buildings (cafeteria, reception desk, etc.) that they know their clients are ready to pay for. Another solution to integrate the benefit of circular economy would be to swap short term value creation which benefits only to the company and its shareholders to long term value creation which should contribute to benefit of all stakeholders. However so far, the environmental managers of the three largest contractors in Sweden have not been able to convince their companies to invest in long term value creation.

## DISCUSSION

If we compare the result of our case study with the list of BM archetypes provided by Bocken *et al.,* (2014), the company is only targeting three of the eight proposals: maximise material and energy efficiency; create value from waste and adopt a stewardship role. They have invested in the maximisation of material for new built, energy efficiency of the production and operation of buildings and optimise the existing practices. The growing interest for green certifications is a sign that the value propositions including sustainable principles are answering a market demand. This trend has already contributed to more integrated design and construction approaches, with a positive impact on the performance of buildings. However, as pointed out by Aho (2013) it does not imply that these new standards participate to the transformation of business model that the circular thinking requires. Similarly, the few show cases of circular building demonstrate the feasibility of such construction but are not so far from generating any substantial revenue. The company is struggling, as do their competitors to create value from waste.

Whereas contractors have invested in some forms of stockage of waste material for reuse, they have not yet succeeded in identifying or creating a market for it. The value propositions still mainly rely on economic revenues and do not yet include long term social benefices and circular principles. There is no tentative to decouple economic activity from the consumption of finite resources (Ellen MacArthur 2015). They timidly attempt to rethink the flow of material within the supply chain by putting pressure on their suppliers and by investigating pilot projects to test material (Lüdeke-Freund *et al.,* 2019). But they do not yet dare to challenge the different roles of the members of the chain. Prolonging the previous work of its Cooperate Social Responsibility activities, the company case adopts partially a stewardship role by

publicly and proactively engaging in different networks and with different stakeholders to advocate for the development of circular principles or by encouraging the use of milieu certified material in their projects. In doing so they contribute to ensure long-term health and well-being for both employees, customers, and the society at large and expect the customers to pay for this contribution (Bocken *et al.,* 2014).

Then again this does not signify that they are able to detach their revenues stream from the classical model of production. We identify a gap between the environmental managers, embedding the efforts towards sustainability and the projects managers who anchor their practice in a business-as-usual understanding, lacking tools, and methods to engage in new proposals (Andersson, 2021). Rather than the market and the demands of hypothetical customers, it seems that it is their own organisation who is not yet ready. So, whereas Lüdeke- Freund *et al.,* (2019) identified a large amount of value creation process options in their literature review, our contractors' companies are still struggling to develop a few solutions enabling them to create revenues.

## CONCLUSIONS

This preliminary analysis of new circular business models in the some of the Swedish construction sector is enabling us to trace the development of some new business proposals. It is clear from the actors interviewed that the pressure on the sector to improve sustainable and circular economy efficiency has been the prime driver for the development of new values propositions and value creations. However, these new business models are still under developments. The EC distant promise to be able to counterbalance additional costs over time through the expected energy savings and the wider benefits (on health, comfort, lower volume of energy consumption and reduced energy bills, etc.) associated to the implementation of circular principles does not seem to be a sufficiently convincing opportunity for our contractors to radically transform their actual mode of production and force the implementation of these necessary changes within their organisation. Instead, they engage cautiously in incremental changes and peripherical initiatives. A closer look at how these initiatives take place and translate or not within organisations and their networks would certainly help to understand and determine why the opportunities for contractors to invest in CBM are not yet realised.

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# WOOD WASTE MINIMIZATION PRACTICES IN RESIDENTIAL CONSTRUCTION

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The construction industry in the United States continues to generate a large amount of waste that is disposed in landfills. A large component of the waste stream emanating from construction projects is composed of wood and wood products. Addressing the problem of minimizing wood waste from construction has large economic and environmental implications. This research investigates industry best practices utilized to minimize wood waste generated by the construction of single family and multi-family housing to determine if these practices can be applied to the industry as a whole. Qualitative research was conducted using semi-structured interviews of construction professionals experienced in wood frame construction. In addition, quantitative research was conducted based on data from the United States Environmental Protection Agency and the United States Census Bureau to quantify the amount of waste wood generated by the construction of single family and multi-family housing. The research indicates that design, schedule constraints and inexperienced labour all contribute to the generation of waste wood. The most effective wood waste minimization practices include segregation and reuse, accurate quantity estimation, and deliveries matching construction sequence. Matching the most effective waste minimizing practices to the causes of waste generation in an economically sustainable manner is the key to wood waste reduction.

Keywords: construction waste, family housing, waste reduction, wood waste

## INTRODUCTION

Historically, construction waste from commercial, institutional, or residential projects account for a large fraction of waste generated in the United States, with wood waste being the second largest component of construction waste behind concrete products (US EPA, 2019). Because of the scale of the construction industry, designing and constructing projects that generate less waste can make a significant difference both economically and environmentally. To minimize the amount of waste generated on residential construction sites, environmentalists, contractors, and designers continue to look for more ways to manage the amount of construction waste generated and to minimize the unnecessary amount of material needed for light-frame wood construction. However, construction and demolition waste continue to be an ongoing issue. According to the latest report published in 2019 by the United States Environmental Protection Agency (US EPA), "569 million tons of construction debris were generated in the United States in 2017, which is more than twice the amount of generated municipal solid waste" (US EPA, 2019). Of this amount, 40.2 million tons consisted of wood products.

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Formulating ways to minimize wood waste on construction projects requires an examination of the root causes that result in the generation of wood waste as well as the reason waste generators fail to take the necessary steps to eliminate waste. The research will investigate methods currently practiced in residential construction that minimize waste generation and maximize recycling wood waste.

## LITERATURE REVIEW

Studies conducted by EPA concluded an increase of Construction and Demolition (C&D) waste generated over the years. An estimated 569 million tons of waste were generated in 2017, the latest data publicly published by EPA, which include buildings, roads, bridges, and other structures in the United States. Of that, about 7% or 40 million tons included wood construction and demolition material waste. Narrowing it down to building related only, in year 1996, the United States produced an estimated 136 million tons of C&D waste, and in year 2017, 184.2 million tons of C&D building related waste were generated (EPA.gov, 2019). Comparing years 1996 and 2017, amounts to an approximate 35.4 percent increase in C&D building related waste in the United States. There are several potential factors and challenges that may be contributing to this continued increase. Waste minimizing opportunities that exist for wood in residential and multi-family structures are investigated in this research. Many states, government agencies and organizations define C&D waste very similarly and sometimes may refer to it as Construction Demolition Waste (CDW). In this study, C&D wood waste is defined as wood framing debris material generated during construction, renovation, or demolition of a structure. This is material that is discarded and disposed and may have been originally intended to be used as part of the construction of a building but was damaged, defected or cut down to scrap material or is a result of material removed during the demolition of a structure. C&D wood can include dimensional lumber, plywood, treated wood, manufactured wood, and engineered wood products. In addition to wood, material considered in this research, other materials that fall under C&D may include concrete, asphalt, metals, gypsum board, roofing materials and specific land clearing debris.

### Construction Wood Waste Impact

There are numerous reasons to reduce wood waste in construction but perhaps the most important is the environmental impact which includes the impact of the natural forest structure, carbon balance and the limited space that remains in the 3000 active landfills in the United States. By reducing and recycling construction materials, landfill space can be conserved and, therefore, reduce the number of new landfills needed in future. In addition, using recovered wood and fibres in place of removing fresh forest biomass reuses biomass which has already been removed from the natural cycle of forest growth structure (Gustavsson *et al.,* 2006). The continued use of new wood material or fresh biomass increases wood material production, reduces natural forests and contributes to global warming. According to a study conducted by Marzouk and Azab (2014), in addition to the conventional construction project objectives of cost, schedule, quality and safety, priority should be given to the problems impacting the environment which include contamination from landfills that lead to serious negative health effects, and the increase in greenhouse gases resulting from the transportation of waste and the processing of new materials.

In addition to the environmental impact, wood waste also effects the profit margins of construction companies. Simply put, wood waste is a commodity wasted. It is the material of choice for residential and multi-family construction in the United States

due the relatively low cost of material and installation. A light-frame wood building can be constructed much faster and cheaper as compared to buildings made of other construction materials. However, while it tends to be less costly than other structural materials, the amount of waste or scrap materials not used as part of the construction can build up and become costly (Multi-Story Wood Construction, 2014). The cost includes not only the material cost of the 3.3 million tons of wood construction waste but also includes the cost of landfill disposal.

**Causes of Construction Wood Waste**

According to Polat, *et al. (*2017), there are 34 contributors or causes of construction waste ranging from design issues, procurement, material handling, storage, construction site staff activities, project management decisions and external influences. Of these 34 contributors, the three causes that result in the most material waste are inexperienced workers, design and construction errors, and the use of conventional design methods.

A large amount of wood waste in construction can be attributed to the activities of workers and staff with insufficient training and limited experience. These activities can include quantity take-offs for wood material procurement or field crew handling the cutting and framing of the lumber material. According to Jing Zhang *et al. (*2005) in "Waste-Based Management in Residential Construction", "…poor quality requires time for fixing or redoing the "product" as well as wasted time and in materials". This can include waste from cutting material incorrectly or errors resulting from an inaccurate quantity take-off.

Design errors and last-minute changes by the architect or changes due to installation errors by the contractor can result in rework of material already installed or material that has already been special ordered, pre-cut or prefabricated. These errors can result in both time, material, and money wasted. These errors can be caused by poor design details that are difficult to construct in the field, last minute changes by the architect or client, design details that call for materials to be cut in non-standard sizes or shapes that result in scrap materials, mistakes during the construction process, lack of work experience by either designer or field staff and, lack of coordination between trades. (Luangcharoenrat *et al.,* 2019).

The traditional or platform design method used in most of today's residential and multi-family construction is also considered a contributing factor to wood waste. The traditional framing method is considered to be a resource intensive form of framing with a high life cycle energy consumption (McGinnis and Fumo, 2018). While moving away from the conventional methods may not eliminate the amount of scrap wood material generated in the field, it will reduce the amount of wood needed to build when compared to newer methods of framing.

**Construction Wood Waste Minimisation Methods**

The "three R's" (Reuse, Reduce and Recycle) are the primary ways to minimize wood waste on construction projects. One of the first activities that takes place before construction of a new residential housing development or multi-family building is the site clearing which can include the removal of existing structures located on the project site. Wood waste generated during the demolition phase or from material left after construction can produce either valuable waste or valueless waste. Valuable waste can be reused directly as construction material for another project or regenerated to be used in another form such as particle board, wood mulch, and wood

compost. The volume of valueless waste is disposed of in landfills (Zhang *et al.,* 2005). In place of choosing to demolish a building, some buildings may qualify to be deconstructed (US EPA, 2019). Deconstruction is the removal of a structure by dismantling it piece by piece in place of quickly knocking it down. To reduce the cost of deconstruction, which tends to be much greater than the cost of a whole-house demolishment, the structure can instead be "soft stripped" or go through a process of selective deconstruction which includes removal of high-value materials or fixtures prior to demolishment. This method minimizes the need for processing new wood material and minimizes the amount of wood that ends up in a landfill. However, depending on the project structural specifications or local requirements, using reclaimed materials may not be an option.

Source reduction focuses on preventing the material from becoming waste at the source. Source reduction can be accomplished in the design phase or in the field during construction. Some examples presented in several studies conducted include lean framing methods such as Advance Wood Framing, pre-cutting mathematical algorithms and material optimization methods that can be practiced in the field. Advance Framing or Optimum Valued Engineered Framing was developed in the early 70's and has slowly begun to appear in building designs. This method reduces the amount of lumber by 5 to 10 percent without compromising the building's structural integrity (McGinnis and Fumo, 2018). As presented by Manrique *et al. (*2011), who created an optimization model for residential wood framing using mathematical algorithms and optimization techniques, using the most appropriate method of planned cutting can reduce wood waste by 96%.

Recycling construction wood waste may be an option provided the waste material has not been contaminated. Waste wood material can be processed and regenerated in the form of wood mulch, particle board, or other engineered products such as recycled wood decking. These products are made entirely from recycled wood and plastic materials. The most common method of managing generated wood waste tends to include the use of dumpsters delivered to the project site. Recycling of wood products can be facilitated in the field by using a separate dumpster for wood products.

Many of the studies presented in the literature review described causes of wood waste and proven methods in reducing the level of waste. Some of these studies also conducted similar surveys ranking the causes of construction waste based on importance according to subjective views of various experienced construction professionals. Some include site observations, but few clarified what is and what is not actually being practiced, and the reasoning behind these decisions. This research is focused on determining the methods practiced to reduce wood waste in construction, the reason various reduction practices are not being used, and the challenges associated with the reduction of wood waste.

# METHODOLOGY

## Research Philosophy and Approach

The literature review revealed multiple ways to minimize wood waste. However, not every builder, framer, or contractor will or is able to adopt every single method. For those that are adopted, they are unlikely to be managed exactly the same by all companies. The wood minimization outcome or lack thereof will likely vary due to individual interests, challenges, feasibility, efforts, core values, etc. For that reason, this research relied on humanistic qualitative data. Qualitative methods such as those

provided through semi-structured interviews or observations provide a 'deeper' understanding of social phenomena than what would be gained from purely quantitative methods (Silverman, 2011).

The research data was collected through a mixed method approach with (1) qualitative data through semi-structured interviews conducted on personnel experienced in wood frame construction and (2) quantitative data consisting of secondary sources provided by government agencies. The quantitative data was limited to government independent agency studies published for public use. This mixed method approach was selected to help evaluate the researchers' interview findings with existing data related to residential construction.

**Research Data Collection and Analysis**

The collection of qualitative data was gathered though semi-structured interviews conducted either in person or over the phone. A total of eight construction professionals were interviewed including project managers, framing quality controls staff, site superintendents and company presidents from both general and framing contractors, based in different areas in the United States.

Each interview included the same set of questions concentrating on the challenges and methods of wood waste minimization. The questions were formulated to provide the interviewees multiple opportunities to share how they practice wood waste minimization out in the field or in the office. Because some of the wood waste reduction methods or strategies are relatively new methods, questions were also formulated to determine if the respondents were familiar with practices that may include advanced framing or wood cutting optimization software. Other questions were formulated to gather perceptions of the amount of waste generated and how they prioritize the issue of wood waste.

The interviews were voice recorded and later transcribed using 'Otter Voice Meeting' software. The transcribed content collected by each interview was read by the researcher to better capture the essence of the context and to correct voice transcription errors. It was further analysed using computer assisted qualitative data analysis software (QDA Software), ATLAS.ti, to capture non-numerical key words and patterns. To prevent associating the context to a specific interviewed candidate and to maintain their privacy, the candidate's name and company name was not included in the analysis.

The quantitative data in this research was collected from reports and studies published by independent government agencies such as The United States Environmental Protection Agency (US EPA) and the United States Census Bureau which is the nation's leading provider of data for the United States people and economy. The goal was to find a relationship between the data as it relates to the amount of residential and multi-family construction and the construction wood waste generated. Thematic analysis techniques were used to evaluate the transcribed data.

## RESULTS AND ANALYSIS

The following are the interview questions and a summary of the responses from the respondents:

Q1, Based on your experience in residential and multi-family construction, which lumber category produces the most waste during construction and which the least?

This specific question was asked to determine which wood material may potentially be contributing the most to wood waste on construction projects in order to investigate the causes and methods practiced in the field. Between all candidates interviewed, the three wood materials categories that produce the most waste were sheathing materials, dimensional lumber, and bracing material. Thematic analysis of responses resulted in the creation of figures depicting summary of the data, as shown in Fig 1. Due to space limitations for this paper, only one figure is shown to demonstrate the analytical processes used in developing conclusions for the study.

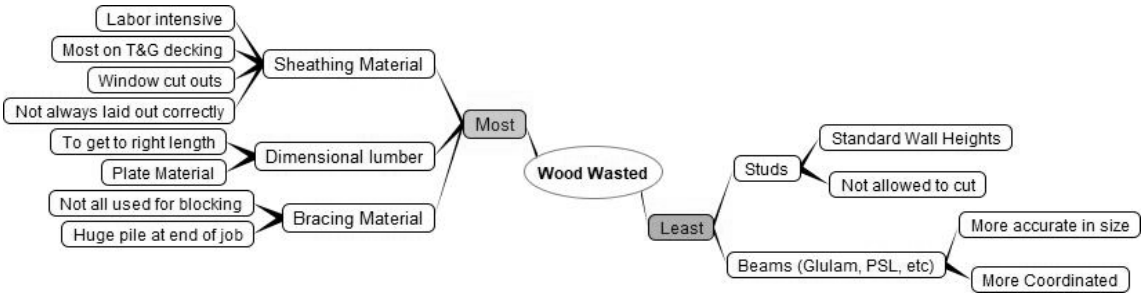


*Fig 1: Materials producing most construction waste.*

Q2, How does labour cost impact your company's decision to practice wood waste minimization?

5 of the 8 respondents stated that the cost of labour negatively impacts their decision to recycle. Another respondent stated they only consider recycling when disposal costs in dumpsters become prohibitive. Only one respondent mentioned that they always recycle. Regardless of the cost of labour, some explained it is a standard for their company to reduce wood material of a certain length from making its way to the dumpster through methods such as using the waste as wall blocking.

Q3, When providing a turnkey framing installation, as opposed to providing labour only, what type of waste minimization methods are practiced?

The main difference between a turnkey framed project and one that is not, could be that is rests on the ownership of the materials during construction. All respondents indicated there is little or no accountability when the framer is not required to supply material. The result is an increase in waste because the framer has no economic incentive to conserve material. Therefore, the framing method that rendered characteristics with greater challenges in material management and contributes more to generated waste is the non-turnkey framing approach. The obvious solution to this problem is in material procurement for the framing contractor's scope of work.

Q4, Based on your experience, from lumber purchased for a project, what percent normally ends up as waste and how does that change by project type?

There was a wide range answers for this question. For projects that did not include turnkey framing, the waste was estimated by the respondents to be 30%. For turnkey framing jobs the average was estimated to be 10-12% provided crews were well trained. However, the consensus of the respondents was that wood waste can vary widely based not only by project size and crew training but also by project design and geometry.

Q5, Can you describe how best to minimize waste of construction materials?

The answers to this question revealed the major factors contributing to wood waste. By far the most common answer was that the specifics of project design was the factor

most effecting wood waste. This was followed closely by time and schedule, labor vs material costs and lack of qualifications/skills/training of framing crews.

Q6, What are some material management techniques you use out on the construction site that helps reduce the number of scrap material created after wood members are cut to size?

All respondents stated that they used scrap wood as blocking in walls. Five of the 8 respondents stated that by having material delivered in bundles that corresponded to the wall section or work section minimizes waste. This is a material management approach in which the lumber material is not delivered all at once, but deliveries are scheduled to match the construction sequence. This method reduces errors in the field by limiting the amount of material available to the framers to draw from at any one time. Five of 8 respondents also responded that good estimating resulted in less waste. Tighter estimating resulted in less material being purchased that will end up as waste to be disposed at the end of the project.

Q7, Are you familiar with a framing technique called Advance Framing or Optimum Value Engineering framing techniques?

These optimized framing methods have been available in some form since the 1960's. However, only one respondent mentioned using advanced framing techniques once in the past. Another stated that the techniques were once presented as part of a value engineering package to help reduce cost, but the non-traditional framing methods were not accepted and as a result not implemented.

Q8, Do you use any software to help cut lumber and to minimize waste?

Unfortunately, among the eight respondents, only one explained how he uses AutoCAD to generate his layouts and lumber list for pre-cutting at the lumberyard. As he explained, using this method allows him to hand a "beautiful" package for his foreman and crew to follow during the construction phase.

Q9, Project metrics normally give priority to cost, schedule, quality and safety. What are your thoughts about the idea of including minimization of lumber waste on this priority list?

The consensus of the respondents was that while wood waste minimization is a good idea, the costs associated with it are prohibitive. They viewed the concept as a virtue, not a business practice.

The perception of the majority of the respondents were that the increase in wood waste corresponded to the increase in construction. However, the quantitative research does not support this conclusion. Data from the United States Census Bureau indicates that residential construction remained steady for the years of 2013-2017. Likewise, data from the US EPA (2015, 2016, 2018, and 2019) indicates that wood waste generated by construction also remained steady. It should be noted that these were the latest years from which complete data was available. It would be interesting to ask these same questions to respondents when the cost of lumber increases.

## CONCLUSIONS

Based on the qualitative data gathered, there are numerous methods that are available that can help reduce construction wood waste. These methods include recycling, reuse of wood from demolished structures advanced framing techniques, more intense material management and more accurate material estimating, as shown in Fig 2.

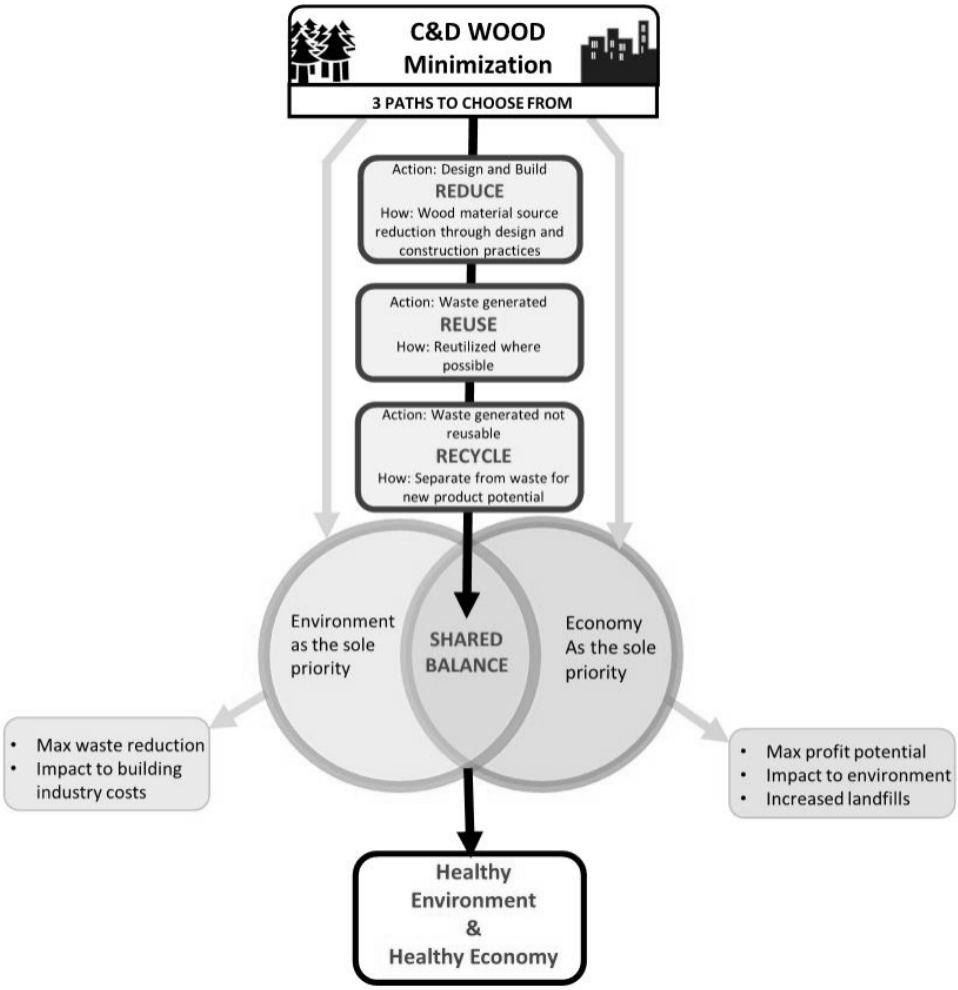


*Fig 2: Research conclusions on ways to minimize wood waste*

However, all these methods include increased cost and/or require contractors to shift the paradigm as to how they manage their operations. In the case of recycling, the perception is that the cost of implementing an effective recycling program costs more that the monetary benefit realized by contractors. Using scrap lumber as blocking and bracing in walls is an effective way to minimize waste. The practice is currently utilized by most of the industry professionals that responded to the survey. However, this accounts for the reduction of only a fraction of the wood waste generated on most projects. In order for a recycling program to be effective, all wood waste must be segregated in dedicated dumpsters on site and taken to a recycling centre for reuse. While this process seems simple, there are still labour costs involved in order to segregate wood waste and additional costs for dumpster fees. The use of advanced framing techniques and framing software are two areas that show promise to minimizing wood waste. However, industry has been slow to adopt these practices because of the significant retraining of both designers and wood crews that would be required to implement these practices. This problem is exacerbated by the existing shortage of skilled labour and an overall resistance to change. Intensive material management practices such as better estimating and having materials delivered in sections show promise and are currently being used by the majority of the construction professions interviewed. However, these practices alone are insufficient to eliminate wood waste on construction projects as evidenced by the large amount of wood waste still being generated on projects.

It is realized that there are costs associated to many of these methods and, as a result, they can be perceived as impractical from an economic standpoint. However, not practicing these waste reducing methods is damaging to both the environment and economy. In the long term, a healthy economy relies on what a healthy environment. Making significant reductions in wood waste will require a holistic approach from both government entities and the construction industry. It is unrealistic to think that the construction industry will implement all of the waste minimization practices on its own. If that were the case, the industry would have already done so. The same is true for reducing construction waste in general. Companies who attempt to implement all of the wood waste reduction strategies would place themselves at an economic disadvantage when compared to their competitors. Therefore, companies who make a concerted to reduce wood waste on their projects are unable to do so from an economic standpoint.

Government at the national, state and local level must take a leading role in solving the problem by implementing rules and regulations that require the reduction of wood waste on construction sites through better designs and project site practices. Requiring all construction contractors to abide the same set of rules will eliminate any competitive disadvantages for companies that are environmentally responsible. Also, as these practices become standardized throughout the industry, innovation in the private sector will minimize costs. In addition to government and the construction industry, education also has a role to play in solving this problem. Institutions who train and teach craftsmen and the next generation of construction professionals have a responsibility to include the latest technology such as advanced framing, improved framing software, and best practices for waste reduction in their curricula.

In the interim, the industry should consider focusing on methods that can support the minimisation of waste while not impacting the project budget. Special consideration should be focused on educating all workers and subcontractors on job site waste management methods that minimize waste going to the landfill.

Future research should focus on expanding qualitative input from a larger pool of industry professionals to address possible gaps in methods to minimize wood waste on construction sites. The research can also be expanded to include all forms of construction waste.

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# INTRODUCING CIRCULAR INNOVATION IN THE CONSTRUCTION INDUSTRY: THE CASE OF THE CIRCULAR VIADUCT

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National and international governments have set ambitious targets to become circular in 2050. The aim is to reduce both the use of virgin resources and the generation of waste. To become circular, not only new technologies are needed in the resource-intensive infrastructure sector, but change is also needed in social and institutional aspects. This research focuses on one circular innovation trajectory in the construction industry: the Circular Viaduct. The purpose of this study is to gain insights into a past trajectory to study how future circular innovations can be fostered in the infrastructure sector from a client perspective. The innovation trajectory was studied using the mission-oriented innovation system (MIS) framework. The narrative of the innovation process was reconstructed in an in-depth case-study. By studying occurrences and sequences of events through MIS functions, underlying dynamics were identified. First, the trajectory shows that for such mission-oriented innovation the direction of the problem and solution together with knowledge development co-evolve rather than being separate stages. Second, the large effect of perseverance of individuals that led to the involvement of high officials and accompanying release of resources suggests that earlier and stronger involvement of client organizations has potential in fostering bottom-up innovations that contribute to the transition towards a circular infrastructure sector.

Keywords: innovation; circular economy; mission-oriented; viaduct; process analysis

## INTRODUCTION

With a share of 33.5% of the total waste generated, the European construction sector was in 2014 responsible for approximately 870 million tonnes of the total waste generated (EPRS, 2017). In addition, the sector is responsible for an estimated 50% use of raw materials (Hu *et al.,* 2010), including critical materials such as copper (Jensen *et al.,* 2020). This is one of the reasons that, since the publication of the Ellen MacArthur Foundation report in 2015 (Schulze, G/EMF, 2016), the Circular Economy (CE) gained popularity in the construction sector as an economic ideology to achieve a healthy economy within the planetary boundaries (Desing *et al.,* 2020). Since its introduction, CE gained interest of national and international governments. The effects of these policies are already visible in the Dutch infrastructure sector, where

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the number of developments with circular ambitions has grown exponentially (Rijkswaterstaat, 2020). These circular solutions aim foremost at reuse and recycling technologies, but increasingly include process-oriented and social solutions, such as procurement methods, design principles, asset lifecycle management, data management and assessment methods.

Because CE "replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (Kirchherr *et al.,* 2017, p.229), it demands not just a change in particular technologies, but a sector-wide transition, including economic, social and institutional aspects. Specific circular technologies have been studied separately, but how these relate to the wider transition towards a circular infrastructure sector remains largely unexplored (Hossain *et al.,* 2020). This is a far-reaching gap, because without a systemic view of the transition, as well as the innovations that constitute it, both the societal challenge and solutions remain ambiguous (Blomsma and Brennan, 2017).

In this research, a specific circular innovation was studied: A Dutch viaduct that was designed using circularity principles from its first idea up to the execution and follow-up initiatives, called the "Circular Viaduct" (CiVi). The CiVi is a typical example of an innovation that addresses circular challenges in the construction industry. It can be considered a mission-oriented innovation that contributes to pre-defined societal benefits beyond efficiency, cost reduction or competitive advantage (Hekkert *et al.,* 2020). The collection of such circular innovations and changes constitutes the wider systemic transition. Studying the unique circular innovation case of the CiVi from a MIS perspective provides insights into drivers and barriers which helps researchers and policy makers to study and govern future circular innovations more effectively.

To study such circular innovation trajectories within its context while being comparable to other trajectories, a research framework needs to be defined. The collection of developments in the direction of a particular societal challenge, including not only the new technologies itself, but also changes in the legislations, behaviour, (organizational) processes, actor relations and wider infrastructure, are together part of a transition towards the societal mission. Collections of these aspects are known as socio-technical systems (Geels, 2005). The concept of technological innovation systems (TIS) builds upon this notion and is employed to study developments of particular technologies and the structure and dynamics of the systems in which they are embedded (Carlsson and Stankiewicz, 1991). More recently, Hekkert *et al.,* (2020) introduced the mission-oriented innovation system (MIS) concept to study systemic change in a specific pre-defined direction, such as circularity. The MIS framework can be largely regarded as a multi-TIS framework using essentially the same methods of analysis to study the system dynamics and interactions. Next to the introduction of new technologies, the MIS also takes novel process and social innovations with a particular directionality into account (Wesseling and Meijerhof, forthcoming). Central to this concept is the structure and alignment of the socio-technical aspects, which are depend on the sectoral, domain or spatial dimensions. The MIS is hence applicable to each unique context, including the construction industry.

At the heart of the analysis of a MIS lays the study of the dynamics in the system, which is determined on the basis of the presence, emphasis and relation between seven main system functions (see Table 1, amended from Wesseling and Meijerhof (forthcoming)). The central idea is that fulfilment of each function is required to form

a healthy innovation system. These functions are substantiated in concrete activities or events, which are collections of incidents or occurrences that took place in a certain moment in time. The functions can be present in different degrees and affect the attainment of the mission either positively, neutrally or negatively. In a MIS, these functions are not isolated, but acquire meaning through causal relations to the other functions and other events. Here, the functions are derived from the micro-dynamics in the trajectory, while these dynamics explain the hampering or acceleration of the innovation and change processes known as "motors of innovation" (Suurs, 2009).

*Table 1: Description of the systems functions for the MIS analysis (amended from Wesseling and Meijerhof, forthcoming)*

| Code | Function | Function description and examples |
|---|---|---|
| *F1* | Entrepreneurial activities | Activities, initiatives, experiments, pilot projects, market introductions, novel business models of market players regarding new (clusters of) solutions towards the mission. |
| *F2* | Knowledge development | Creating knowledge on the problems and solutions "by research" and "by doing", including forecast studies, lab work, working groups and strategic studies. |
| *F3* | Knowledge diffusion (through networks) | Dissemination of knowledge regarding the problems and solutions through media, stakeholder meetings, knowledge networks, governance structures, publications and "learning by interaction". |
| *F4* | | |
| *F4a* | Problem directionality | Formulation of the societal problems with respect to the mission and the priority in relation to other (societal) challenges. |
| *F4b* | Solution directionality | The efforts made to provide direction towards the mission goals in terms of (clusters of and coordination between) solutions and their priorities. |
| *F4c* | Reflexive governance | Monitoring, evaluation, impact assessment and anticipation of the progress to provide input for guidance towards the mission achievement. This is also understood as second-order directionality. |
| *F5* | Market formation and destabilization | Creation of conditions such that new solutions can compete with existing practices, e.g. by the creation of "mission arenas", business models and pricing mechanisms, as well as phasing out and destabilizing undesired markets with respect to the mission. |
| *F6* | Resource (re)allocation | Mobilization of financial, human and material resources to facilitate the other system functions and withdrawal of resources that support undesired activities with respect to the mission. |
| *F7* | Creation and withdrawal of legitimacy | Establishing and eliminating legitimacy for the initiation and prioritization of problems and solutions through raising awareness, stakeholder engagement, lobbying, championing, etc. |

*Case introduction: The Circular Viaduct*

To study the micro dynamics in the transition processes towards a circular infrastructure sector, a single trajectory of a circular infrastructure innovation was analysed in-depth. The Circular Viaduct (CiVi) is a modularly designed and built viaduct that through disassemble-ability decreases the chances of pre-end-of-life demolition. The innovation was initiated by a medium-size Dutch contractor who was exploring innovative way to design in the Netherlands and stated in 2015 to aim to become the "most sustainable contractor" in the Dutch construction sector. While starting off with only a handful of individuals within a contractor organization, it began slowly involving enthusiasts from the client organization (i.e. Rijkswaterstaat - Dutch governmental infrastructure agency), concrete element suppliers and engineering firms. After the formalization process, it grew into a network of actors comparable to a regular small infrastructure construction project.

After the allocation of funds and a construction location by the client, the innovation system was further formalized by means of a collaboration agreement. In 2017, Rijkswaterstaat (the Dutch governmental infrastructure agency) initiated so-called living labs to create protected spaces for innovative experimentation. Although the CiVi was not officially selected as one of these living labs, it was regarded in a similar way. As such, it gradually became part of the circularity agendas and strategies within

the infrastructure agency because of the alignment with the existing circularity strategies and policies. The eventual CiVi was located on a construction site of the Reevesluis near Kampen, a medium-sized city in the Dutch province of Overijssel. The completed CiVi was delivered in the beginning of 2019. Currently, the CiVi is regarded as one of the only integrally circular innovations in viaduct construction and it has, since the official opening in 2019, been promoted as flagship of circular bridge and viaduct construction in the Netherlands (TCB, 2019).

After the viaduct was delivered - and when the project success became clear - follow-up initiatives were organized through network events involving dozens of contractors, advisors, suppliers and public clients, as well as environmental, financial and legal experts. As a result of these network events and explorations, so-called "Small Business Innovation Research" (SBIR) tenders were commissioned by the infrastructure agency, which are innovation-oriented tender competitions to actively promote innovation with specific goals in mind. These resulted from 2020 onward in the initiation of several other projects involving circularly designed viaducts.

The narrative of the mission-driven innovation process was reconstructed by employing the MIS framework. Following Wesseling and Meijerhof (forthcoming), the performance of the MIS was analysed in three steps: (1) problem-solution analysis; (2) structural system analysis; and (3) systems function analysis. First, the problem-solution analysis was studied by relating the societal problems to the envisioned mission by studying policy and project documents. Second, the structure of the studied system was determined by creating an overview of the parties involved in the actual trajectory (mission arena) and contrasting those to the wider infrastructure system. Third, the functional analysis has been executed, to study the underlying dynamics of the trajectory. The paper will focus on the results of the third step.

In order to find the underlying dynamics of the case, the events and their connections were determined. Therefore, the events and their connections were identified by studying progress reports, project notes and evaluation reports as well as by conducting five interviews with key individuals in the trajectory. An important source for the reconstruction of the trajectory was the "Learning History" evaluation study (Rijkswaterstaat, 2019). The interviews included an initiator, the technical manager, the sustainability advisor, and senior CE advisor. These various data sources proved sufficient to create a complete and validated overview of the trajectory.

As a first step in the analysis of the CiVi trajectory, the processes were reconstructed and mapped as an event sequence consisting of almost 100 unique events. To be able to identify dominant function sequences, data needed to be quantifiable, which demanded a comparable unit of analysis. The events were hence coded into second-order codes (Saldaña, 2013), whereupon these were linked to the functions presented in Table 1 using the Atlas.ti software tool. This resulted in an extensive overview in which the sequence of functions became apparent. Finally, in addition to the functional overview, the full narrative was chronologically classified into phases in order to analyse the temporal overview and overarching dynamics (Poole *et al.,* 2000).

To determine and analyse the overall dynamics, the presence of both the functions and the particular sequences of functions were compared with "motors of change" in literature (Van de Ven and Poole, 1995). These motors are the causal relationships between functions that reinforce one another (Suurs, 2009). An example of such relationship is the creation of legitimacy (F7) that is required before resources are

allocated (F6). In order to determine such relations of functions within the narrative, sequences based on two functions were determined using first-order Markov chains. In addition, a gamma analysis was conducted to determine the dominance of particular time sequences of functions. The gamma analysis shows to what extent a function precedes another and vice versa. Through the connection between each function, event and original source data, the underlying mechanisms of the most striking results of the quantitative analyses were studied in depth. This provided insights into the conspicuous developments of the CiVi trajectory and revealed explanations.

# RESULTS

*Narrative of the innovation trajectory*

Throughout the CiVi trajectory, five phases were identified by pinpointing moments in the narrative in which the rate of progress radically changed: (1) idea and start; (2) initial attempt and muddling through; (3) further formalization steps; (4) successful attempt and execution; and (5) follow-up initiatives. Below, the narrative of the most striking aspects of the event sequences is presented and indicated by the functions in Table 1. Collections of events are mapped per phase in Fig 1.

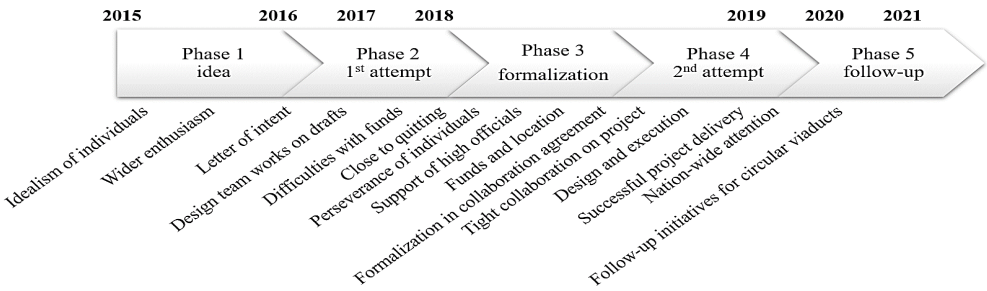


*Fig 1: Overview of main events per phase in the CiVi trajectory*

Findings indicate that during the course of 2014 and 2015, a manager within a Dutch contractor firm initiated the idea for a circular approach to infrastructure as a response to personal wider environmental concerns. In this initial phase, a small thematic group at the contractor explored both the meaning and fundamental problem of CE (F4a) and its potential solutions for infrastructure (F4b). Given that the theme "circularity" was rather new at the time, knowledge on both circularity and its implementation in infrastructure was developed (F2). After some initial ideas and sketches on circular design, in 2016, the manager of the contractor firm approached a sustainability manager of the infrastructure agency to discuss and explore opportunities for circular infrastructure (F3). In the meantime, potential solutions were further explored, while the resulting knowledge was shared and discussed within a small group, including an engineering firm, concrete supplier, knowledge organization and infrastructure agency, in order to explore opportunities for implementation in practice (F3, F4b), These actors knew each other from the national sustainable concrete programme "Green Deal verduurzaming betonketen". Eventually, a letter of intent was drafted by the contractor firm and signed by the contractor, two advisory firms, a sectoral research institution, a supplier, and the infrastructure agency as a pseudo-formal "consortium". This document stated that all undersigned parties would commit to put effort in designing and delivering a circular viaduct. In the second phase, the ideas were developed further by the consortium (F2, F3) and it was attempted to operationalize the ideas and knowledge into an actual project (F1, F4b). However, because lack of funds and commitment at the client side

at that time (-F6), the project almost ended there, which had a discouraging effect on the individuals involved.

However, due to the perseverance of several individuals at the contractor and at the client organization, support of a high official in the client organization was found (F7), which resulted in the creation of a business case (F5). As the high official put it: "the enthusiasm of [three initiators] infected me. Indeed, it was the right time for a real product". The infrastructure agency allocated funds, people and a location for a project (F6). However, due to procurement legislation, the innovation could not be purchased as a regular project, and it was shaped as a collaboration agreement (F5). Consequently, the revived motivation led the individuals to design and plan a concrete and feasible solution for a modular viaduct aimed at flexibility and reusability (F1).

After the modest involvement of the client organization resulted in difficulties regarding project requirements and technical norms, the client organization allocated people to the project, which helped the project getting closer to operationality. Increasingly, the solution space got narrowed down towards standard viaduct girder segments and the preliminary designs were finished collaboratively in 2018 (F1, F4b). One of the people from the contractor illustrated the dependence on individuals' motivation and collaborative nature of the project as: "I have never collaborated so closely with three different parties. […] Everyone did it as a side project and had actually 'too' little time." Yet, despite some minor technical and time-related problems, the bridge parts were successfully designed, produced in a factory in this fourth phase, and assembled at the location by the segment supplier (F1). During installation of the viaduct segments, a monitoring system was set up by an external company to track the structural behaviour of the CiVi (F4c). The finished viaduct, which was officially opened in January 2019, was - and still is - considered a major achievement throughout the sector, as indicated by the appearance of national media and high officials, among which a state secretary, during the opening (F3, F4b, F7).

The story continues, because in the fifth and final phase of the trajectory, the client organization established, together with other parties involved in the CiVi trajectory, a central platform to structure and share the lessons learnt. In this "Open Learning environment" and several adjacent networking events, the lessons were shared and future directions for circular viaducts were explored (F3, F4b, F4c). At the same time, the process was reconstructed and meticulously reported in an evaluation booklet called the Learning history Circulaire Viaduct (F4c, F3). The widely shared enthusiasm and shared circularity goals (F7) led to relatively easy access to public funds (F6). The infrastructure agency initiated several unique yet large Small Business Innovation Research (SBIR) tenders, which resulted in thirty submissions by market consortia (F5). The main goal here was to explore further solutions towards circular design, construction, management and operation of viaducts (F4b, F2). From the ten initial winners who got the opportunity to develop their ideas further, three winning consortia were selected in the beginning of 2021 with each a unique and innovative circular viaduct design (F5). Throughout 2021, the three selected consortia are developing their new ideas regarding circularizing more viaducts (F1, F4b, F2).

*Dynamics in the trajectory*

The narrative of the trajectory shows a high dependence of project progress on individuals, particularly in the early stages of the project. As one of the circularity experts at the infrastructure agency put it: "The fact that there is now this circular viaduct can be fully attributed to the idealism and perseverance of [the initiating

individual at the contractor firm] who kept pushing and inspiring others - particularly in the early project stages". While a lot of time and effort was put into the design and production of the viaduct segments, the moments in time in which the continuity was jeopardized were mostly due to a lack of funds and legitimacy. Furthermore, the end-product and its media and political attention worked as a catalyst for further explorations towards circular design, construction and management of viaducts. In other words, the CiVi itself, which has only been implemented as a temporary viaduct on a particular construction site, had in itself barely impact on the overall infrastructure resource and waste savings. Yet, it created wide interest and boosted further developments that aim for large future impact in viaduct construction and has contributed to the directionality of circular solutions.

Given the high dependence on public funds in the infrastructure sector, the progress of the trajectory depended very strongly on the prospect for a project, including funds and a physical location. Availability and allocation of resources did not directly result in the initiation and direction of circular solutions in the CiVi trajectory, yet it did strongly determine whether and to what extent next steps were taken in terms of design and construction - also with respect to adapting legislation and stimulating collaboration. The allocation of these funds depended on the legitimacy, especially in the shape of high-level support at the client side. However, it seemed that the support of high officials, and hence legitimacy, was only gained after concrete solutions were designed. The mutual dependency between client legitimacy and maturity of the market solution turned out to be an important reinforcing loop in the CiVi trajectory.

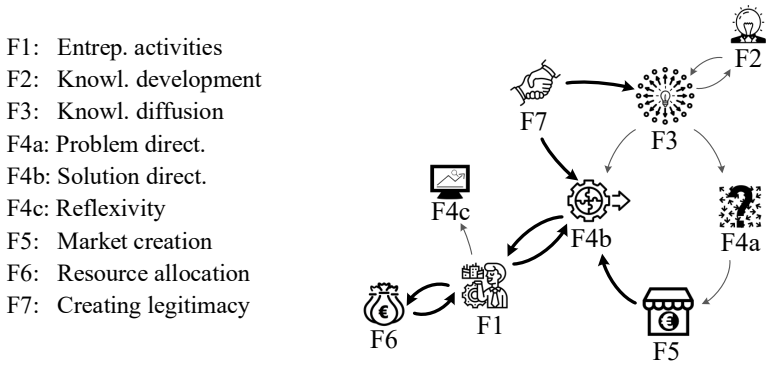


*Fig 2: Sequences of functions in the CiVi trajectory analysis using a first-order Markov chain. The width of the arrows illustrates the number of occurrences.*

*Dominant function sequences and motors of change*

By using a first-order Markov chain, the individual sequences of events were analysed. Fig 2 summarizes the predominant sequences. It shows that there are strong reinforcing loops between solution directionality (F4b) and entrepreneurial activities (F1), and between entrepreneurial activities (F1) and resource mobilization (F6). However, the fact that the execution of a project in the construction industry is strongly dependent on the client, who both provides legitimacy and funding, explains that the creation of legitimacy (F7) and mobilization of resources (F6) are often one and the same act. The same goes for knowledge development (F2), knowledge diffusion (F3) and entrepreneurial activities (F1), where the market parties create knowledge about the solution space through design activities. Since these activities often correspond to the same thing, they do not appear in Fig 2 as linkages.

The results indicate that the MIS functions are strongly interwoven in events of the CiVi case. Particularly in early stages, the concerns of a single individual about the

sustainability problems and rising CE concept resulted in a working group where the solution direction shaped the definition of the circularity challenge (i.e., modular design). The entrepreneurial activities that resulted stimulated the effort to develop the directions of solution further. However, according to all interviewees, the willingness to collaborate between parties that are usually opposed - particularly between client and contractors - was an important success factor. In this case, the embeddedness in the infrastructure agency strategies and policies only came after the first moves of the contractor. In other words, the initiator created its own market and provided an impetus for further developments. Yet, it was only able to execute the project after the legitimacy (which could be found in the "circularity" label attached to the project) and accompanying funds from the client organization. This strongly collaborative effort is also indicated by the interwovenness of the functions.

Despite the many events that contributed to the accomplishment of the CiVi, the lack of events that actively promoted the destabilization of current non-circular practices was striking. The trajectory was executed in a rather protected space, while, for wider diffusion, it will need to compete with incumbent, non-circular alternatives with lower investment costs and highly normalized ways of designing, producing and managing infrastructure. However, the SBIR trajectories, in which the CiVi contractor did strikingly not participate, offer opportunities to normalize these circular principles and to innovate on a process and institution level. The SBIR trajectories are hence promising steps in next innovation trajectories within this MIS, because the public client has supported these functions in a very early stage of the trajectory. In addition, several initiatives were launched nationally and internationally to consolidate the circular economy mission in construction and infrastructure. CE is also increasingly specified in infrastructure tenders and often additional resources are made available by client organizations to stimulate suppliers in offering for circular solutions. Nevertheless, other initiatives are launched in the wider MIS that aim to stimulate circularity by, for example, introducing procurement criteria that include circularity assessment methods to price non-circular practices in asset design (e.g. CB'23, 2019).

## DISCUSSION

The narrative presented in the previous section is much alike innovation journeys (Van de Ven *et al.,* 2008), but the fact that it is aimed at the circularity mission, with a specific solution direction (modularity) has several implications for studying such innovations. First, the analysis has revealed that the shared mission towards a CE has been a crucial element for the allocation of funds and individual perseverance in several occasions. These aspects would have been difficult to uncover without the MIS framework. Second, the learning trajectory of exploring circularity in infrastructure appeared at least as important as the impact or the actual future uptake of the innovation itself. While the CiVi has, as an individual asset, not much impact on resource depletion, its way of thinking sparked novel initiatives across the sector that have the potential to change viaduct design more systemically. Third, by placing this innovation in the circularity transition context, it becomes clear that it encompasses but one of the many innovations and changes in the transition. For example, the CiVi trajectory has revealed that the existing technical legislation for viaduct design does not support circular decisions and, consequently, a working group has been started to revise this legislation. This is in line with the theory that transitions require changes in the encompassing socio-technical systems rather than single innovations (Geels, 2005).

While the technical and legislative challenges demanded creative solutions, it was the emergence of funds and support by higher officials that turned out to be critical for continuity, which only appeared after existence of draft ideas. This can be explained by the structure of the construction and infrastructure sectors in which the market is highly dependent on only several large public clients (Brandon and Lu, 2008). The unique opportunity for the construction and infrastructure sectors is the fact that legitimacy, solution directionality, resources and the ability to create markets is predominantly with one party - the public client - while it is also this client that largely defines the mission and sets the terms. As such, the role of public clients involves both serving public values and commissioning high-value assets (Kuitert et al., 2019). This offers opportunities for the clients to both take a leading role in the CE transition and to create the conditions for market initiatives on an asset level.

## CONCLUSIONS

In this study a unique infrastructure development trajectory was studied in-depth to find both how circular innovations evolve in the construction industry and how they differ from regular innovations in the sector. It shows that, despite the embeddedness of circular goals as well as a coherent circularity strategy at the client side, it can be difficult to acquire funding for circular innovations that do not originate in such strategy. To achieve the mission of making construction more circular, frontrunning innovation projects are needed. Such market-initiated projects run into difficulties regarding existing structures of procurement law and innovation processes but can be successful when they are sufficiently developed to convince public clients that they will contribute to the missions while accepting the risk inherent to radical innovation. Key drivers for project success appeared to be the creation of legitimacy through the support of high officials at the client side as a result of strong perseverance of individuals. To further theorize mission-oriented innovation in a construction context, comparison with other types of circular innovations is needed, such as circular business models, process innovation and social change. Such comparisons could contribute to understanding the circularity transition and to develop policies that aid in meeting the long-terms goals on circularity in the infrastructure sector.

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# HOW COMPLIANCE IMPERATIVES STIFLE THE IMPACT OF SOCIAL PROCUREMENT

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Indigenous procurement policies (IPPs) have exceeded their mandated targets in the construction industry and thus been promoted as an effective social procurement initiative to increase Indigenous peoples' participation in the economy. However, it is unclear if Indigenous procurement policies generate social value for Indigenous businesses and communities. Addressing the lack of knowledge in this area, this empirical paper presents the results of 18 interviews with Indigenous contractors to document the impact Indigenous procurement policies have on the businesses they are meant to benefit. The results indicate that IPPs can create social value. However, contractors may suffer from being used by larger companies to 'tick the box' and comply with the requirements of IPPs, without being invited to compete for ongoing work packages or employment on the live project. It is concluded that, if IPPs are to create sustainable social value, greater commitment may be needed by industry and policymakers to realise the opportunities these policies create. This research has implications for IPPs, social value theory and practice. These implications include theoretical and practical insights on what to avoid in order to maximise the impact of Indigenous and other social procurement strategies more broadly, as economies recover from COVID-19.

Keywords: compliance; Indigenous procurement; social procurement; social value

## INTRODUCTION

Internationally, Indigenous procurement policies (IPPs) have gained popularity as a social procurement strategy as colonised nations look to address historical treatment of Indigenous peoples or fulfil treaty obligations (Panezi 2020). The construction industry is one of the largest contributors to the performance of policies like Australia's Commonwealth Indigenous procurement policy (CIPP) given the significant infrastructure investment commitments made by Australian governments before, and in response to, the COVID-19 pandemic (Denny-Smith *et al.,* 2021).

IPPs work by setting contract targets that government agencies must reach. For instance, the CIPP establishes annual targets for the volume and value of contracts to be awarded to Indigenous enterprises by government agencies (NIAA 2020a). And thus far, the CIPP has been successful in exceeding its targets in each year since the policy was introduced, with over $3.5 billion and 24,470 contracts awarded to Indigenous enterprises, of which the construction industry is one of the largest contributors (NIAA 2020b). However, a review by Australia's Auditor General

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(2020) raised significant concerns about the CIPP's implementation and compliance; there are therefore questions over the policy's effectiveness at creating social value for Indigenous Australians. Indeed, Indigenous policy in Australia is often embellished to exaggerate its successes (Bargallie 2020), adding weight to concerns about the lack of understanding of the impact of construction procurement on the intended outcomes of social procurement policy.

Considering the above concerns, this empirical paper aims to critically evaluate how IPPs impact Indigenous contractors and workers in the Australian construction industry. This research is especially important in the context of the issues raised above and the long history of socioeconomic inequities experienced by Indigenous Australians since colonisation in 1788. It is also especially timely given recent calls that "there needs to be specific analysis for [the] effectiveness of social procurement for Indigenous peoples" (Panezi 2020: 245). Specifically, this paper answers the following research question: How do IPPs promote or inhibit the creation of social value in the construction industry? To answer this, the following section critically reviews social procurement and social value in relation to Indigenous peoples and the construction industry. The method used to explore the research question is then discussed. Results indicate that IPPs can create social value, but this can be negated by compliance imperatives, where contractors 'tick the box' to superficially meet contract requirements and leads to negative social value being created. It is concluded that improving IPPs could involve greater collaboration between contractors and Indigenous suppliers to minimise the incidence of tokenistic engagement with Indigenous suppliers and employees, which could create greater social value.

## Social Procurement and Social Value

In construction, social procurement requires contractors tendering on public projects to demonstrate the social value they create, which typically refers to the economic, social and cultural impacts of a construction project on the community in which it is built (Raiden *et al.,* 2019). In Australia, policies like the CIPP seek to create social value in the form of financial independence and economic development for Indigenous Australians, who have historically been excluded from participating in business and experience significant socioeconomic inequities compared to non-Indigenous Australians.

Although social procurement is not a new phenomenon, interest in construction social procurement is relatively recent, and social procurement is still creating new roles in the industry which are not yet fully developed and explored (Troje and Andersson 2021). Therefore, a critical evaluation of social value in the context of social procurement policy in construction may extend knowledge in this area and lead to improved practice, creating better social and economic outcomes for the marginalised populations that social procurement is meant to benefit.

Despite the interest in the potential social value created by construction procurement, it remains an underdeveloped concept, which Raiden et al.'s (2019) critical literature review revealed is the result of competing notions of what social value is, and practical examples of how it is evaluated. This is in part because the social outcomes of construction procurement are often intangible, which presents difficulties for construction clients seeking to evaluate the social value they create. Construction stakeholders also have competing interests and therefore different expectations of social value which can reduce the legitimacy of social value reports (Watts *et al.,* 2019). Despite these significant limitations to understanding social value in

construction, recent scholars have begun trying to build up our understanding of how social value is created in the construction industry.

To address the above conflicts, Watts *et al. (*2019) developed a social value tool that they argue captures the more nuanced aspects of social value not captured in standard social value reporting tools. The tool measures the impact of construction employment on participants' non-financial wellbeing but does not capture other elements like economic development which are central to the CI Murtagh and Brook (2019) produced a matrix of critical success factors to create social value in construction procurement, but their research was targeted at contractors and commissioners and contains no insight on evaluating social value from the perspective of beneficiaries. In arguing that construction companies need to move beyond compliance driven 'tick-box' exercises to meet social value requirements, Daniel and Pasquire (2019) recommend adopting principles of lean production which include: meeting stakeholder expectations, reducing waste through process standardisation, and reducing cycle time and variability. While this appears to be a promising step given it supports recommendations to involve and consult stakeholders in social value measurement (Nicholls *et al.,* 2012), it remains highly conceptual and, to address this, Denny-Smith et al.'s (2021) research recommends that construction employers create 'work' and 'culture' benefits to create social value for employees in response to COVID-19. The above works are also not grounded in Indigenous epistemologies and to address this, reviewing Indigenous research that may contribute to conceptualising social value are beneficial.

**Social Value and Indigenous Australians**

No social value research in an Indigenous context can occur in a vacuum of Indigenous epistemologies and acknowledging this, Wiradjuri scholar Williams' (2018) Ngaa-bi-nya Aboriginal and Torres Strait Islander evaluation framework was deployed in this study. Ngaa-bi-nya has four domains that must be supported by IPPs to create social value. In a construction context, the four Ngaa-bi-nya domains include: Landscape, whether the project and supply chain improved the socioeconomic position of local Indigenous people; Resources, the business and employment opportunities available to Indigenous people and associated financial and skill outcomes; Ways of working, how engaged the workforce and community is on a construction project; Learnings, the challenges and set-backs experienced on construction projects and how they were overcome.

For social value to be created in an Indigenous procurement policy context the Ngaa-bi-nya domains need to be supported on construction projects. Indigenous entrepreneurs are generally oriented towards social, cultural and economic outcomes for them and their communities (Evans and Williamson 2017), which could support all Ngaa-bi-nya domains as the outcomes are diffused through the community. Promoting the transformative potential of Indigenous procurement strategies to create social and economic value, Jawoyn and Wiradjuri business professional Kinsela-Christie (2019) argues the specific social value outcomes of Indigenous procurement include self-determination and empowerment (Landscape), more training and employment opportunities for Indigenous businesses and workers (Resources), business owners and workers becoming positive role models for younger generations to look up to (Ways of working), and reinvesting in communities to fund more strategic initiatives and create a multiplier effect of social value (Learnings). Pearson et al.'s (2020) critical review also found that Aboriginal community-controlled

organisations promote the social determinants of health and wellbeing by focusing on socioeconomic outcomes for their stakeholders, a notion aligning closely with the domains above. Thus, if implemented effectively, IPPs may support the Ngaa-bi-nya domains and create social value. The method to evaluate IPPs for social value using Ngaa-bi-nya is outlined below.

## METHOD

'Research' is one of the dirtiest words in Indigenous peoples' vocabularies because it can be linked to colonial histories that extracted and claimed ownership over Indigenous knowledge (Smith 2012). Therefore, extensive consultation was undertaken with Indigenous stakeholders on appropriate methods to examine the social value created by IPPs that respect Indigenous epistemologies. All stakeholders agreed that focus groups were appropriate in this context before COVID-19 caused Australian universities to halt face-to-face research. Further consultation determined that interviews held remotely would meet the study's aims while ensuring the safety of participants.

Interview questions were based on the above literature review, which were cross-checked for validity with Denny-Smith et al.'s (2021) findings about employment characteristics that create social value in construction and structured around the Ngaa-bi-nya framework. Interviews were held remotely via Microsoft Teams and participants were recruited by advertising the study at the end of a survey asking Indigenous businesses about the impacts of IPPs. Of 150 completed surveys, 18 interviews were organised and conducted with senior management and owners of Indigenous businesses. Only qualitative data are reported here for brevity and because the qualitative data gives significant insight into how IPPs operate. The qualitative data reported in this paper includes the text entries of survey respondents and interview data.

The semi-structured interview guide contained seven questions and interviews lasted for 30 minutes. Semi-structure interviews were used for flexibility in case unexpected themes arose during interviews. Data were thematically analysed using structural codes based on Ngaa-bi-nya and to ensure rigour, this involved several stages such as immersion in the data and structural coding (Saldana 2021) based on Ngaa-bi-nya. A structural qualitative analytical approach based on Ngaa-bi-nya is appropriate in this research because qualitative analysis does not occur in an epistemological vacuum (Braun and Clarke 2006). Analysing and reporting data using codes and themes distilled from Indigenous and social procurement scholarship was beneficial to manage the researcher's subjectivity, thus ensuring data validity (Hennink 2014). Ethics approval was obtained from an Australian university before data collection began, and a condition of ethical approval included asking interviewees if they wanted to waive their right to not be identified, which was recorded on signed consent forms.

## RESULTS

This section presents the results of qualitative data collected in the study. Results are presented under the four Ngaa-bi-nya domains as Ngaa-bi-nya provides conceptual guidance for the study and to further manage the researcher's positionality as a non-Indigenous person.

**Landscape**

Generally, participants reported that IPPs can create more opportunities for Indigenous business owners to create social value for staff and communities. Supporting scholarship that argues Indigenous businesses focus on broader social and cultural outcomes instead of strictly financial ones (Evans and Williamson 2017), participants had set their own "policies for Indigenous participation (employment, training, giving back to community) and Indigenous B2B (business-to-business) relations prior to the IPP)" (Survey respondent). Supporting research that found an association between positive experiences of the commercial relationship for Indigenous Australian businesses and the value of networks and growth opportunities (Jarrett 2019), other respondents wrote of the impact that IPPs are having on Indigenous supply chains and entrepreneurial success, where IPPs have helped companies "'get work' in government sectors" and " create more Aboriginal businesses (and associated supply chains and opportunities for Indigenous people)" (Survey respondent), creating opportunities for Indigenous businesses to multiply the social value they create.

**Resources**

As above, the results indicate that IPPs may produce an environment that multiplies opportunities to create business and employment opportunities (Resources) for Indigenous people. As Mike (business owner) explained when describing how his business expanded its services to take advantage of greater opportunities because of IPPs: "(diversifying the business function) opened up a door where we could engage unskilled labour as well as skilled labour, which means…we can have a higher rate than 15% indigenous content" and create more employment outcomes for Indigenous staff.

Similar to Lee *et al. (*2019: 1513), who argue that "new kinds of resources and relationships…can serve as the basis for regional development action", business owners also emphasised how the opportunities created by the policies are driving their own business development: "We wouldn't have that access (to larger construction contracts). So, we'd be working…in steel and in construction, but we certainly wouldn't be engaged with (a) tier one construction company" (Ashley, business owner). Indeed, Ashley's comments demonstrate how Indigenous business owners adopt a business-led approach to their company's capacity development (Spencer *et al.,* 2017), by taking on risk to forge new partnerships and opportunities on larger projects. Others explained how IPPs create more opportunities for Indigenous businesses to employ more Indigenous staff and invest in their professional development: "we put on an apprentice (straight away after winning an IPP contract)" (Tim, business owner). IPPs can thus create more employment opportunities for Indigenous Australians because they create more business opportunities for Indigenous businesses, multiplying businesses' existing efforts to create social value.

**Ways of Working**

To support Indigenous Ways of working, IPPs, and the contractors who must deliver on their obligations, must engage Indigenous workforces and communities. But participants described assumptions on construction sites that can be harmful to the identity and wellbeing of Indigenous staff: "So (Employee) who's our Indigenous foreman…one of the site managers…goes 'oh (Company) ay. S'posed (sic) to be an Indigenous business but…don't employ any Indigenous people' and (Employee) just happened to be the one who is an Indigenous foreman" (regional manager). To

counter this, Indigenous businesses find themselves "actively discouraging the view that the IBPP is another handout path" (Survey respondent). Instances like this detract from the positive value that IPPs are creating because it leads to feelings of stigma and embarrassment for the staff who are affected by it. Such occurrences are antithetical to the intentions of IPPs and suggest a need for an ongoing cultural shift in parts of the industry.

Despite negative instances like the above, other participants described how the policies can lead to more positive engagement, and better relationships, between Indigenous and non-Indigenous Australia. For example, as one respondent wrote: "There has been a good two-way learning on projects that we have been part of and clients have valued the learning experience" (Survey respondent). The two-way learning is a significant experience for non-Indigenous staff, who can gain a greater appreciation for Indigenous Australians and culture, as one senior manager at an Indigenous construction company explained when cultural events are celebrated: "And then coming to work for an Indigenous business, it's a bloody eye opener… we've done cultural walks and bits and pieces...I've…taken our kids, the very next weekend." Overall, IPPs can support Indigenous Ways of working because they allow Indigenous construction companies to promote Indigenous culture in their operations. This has a spread effect, where non-Indigenous companies and workers gain a greater appreciation for the history and diversity of Indigenous culture in Australia, empirically supporting research that argues Indigenous businesses create a sense of cultural pride and identity in their workplaces (Burton and Tomkinson 2015).

**Learnings**

When given the chance to reflect on their Learnings from IPPs, the qualitative responses were mixed. For example, while some participants were “glad that Government agencies have to employ a percentage of Aboriginal businesses so small businesses like mine can gain contracts” (Survey respondent), others had experienced significant challenges in the construction industry that are important to be raised.

A pressing concern common to all participants was the practice of 'black cladding'. Black cladding occurs when a larger non-Indigenous contractor forms a joint venture company with an Indigenous shareholder to take advantage of government procurement opportunities. While the Indigenous partner owns at least 50 per cent of the company, to qualify as an Indigenous business, they retain little to no control over the business' operations and strategy, while the business employs little to no Indigenous people (Mundine 2016). Black cladding can undermine the social value created by IPPs by taking away opportunities from Indigenous businesses whose focus is employing Indigenous staff: "The goodness of the IPP is being diluted by many black clad businesses and therefore margins are tightening and the ability to give back is also lessening" (Survey respondent). Black cladding may be a significant setback to the ability of IPPs to create social value because it takes money away from businesses that genuinely want to create social outcomes for their staff and communities: "They've (black clad businesses) got no Indigenous staff. They're not hiring (Indigenous staff). They're not doing the hard…I'm not saying I'm perfect, but…I'm definitely chasing and hiring Indigenous staff" (Business owner).

The most significant setback to creating social value in an Indigenous procurement policy context comes from the compliance imperatives that motivate contractors to 'tick the box' and meet participation requirements, as the following section explains.

### *'Tick-the-Box': Compliance Imperatives Negate Social Value*

Delivering social value on construction projects is predominantly seen as a 'tick-box' exercise as contractors aim to comply with client requirements rather than being genuinely motivated to positively impact their communities (Daniel and Pasquire 2019). For example, a contractor's past compliance with Indigenous participation targets is considered in future Commonwealth tender evaluations under the CIPP (NIAA 2020a). The qualitative results indicate that this may lead to perverse behaviour by contractors seeking simple ways to meet contract requirements rather than promoting the aims of the policies, economic development and financial independence. 'Ticking the box', therefore, involves contractors hiring short-term Indigenous labour from labour-hire or traffic control companies. This creates 'token jobs' where Indigenous workers are brought to site and not given anything meaningful to do. As Leach *et al. (*2010) note, poor quality jobs can be detrimental to the physical, social and mental wellbeing of workers, and token jobs do not therefore create any social value. Instead, token jobs to meet compliance imperatives create negative social value and leave Indigenous workers with a sense of worthlessness, as recounted by participants: "They (a contractor) wanted…half a dozen Indigenous employees. So, we sent half a dozen good guys that wanted to work...And were left sitting under a tree all day...So this was their...token indigenous people" (Business owner).

Compliance imperatives mean that contractors place demands on Indigenous businesses at short notice, leaving them little time to meet demands placed on them by head contractors. This can contribute to perceptions that Indigenous businesses are not as capable when they are unable to meet these demands or when Indigenous workers are left sitting idly on site to 'make up the numbers'. Developing Loosemore *et al. (*2020), who found that new social procurement policy requirements are creating a mistrusting and unsustainable compliance-based environment which could emphasise the inequities experienced by the people they are meant to benefit, these compliance imperatives can create a sense of cynicism about the commitment of policymakers and contractors to make a difference in Indigenous communities: "we're kind of on a tick and flip kind of thing" (Business owner).

## DISCUSSION

Adding a new dimension to recent research that argues social procurement policies are unlikely to be successful without an understanding of the industry's capacity to comply with prescriptive targets (Loosemore *et al.,* 2020), the findings above indicate that Indigenous construction businesses are capable of complying with Indigenous procurement policy requirements and are using them to multiply the social value they create. They do this by promoting better socioeconomic outcomes and more employment and business opportunities for Indigenous Australians, something that Raiden *et al. (*2019) argue is critical to creating social value in construction and supporting the Indigenous epistemologies that have underpinned this work.

Despite facilitating more opportunities to create social value, IPPs can negate social value by creating perverse behaviours by construction contractors. This may occur through two means: 1) black cladding that allows non-Indigenous companies to take most of the profits made through IPPs, and 2) compliance imperatives where superficial, tokenistic jobs are created to fill the numbers and meet contractual participation requirements. Indeed, the second observation supports new themes in construction research about the limitations of compliance-driven behaviour in creating

social value instead of focusing on local communities (Daniel and Pasquire 2019). It also highlights that the construction industry is still developing the ability to respond effectively to social procurement requirements (Loosemore *et al.,* 2020). According to Loosemore *et al. (*2020), the new relational skills required by social procurement policies like the CIPP are still being developed and principal contractors simply transfer risk down their supply chains, and these findings support that argument by showing that risk transfer results in tokenistic opportunities driven by compliance behaviour, which negates the social value that IPPs can potentially create. This research gives some evidence of the adverse effects that such behaviour can produce.

These findings have significant implications for policy development and construction management theory and practice. Regarding the under-researched area of social value theory, this research illustrates that social value may not be created for marginalised groups if social procurement is driven exclusively by compliance behaviour to meet contractual targets. Supporting Daniel and Pasquire's (2019) argument that social value should be incorporated with economic objectives in construction, the findings suggest that it is difficult to create social value as an 'add on' compliance requirement because this motivates the tokenistic behaviour described above. As Murtagh and Brooks (2019) argue, process and preparation, and social and local awareness are critical to creating social value through construction procurement, and policymakers and construction managers in Australia could learn from the UK's flexible approach to creating social value in the Public Services (Social Value) Act 2012, which allows public bodies to negotiate with contractors to decide on the social value that will be created and how it will be reported (Raiden *et al.,* 2019). For example, government procurement managers could negotiate with contractors to ensure that local Indigenous businesses and workers are not given menial packages of work. This could minimise the risk of offering poor quality jobs that create negative value and create more opportunities for local people to develop their skills. These adjustments to policy could lead to more opportunities for social value creation, thereby expanding the success of IPPs beyond simple contract targets to broader socioeconomic improvements through sustained and meaningful employment.

In discussing the utility of these results it is acknowledged that a qualitative sample of 150 completed surveys and 18 interviews may raise questions about the generalisability of the findings. However, in answering the research question How do IPPs promote or inhibit the creation of social value in the construction industry, reporting the qualitative results in this paper gives some insight into how social value is or is not created in an IPP context. Future research could further test these findings with larger samples, which may create opportunities for generalisation and potential theory development.

## CONCLUSION

This paper aimed to examine how IPPs are impacting the businesses and workers they are meant to benefit. Using an agile approach to carry out the research in the context of COVID-19, the 18 interviews reported in this paper illustrate that IPPs can create opportunities for some Indigenous businesses to multiply the social value they create, through more contracting opportunities which allow them to keep employing Indigenous staff and investing in local communities. Long-term, this could help address the significant socioeconomic inequities experienced by Indigenous Australians, however this is being negated by contractors' compliance-driven behaviour which creates tokenistic jobs and contract opportunities. For the

construction industry to contribute to addressing the longstanding marginalisation of Indigenous Australians it could improve its engagement with Indigenous communities and businesses. Strategies to do this include better processes and preparation for engaging Indigenous communities and businesses, and these changes could maximise the social value IPPs create and leading to socioeconomic improvements for Indigenous Australians and indeed, other marginalised groups targeted by social procurement strategies in Australia and internationally.

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# SCENARIOS OF OCCUPATIONAL CAPACITY FOR HIGH EDUCATIONAL BUILDINGS IN THE TIME OF COVID

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The study investigates different scenarios for the occupational capacity of educational spaces in the time of the COVID pandemic. A whole system thinking approach is used to consider the integration of physical and tactical parameters. The former accounts for ventilation rates and furniture settings while the latter accounts for occupational densities. The research method started with a qualitative step: collecting data and information about the current situation and standards of spaces as well as local building codes for high educational buildings during pandemic outbreaks. Then, computer simulation programs were used to study indoor ventilation requirements inside an educational space (design studio) with varying occupational densities of 25%, 50%, 75% compared to a reference case of 100%. The result showed that occupation densities of 50% (IDA 2) and 75% (IDA 3) provide medium and moderate indoor air quality, respectively. Nevertheless, the latter can increase risk scenarios with the increase of carbon dioxide concentration level above 1000ppm. This requires increased airflow and the rate of air change by a rate of 40% above normal levels.

Keywords: COVID; high educational building; indoor air quality; whole system

## INTRODUCTION

The first case of novel coronavirus was recorded at the end of 2019 in Wuhan, China (Johnson, 2020). The virus spread worldwide, and local governments adopted precautionary measures to manage and control occupational densities particularly in public buildings (Medhat and Kassas, 2020). Recently in Egypt, 110 thousand people were affected by COVID-19 and still counting (World Health Organization, 2020b). Public buildings adopted contingency plans in response to the situation. Many countries put a set of regulations and tactical measurements to decrease the spread of the virus by managing the occupation density in educational spaces and set the precautionary distance between students and staff members (Schleicher, 2020). In April 2020, 94 percent of students worldwide were affected by the pandemic, which represented 1.58 billion youngsters and youth, from pre-primary to higher education, in 200 countries (De Giusti, 2020). Nevertheless, there were no defined parameters for universities to be taken into consideration during contingencies on the national scale, e.g., occupational densities in indoor spaces, hence, this leads to variation among them.

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Ismaeel, W S E, Mohamed, F and Elakkad, N (2021) Scenarios of Occupational Capacity for High Educational Buildings in the Time of COVID *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 37th Annual ARCOM Conference,* 6-7 September 2021, UK, Association of Researchers in Construction Management, 644-653

Previous studies discussed the effect of COVID on the educational system and new means of online and blended teaching to reduce occupational densities indoors (Dua *et al.,* 2020). Other studies discussed the COVID effect on the indoor climate; occupation densities and occupants' health, comparing risk scenarios to normal operation and how this may affect post-pandemic architecture (Lassen, Josefsen and Goia, 2021; Megahed and Ghoneim, 2021). Furthermore, the discussion was expanded to energy consumption in relation to increased ventilation rates especially in public buildings (López Prol and O, 2020; Burridge *et al.,* 2021), where studies pointed to the increase in electricity demand (Edomah and Ndulue, 2020; Santiago *et al.,* 2021).

This study discusses means of evaluating the variations in occupational densities in indoor spaces of a university building in Egypt, taking a design studio as a sample for the study. The discussion adopts a whole system thinking approach taking into consideration physical measurements including variations in ventilation rates and furniture settings and tactical measurements including planning for occupational densities. The discussion expands to include means of compliance with the local building code for ventilation rates and techniques as well as for the instructions of the world health organization (WHO) for indoor occupation density in time of the COVID pandemic. This is in light of furniture organization standards for universities. Also, it considers recommendations for educational space's adaptation according to the decisions of the Egyptian ministry of health to increase safety and health. Hence, this study can be replicated to obtain a well-planned occupational strategy in the time of contingency for different educational spaces, e.g., lecture halls, classrooms, laboratories and staff rooms. This should be based on a profound study of airflow, ventilation rates and the type of educational activity undertaken which determines the furniture settings.

## LITERATURE REVIEW

This section investigates indoor air quality (IAQ) in the time of contingency by reviewing relevant journal papers and conference proceedings using science direct from 2011 to 2021. The query used the following keywords: IAQ, High educational buildings, COVID Pandemic, Indoor air quality, Ventilation and Whole system thinking. Previous literature discussed IAQ, ventilation regulations during COVID - 19 and precautionary measurements, but did not discuss the integration between physical and tactical measurements for proper management scenarios of occupational capacities in time of pandemics. The research hypothesis and review scenario are shown in Fig1.

### Concern for IAQ in educational buildings

IAQ is defined as the quality of a building's indoor environment with relation to occupants' health and safety (Karapetsis and Alexandri, 2016). Proper ventilation requires providing proper ventilation rates according to the number of occupants and type of indoor activity. This is in addition to considerations for the direction of airflow and distribution of air inside the space. According to the national ventilation code of Egypt, the ventilation rate of breathing inside closed spaces and is classified according to the metabolic activity inside a space e.g., 0.8 L/s for sitting, and from 1.3 to 2.6 L/s for light work. In addition, temperature, humidity and carbon dioxide concentration levels are some of the parameters that affect the air quality inside an indoor space. These different factors should be monitored for better IAQ with fewer pollutants (Ha, Metia and Phung, 2020; Marques *et al.,* 2020). Hence, previous

studies pointed to the importance of monitoring $CO_2$ levels as a significant indication for the quality of ventilation rates, favouring natural ventilation when possible (Yang and Mak, 2020).

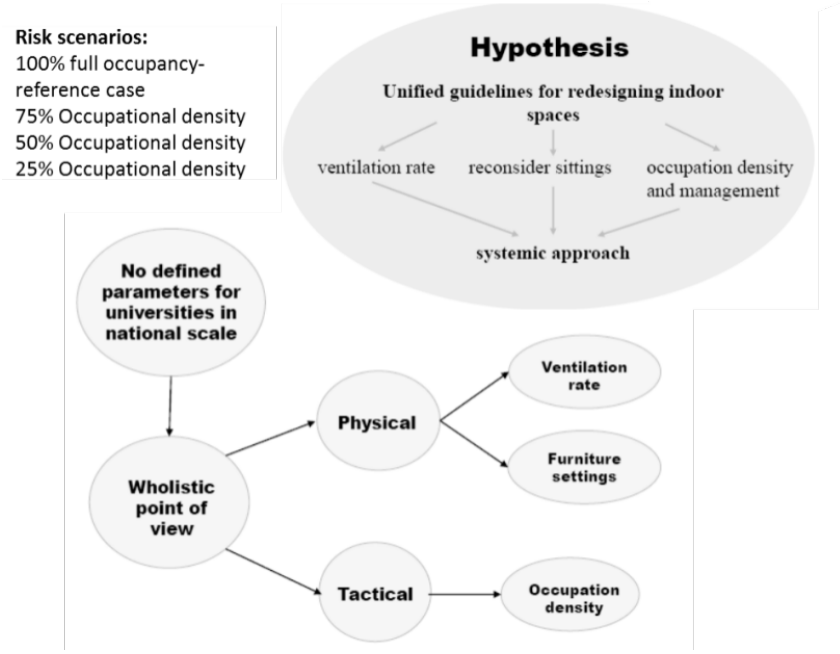



*Fig 1: The research approach*

It is noted that $CO_2$ based demand control achieves ventilation requirements in response to $CO_2$ concentration level monitoring (Pavlovas, 2011). The minimum fresh air in educational spaces according to ASHRAE and the Egyptian code for ventilation is 5 L/sec, while the mechanical ventilation is 0.9 L/sec. Indoor air quality classification is shown in Table 1, showing $CO_2$ level classification.

*Table 1: Indoor air quality classification, PN-EN 13779 classification of indoor air quality (IDA)*

| Classification | Indoor air quality | Outdoor air level for each person | | Co2 level classification |
|---|---|---|---|---|
| | | Range | Recommended | Range (ppm) |
| IDA 1 | High | > 15 l/s | 20 l/s | ≤ 400 |
| IDA 2 | Medium | 15-10 l/s | 12.5 l/s | 400-600 |
| IDA 3 | Moderate | 6-10 l/s | 8 l/s | 600-1000 |
| IDA 4 | Low | < 6 l/s | 5 l/s | > 1000 |

## Impact of COVID-19 in educational buildings

The WHO stated that the transmission methods of the virus include close direct contact with infected people of less than one meter especially in indoor closed spaces with poor ventilation. It can also occur by indirect contact through contaminated surfaces that can carry the infection agent for hours or days- depending on the surrounding climate or the material of that surface.

According to the WHO operational consideration of COVID-19, ventilation is one of the vital strategies that should be considered during pandemics in educational buildings and considered by increasing the natural airflow inside a space. As for

using mechanical systems, it should depend totally on the outdoor air and HVAC operation system considered for two hours after and before occupation time (World Health Organization, 2020a).

Some researchers stated that the furniture layout has a great impact on the indoor airflow and the distribution of pollutants. Other researchers stated that furniture arrangements and the location of occupants inside indoor spaces have a low impact on the indoor quality of air as long as they do not block the airflow in large spaces (Zhuang, Li and Tu, 2014). Moreover, changing the pollutant source location is an optional decision, while rearranging occupants' locations is a good solution (Rim and Novoselac, 2010). The relation between IAQ parameters, Ventilation rates and $CO_2$ concentration is shown in Table 2.

*Table 2: IAQ parameters, Ventilation rates and $CO_2$ concentration*

| IAQ parameters | Ventilation | $CO_2$ concentration |
|---|---|---|
| Data gathering | Outdoor air ventilation 3 to 5 L/s in educational spaces. | Occupied learning spaces ventilation must provide a minimum indoor air quality range of 1000-1500 ppm $CO_2$ or less. |
| COVID recommended requirements | Ventilation rates in standards are 4–6 air changes per hour (ACH) for classrooms and relative humidity (RH) of 40–60 %, maybe low in pandemic conditions. | The $CO_2$ concentration should not exceed 1,000 ppm. |
| Egyptian ventilation code | Ventilation rate required for breathing inside closed spaces: | |
| | 0.8 l/s for sitting people, and from 1.3 to 2.6 l/s for light work. | |
| | IDA classification | Values ppm according to IDA classification |
| | Recommended inside design studio 5-7 litre/sec with minimum 3.3 l/s | |

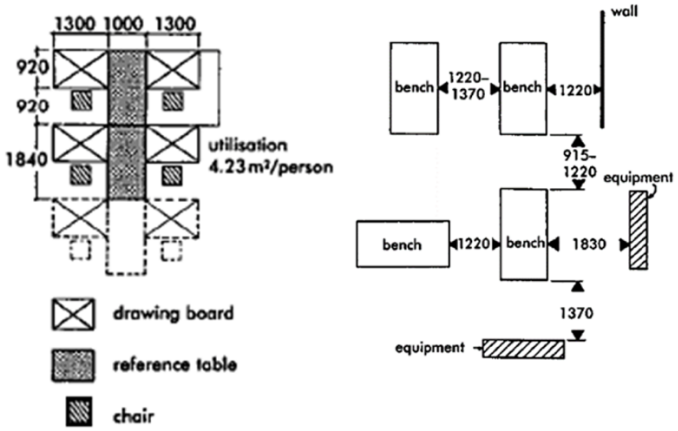
## Whole system thinking

A system is a frequent interacting and interrelated components that integrate forming a unified whole or a common purpose. It consists of variables and sub-variables and any change in them affects the whole system. System thinking is an approach to know how the elements interact in the system and enable solving complex problems (Hassan *et al.,* 2020). Vensim is general-purpose software for simulation created by Ventana Systems, Inc. of Harvard, Massachusetts in 1985. It was developed to solve difficult management problems, but its use is extended to several other applications. In 1991, the first version was released and was primarily intended for a specialist of model designers who had some experience developing and using dynamic simulation models. Also, it is used to build, run and analyse models (Environment, 2007). It performs on two levels of model analysis; causal loop diagram (sometimes called influence diagrams) and the stock and flow analysis. On one hand, the former shows the causal relations between variables. An arrow going from A to B indicates that A causes B. Causal loop diagrams can be very helpful in conceptualizing and communicating structures. Hence, feedback enables revising the system's structure and operating parameters (Environment, 2007). On the other hand, the Stock and flow diagrams show the dynamic change of variables in time. It is a way of representing the structure of a system with more detailed information. Stocks (Levels) are important to express the system's behaviour; flows (Rates) cause stocks to change. Stock and flow diagrams are the first step to develop a simulation model because they help define the types of variables that are important in causing behavioural change (Environment, 2007). Vensim software is used to visualize the integration between

different parameters to make it easy to know what and how each variable affects others.

**Case study and standards for Design studio**

The study discussed an educational space (design studio), located on the ground floor on the north façade of the building (A) at the British university in Egypt. This provided a comprehensive view of occupants' health and wellbeing. According to the national standards, the required $CO_2$ concentration inside the design studio during the pandemic should be less than 1000 ppm, this means that according to the national ventilation code of Egypt the classification of indoor air quality should be (high, medium or moderate) according to occupation densities. Moreover, the required ventilation rates should range from a minimum of 3.3 l/s to a maximum of 7 l/s with 4-6 air change hours. According to the national ventilation code of Egypt that in design, drawing studio, an occupation of 20 people for 100 square meters per floor, should achieve a minimum ventilation limit of 3.3 litres/sec and recommended of 5-7 litre/sec. Full data about the case study is summarized in Table 3. The standard spacing between workstations is 1.4 meter and between the wall and workstation is 1.2 meter and the pathway between rows equal to 1 meter as shown in Fig2.




| Studios | m2 /UFA |
|---|---|
| Drawing Studios Architecture, Town Planning, Engineering | 2.8/student (1st year)<br>2.2/student (2nd/3rd year) |
| Design studios postgraduates | 2.8/student |

*Fig 2: Standards of furniture settings in a typical drawing studio*

# METHOD

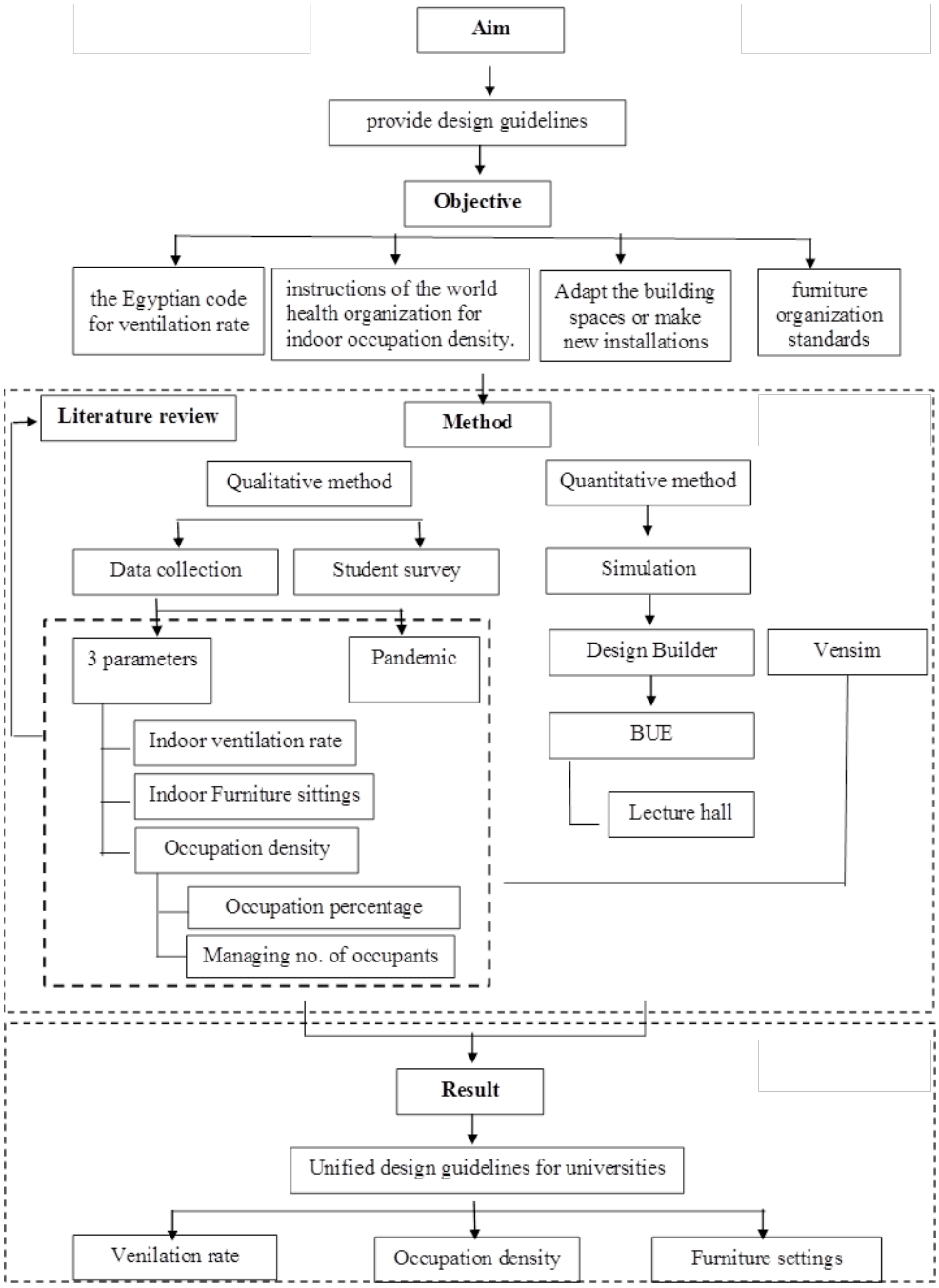
The study used computer simulation as shown in Fig3. Design-Builder is a computational fluid dynamics (CFD) software tool to show the air pressure, airflow, air temperature distribution, relative humidity for indoor and outdoor that leads to thermal comfort.

These can be used to assess the integrated environmental performance such as energy, comfort, and ventilation of existing and new buildings. It allows you to rapidly compare the function and performance of a building's design and deliver results on time. Also, it calculates thermal comfort and indoor temperature based on different types of ventilation systems (Baharvand *et al.,* 2013).

*Table 3: Data collection*

| Existing case parameters | Data |
|---|---|
| Occupied floor area (m2) | 116.6 |
| Occupied volume (m3) | 355.4 |
| Number of occupants | 40 |
| Furniture | 40 drawing table |
| | 40 chairs |
| | 1 instructor table with chair |
| HVAC system | Centralized cooling system (VAV) |
| Number of windows | 7 |
| Number of doors | 1 |

*Fig 3: Research methodology*




The computer simulation was used to study indoor ventilation requirements inside an educational space (design studio) with varying occupational densities of 25%, 50%,

75% compared to a reference case of 100% while studying variations in furniture settings and ventilated rates from a whole system thinking approach to see interrelations of these varying parameters. This is summarized in Fig4.

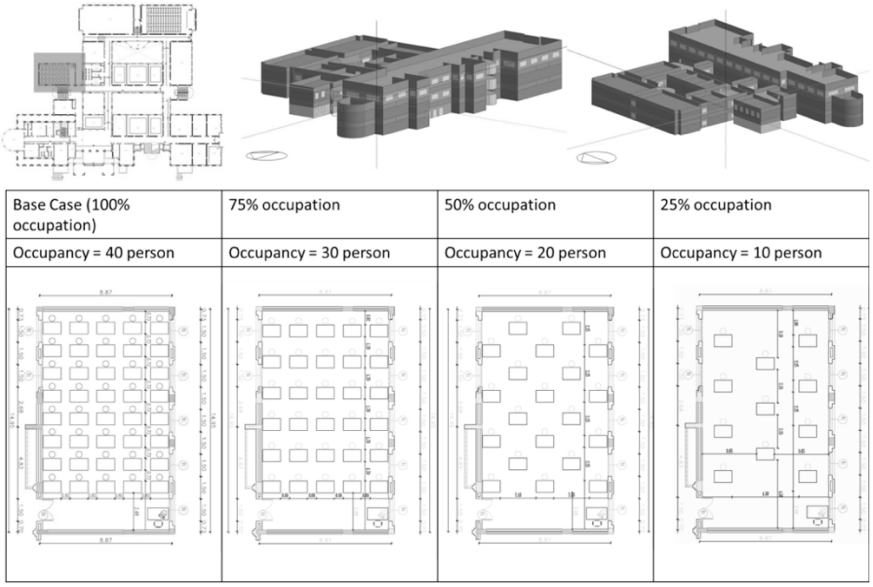



*Fig 4: Summarizing the four tested scenarios of occupational capacities*

# RESULTS

The results investigated different occupational scenarios inside the design studio compared to ventilation specifications of the local building code. This showed that occupation densities of 50% (IDA 2) and 75% (IDA 3) provide medium and moderate indoor air quality, respectively. Nevertheless, the latter can increase risk scenarios with the increase of carbon dioxide concentration level above 1000ppm. This requires increased airflow and the rate of air change by a rate of 40% above normal levels as shown in Table (4).

*Table 4: The variation in co2 levels and airflow rates as a result of the tested scenarios of indoor occupational capacity*

**CO2 level**

| case | Occupation | Indoor classification | Indoor air level | Co2 level (ppm) |
|---|---|---|---|---|
| Covid risk scenarios | 25% | IDA 1 | High indoor air quality | ≤ 400 |
| | 50% | IDA 2 | Medium indoor air quality | 400-600 |
| | 75% | IDA 3 | Moderate indoor air quality | 600-1000 |
| Base case | 75% | IDA 4 | Low indoor air quality | > 1000 |
| | 100% | IDA 4 | Low indoor air quality | > 1000 |

**Air flow**

| case | occupation | No. of person | Air change per hour (ac/h) | Air flow (m3/s) | Air flow per person (m3/s – person) | Air flow per person (l/s – person) |
|---|---|---|---|---|---|---|
| Covid risk scenarios | 25 % | 10 | 2.25 | 0.222125 | 0.022125 | 22.2125 |
| | 50 % | 20 | 2.32 | 0.229 | 0.01145 | 11.45 |
| | 75 % | 30 | 2.38 | 0.235 | 0.00784 | 7.84 |
| Base case | 75% | 30 | 1.69 | 0.167 | 0.00557 | 5.57 |
| | 100 % | 40 | 1.73 | 0.171 | 0.004275 | 4.275 |

Then, the results were configured in a cause-and-effect vensim diagram to show the effect of interrelations as shown in Fig 5. Loop A, starting by IAQ if it increases inside the space the ventilation rate increases, by the time when ventilation increase, the IAQ increases. This feedback loop is reinforced loop moves anticlockwise, as the loop starts and finishes with IAQ increases. Loop B starts with IAQ if it increases inside the space, the occupation density increases, hence, the IAQ decreases. This

feedback loop is a balancing loop and moves clockwise, as it begins with IAQ increases and the loop finished by decreasing IAQ. Loop C starts with IAQ if it increases inside the space the occupation increases so the furniture increases, and the ventilation rate decreases so the IDA decreases. This loop is a balancing loop and moves anti-clockwise, as at the beginning IAQ increases and the loop finishes by decreasing the IAQ.

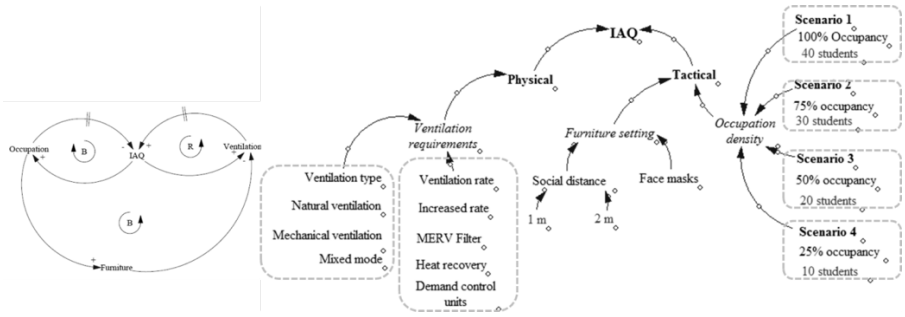



*Fig 5: Integration of parameters and possible occupation scenarios for IAQ*

## DISCUSSION

The results can be discussed using a system thinking approach to show the integration of three distinct parameters to maintain proper IAQ during the pandemic time. This shall provide better occupants' health and reduce the risk of infection.

The simulation output may be used to investigate the building level, block, and zone, requirements depending on the input data and expected outcome. These can in turn widen the perspective of the system thinking approach. The main outputs for the simulation calculation are energy consumption, heating and cooling loads, light distribution and the CFD model that show air distribution of temperature distribution inside or outside the building. On the building scale simulation, the data can be generated from the simulation calculation tab are including unoccupied zones, zone data output on building and block level, report, surface heat transfer, environmental calculations, comfort, internal gains, energy, HVAC and temperature distribution, the output of daylight map, and construction and surface details.

## CONCLUSION

This study investigates occupational scenarios in an educational space in a university building for a better IAQ in time of the COVID pandemic. This highlights the integration of distinct parameters such as space dimension, furniture settings, and occupation density and ventilation rates. The discussion adopts a whole system thinking approach taking into consideration physical measurements including variations in ventilation rates and furniture settings and tactical measurements including planning for occupational densities. This is useful to set updated building operation plans based on the latest scientific findings. For a case study building, four scenarios were proposed based on occupancy: 100%, 75%, 50% and 25%. The former showed great risk scenarios due to the limited design for flexibility in indoor spaces. The second was a possible scenario that won't endanger students' health but would require more ventilation rates. Finally, the third scenario provides acceptable ventilation measures and balanced energy needs. Hence, an occupation density of 75-50% is recommended indoors during the time of the pandemic. Furthermore, recommendations for applying natural ventilation and design for flexibility in furniture settings shall reduce the risk of contamination.

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# LEAVING NO ONE BEHIND: A GLIMPSE INTO THE STATE OF ADOPTION OF THE SUSTAINABLE DEVELOPMENT GOALS IN THE DANISH CONSTRUCTION INDUSTRY

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The 17 Sustainable Development Goals (SDGs) presented in the 2030 Agenda by the United Nations in 2015 provide an ambitious, global framework for sustainable development. The construction industry holds great potential for contributing to achieving the goals towards 2030. This study investigates the current state of implementation of the SDGs within the Danish construction industry, both on a strategic and project specific level. It provides insights into the barriers for implementation. A survey was distributed to actors within the construction industry and responded by 54 people, involving architects, engineers, building owners, contractors, suppliers and manufacturers, along with academic experts. The results indicate that 90% agree that the SDGs can add value to construction project, and 79% had implemented the SDGs on a strategic level. 45% had worked with the SDGs on a project level, where the goals 7 (clean and affordable energy), 12 (responsible consumption) and 13 (climate action) were most often applied. The main barriers to implementing the SDGs were a lack of measurability, time, and resources. The prioritization of goals was discussed in the light of previous research. This study provides valuable insights into the current state of implementation of the SDGs in the Danish construction industry and points towards the following directions for future research: 1) further development of tools and methods to support the actors within the construction industry, especially focusing on measurability and prioritization, 2) in-depth investigation of the state of implementation of the SDGs for the different actors within the construction industry, and, lastly, 3) further studies on the challenges and barriers for implementing the goals within the construction industry.

Keywords: green buildings, SDGs, sustainability, building design, 2030 Agenda

## INTRODUCTION

Sustainable development has gained increasing focus within the construction industry in recent years. In 2015, the 17 Sustainable Development Goals (SDGs) were presented in the 2030 Agenda. They were agreed upon among the 193 member states of the United Nations, marking a global milestone for sustainable development (United Nations 2015). The SDGs dedicate equal attention to the social,

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environmental and economic dimensions of sustainability and are supported by 169 targets and 231 global indicators (United Nations 2015; Diaz-Sarachaga, Jato-Espino, and Castro-Fresno 2018). According to the 2030 Agenda, the SDGs should be translated to the local and project-specific levels to become operational (Caiado *et al.,* 2018; United Nations 2015; Ike *et al.,* 2019). In Denmark, local supplementary indicators have recently been introduced, taking a step towards improved operationalizability for the goals in a Danish context (2030-panelet 2020), along with the Danish action plan towards 2030 (The Danish Government 2017). A united approach from all levels of society is needed to mobilize the transformation required to achieve the SDGs. Therefore, a great responsibility for achieving the 2030 Agenda lies within the construction sector, where the SDGs can provide a common and stable definition for sustainability (Goubran and Cucuzzella 2019). However, practitioners within the construction industry experienced multiple barriers to adopting and implementing the goals both strategically and on an operational level (Gade and Opoku 2020; Deloitte 2020). This study investigates the state of implementation and adoption of the SDGs within the Danish construction industry and how the SDGs are prioritized in individual construction projects. This was done exploratively using a survey method, targeting professionals within the construction industry, such as architects, professional building owners, engineers, contractors, and suppliers. The results provide preliminary insights into the practical state of implementing the SDGs in the Danish construction sector both on a strategic and project specific level and serves as a foundation for further investigation of the topic.

## LITERATURE REVIEW

Due to the recency of the SDGs, the academic literature investigating the link between the SDGs and the built environment is still limited. However, multiple studies exploring the topic exist. Goubran and Cucuzzella (2019) provided a state-of-the-art overview of how the SDGs have been utilized in building design and proposed two mapping tools that can be applied to track the integration of SDGs in construction projects (Goubran and Cucuzzella 2019). The first mapping tool supports the analysis of sustainable design visions around the SDG topics in building projects. The second tool supports evaluating the SDG integration in the projects. Furthermore, Goubran (2019) identified SDG targets that directly or indirectly depend on construction activities. The study concludes that 17% of the targets depend directly on the construction sector's activities, and 27% of the targets depend indirectly (Goubran 2019). A research agenda for the SDGs in construction was proposed by Thuesen and Opoku (2018), including research in the relationships between the goals, measures for evaluating progress, addressing the targets with specific projects, and facilitating knowledge transfer. Opoku (2016) highlighted that the role of the sustainable built environment, in particular, can contribute to the socio-economic development and well-being of society in relation to the SDGs. The link between existing frameworks for the sustainability assessment of buildings and the SDGs have been explored in several studies. Multiple frameworks supporting the achievement of the SDGs, which are applicable in a construction context, exist, such as the SDG Compass (GRI, UN Global Compact, and World Business Council for Sustainable Development 2016), which suggests a process for integrating the SDGs within a business on a strategic level, SDG Capture (Niras 2019), which supports an early dialogue and goal setting in relation for the SDGs in both projects and on a strategic level, and the SDG impact assessment tool (Chalmers University of Technology and University of Gotheborg 2020), which is a strategic decision support tool for self-assessment of how an

activity, organisation or innovation affects the SDGs. Grainger-Brown *et al. (*2019) reviewed existing tools and frameworks for strategic implementation of the SDGs in organisations. However, other studies have shown that the tools are often conceptual and not adapted to the specific needs of the actors within the construction industry (Caiado *et al.,* 2018; Goubran and Cucuzzella 2019). Allen *et al. (*2019) and GRI *et al. (*2016) proposed a framework supporting the strategic implementation of the goals, and Stafford-Smith *et al. (*2017) presented suggestions to how the SDGs can be implemented in an integrated way. The barriers of operationalising and monitoring the implementation of the SDGs have been explored, e.g., in a literature review by Caiado *et al. (*2018). Gade and Opoku (2020) investigated the barriers to implementing the SDGs among Danish building owners and pointed towards a broader investigation of applying the goals in practice. Jaiyesimi (2016) explored the challenges of implementing the SDGs in Africa. The barriers and challenges of sustainable building design have been investigated by, e.g., (Häkkinen and Belloni 2011), (D. J. Opoku, Ayarkwa, and Agyekum 2019), and (Tokbolat *et al.,* 2019). While these studies provide valuable insights into the barriers for designing sustainable buildings, there is a need for identifying and investigating the barriers of practical implementation of the SDGs among the different actors/professions within the construction industry, as well as practical examples to push the integration of the 2030 Agenda.

## METHODS

This study aimed to investigate the current state of practical implementation of the SDGs within the Danish construction industry. An online survey/questionnaire was chosen as the method for data collection. The survey method was chosen as the purpose was to do an initial, broad, explorative investigation involving different actors from different professions within the construction industry. The target population for the study were actors within the construction industry, such as architects, engineers, professional building owners, and contractors with an interest and practical experience in sustainable construction. Furthermore, academics within the field were also targeted to achieve a theoretical perspective of the topic. The survey was in Danish and consisted of a mix between open-ended questions and closed questions with answering options and yes/no questions. The level of complexity of the questions was not high as the goal was to do a broad, explorative investigation of the topic.

The survey was distributed through the social media LinkedIn. In this way, the survey was initially shared within the researchers' network, targeting building professionals interested in sustainable building design and the SDGs. Snowball sampling was used, as respondents within the target population could share the survey with other subjects similar to them through a chain of referral (Goodman 1961). To ensure that the respondents were within the targeted population, the respondents first had to clarify their profession in a screening question, which had to be within the construction industry to qualify. The advantages of distributing the survey through LinkedIn was that it was time efficient. The respondents did not feel pressured to answer (in opposition to a mail survey), and only the actors interested in the SDGs application in construction responded. The limitations of this method are that the population might not be representative of the construction industry due to the number of respondents and are therefore not generalizable. However, the results can provide indications on the general state of implementation of the SDGs within the different professional groups and provide directions for further research.

## Results

In the following, the results of the survey are presented. 54 respondents answered the survey, distributed between 14 architects, 11 engineers, 9 professional building owners, 7 contractors, 9 academics, and 8 "others", including suppliers and manufacturers. The first step in this investigation was to explore whether the respondents knew the SDGs, as this is of course, a foundation for implementing them. 90% of the respondents answered they knew the SDGs, and 10% did not, divided almost equally among the professions surveyed, where only the architects and the academics all responded that they know the SDGs. This is above the general knowledge of the SDGs in Denmark, which was 74% in February 2020 (Verdensmaal.org 2020), but since the questionnaire was clearly marked with the SDG topic, there will also be a tendency to have respondents with high knowledge on the topic since their interest in the topic is a driver for answering the questionnaire. The 10% who did not know the SDGs were not able to answer the rest of the questions.

*Can the SDGs add value to construction projects?*

The respondents were asked what their overall impressions of the SDGs in relation to construction are and whether implementing the SDGs can add value to construction projects or not. 90% of the respondents think that the SDGs can add value to construction projects, 3% do not think they can, and 8% do not know. This might reflect that the 8% do not know the SDGs well enough to judge if they can potentially add value or are simply unsure. Divided into professions, 92% of architects expressed that the SDGs could add value in construction projects, while 100% of engineers and building owners agree on the potential value. Only 50% of contractors believe in potential added value. Also, 100% of the academics think that value can be added. This group especially focused on the process and issues regarding measurability. The respondents were also able to elaborate their responses by providing further comments on how the SDGs can add value to construction projects. One respondent argued that, on the one hand, the SDGs could be used to strengthen the arguments of architectural decisions, and on the other hand, it is not measurable. The respondent said that the goals require interpretation to provide practical value. Furthermore, it was expressed that the SDGs can provide a common language for sustainability, which can benefit both the communication among involved actors and with the client. Goal 8 (decent work and economic growth) and 12 (responsible consumption) were highlighted as goals where the construction can significantly contribute. The construction industry's contribution to the goals will be further elaborated in the discussion section. Several respondents answered the SDGs could support pushing the industry towards better and more sustainable buildings, and specific examples were given, especially focusing on environmental dimensions of sustainability. Some examples are elaborated in the section "Examples of implementation".

*Experienced barriers*

The respondents overall agree that there is a great potential in implementing the SDGs in construction projects. However, several barriers were highlighted. Of the respondents, 61% had experienced barriers in implementing the SDGs, and 39% had not. Mainly, the issue of the SDGs being difficult to adapt to specific, measurable activities was raised. It was expressed that the SDGs are perceived as a strategic framework rather than operationalised goals, that can be applied in individual construction projects. One respondent answered that it could be challenging to see the relevance of the goals, and that there was a risk that it was perceived as "just another

concept of sustainability", among the other concepts for sustainability assessment such as DGNB. It was expressed that the SDGs serve well for sustainability awareness and branding purposes but that they are not sector specific and therefore difficult to apply. The positive site of this is possible increased awareness of the goals, but with this follows a pitfall of greenwashing if the goals are not actually implemented. Along these lines, it was expressed that without actual documentation for how a project support the SDGs, it is obviously challenging to measure whether the project contributes to the SDGs or not. The culture within the construction industry was highlighted by several of the respondents as being conservative and too economy-driven, which was seen as a barrier to sustainable development. Also, it was highlighted that all actors need to understand the SDGs and are engaged in achieving the goals to ensure successful implementation and that it is crucial that the building owners set goals for sustainability and include these in the building brief and contracts. The question of whether building sustainably is rentable was raised among the respondents. Lastly, it was expressed that it takes time and resources to understand and apply the goals. Regarding the process of implementing the SDGs, different approaches were elaborated by the respondents. One respondent argued that it is important to consider all 17 goals as a whole in order to achieve a balanced approach to sustainability. In opposition, another respondent replied that a good starting point is to choose a few of the SDGs and do them well. These approaches will be further explored in the discussion section.

*The current state of implementation of the SDGs*

In this section, the strategic implementation of the SDGs within the respondents' companies/organisations are explored, followed by specific examples and prioritization of the SDGs in individual construction projects. The SDGs are future-facing, and therefore any organizational action towards the SDGs requires some level of strategizing and planning, encompassing the development of key decisions and actions in organisations and their execution (Rasche 2007). It can therefore be argued that strategic action is required to ensure consistent and ongoing SDG impact within organisations (Grainger-Brown and Malekpour 2019). The respondents were asked if their company/organisation works strategically with the SDGs to get an overview of the state of strategic implementation of the SDGs. In total, 79% answered that they do, 17% do not, and 4% don't know. A majority of architects (85%) and engineers (89%) stated that the SDGs are strategically implemented in their company/organisation, with only 78% of clients and 40% contractors.

All academics responded that their organisations work strategically with the SDGs. However, this result does not provide insights into the current state of the construction industry but indicates that the SDGs are well integrated into the educational system and thereby future workforce. 75% of the suppliers answered "yes," and the rest were not sure. Respondents were then asked whether the SDGs have been implemented in a specific construction project that the respondent was involved in to investigate the SDG integration on a project level. A majority of respondents (45%) had not worked with the SDGs on a project level, 38% had worked with the SDGs, and 17% were unsure of whether they had or not. The large group of unsure respondents might reflect that they have worked with several aspects that could relate to the SDGs but were uncertain if the link was explicit. A majority of engineers (56%) and contractors (60%) had worked with one or more SDGs in a project, but only 31% of architects, 44% of building owners, 38% of academics and 25% of "others". The respondents who worked with SDGs in construction projects were asked which specific SDGs and

targets had been integrated into the projects. The responses differed slightly within the different professions. However, goals 7, 12 and 13 (climate action) were the ones most often applied. Among the professions, the priorities of the architects differed and highlighted goal 3 (health and well-being) as often applied in their projects. Only 29% of the respondents had implemented the SDGs in practice. Therefore, the prioritisations only reflect this small group of 16 persons but can still be used as an indicator for focus areas despite the statistical insecurities.

The priorities might reflect where in the design process the actors are involved, e.g., the contractors are often not a part of a project until the detailed design phase and are therefore not as concerned with the indoor environment and climate action as, e.g., the architects.

*Examples of implementation*
The respondents provided specific examples of how they had implemented the goals in practice. This seemed like a challenging task, as only a few provided specific examples. One responded that it was hard to provide an example as many aspects could be related to the SDGs in some way. Along these lines, it was expressed by one respondent that many sustainable initiatives had been applied without linking these to the SDGs. Others were very specific with answers like "flexible installations", "limited use of resources", "energy", "indoor climate", and several answered that they apply the sustainability assessment method DGNB and thereby contribute to achieving multiple goals. Others responded that they apply multiple SDGs and use them actively in branding the projects, emphasising that they only highlight the goals they actively contribute to.

Also, one architect responded that the SDGs were applied during the early design phase as a checklist. Several tools supporting the SDG implementation were highlighted, such as Frame (Frame ApS 2020) and the Danish SDG barometer (Bygherreforeningen and Arkitektforeningen 2020). Sustainable construction sites were also highlighted as a practical example, emphasising social responsibility, better waste management and partnerships across the supply chain. Also, it was expressed by one respondent that it is a priority for advisors to estimate how a project will contribute to the SDGs, including a plan for how it can be approached throughout the design process. Several respondents expressed that early dialogue among the involved actors, such as building owner and advisors, was crucial for successfully implementing the goals. Along the lines of goal 12, it was expressed that the reuse of construction materials and a circular mindset was a priority among several respondents, including increasing requirements for LCA documentation of materials.

## DISCUSSION

In this section, the results will be discussed in relation to previous studies to reflect on how the construction industry can contribute to the SDGs and whether the SDGs should be approached as a whole or only focus on the SDGs that are found relevant - both approaches were taken by respondents in this study. Though progress has been made in recent years, little has been written on how organizations manage the challenge of interpreting and prioritising sustainability goals (Ranängen, Cöster, and Isaksson 2018; Gade and Opoku 2020). The goals are interconnected, interlinked, and designed to encompass a balance between the social, environmental, and economic dimensions and should therefore be viewed as a whole (United Nations 2015). However, approaching the goals individually and focusing the effort can be a good start and a practical point of departure for broader implementation of the goals, but

this approach might compromise the holistic approach to sustainable development. Also, it is a danger that the understanding of the potential positive interactions between goals is missed (Morton, Pencheon, and Squires 2017). Several tools can support organisations, within the construction industry and beyond, in implementing the SDGs on a strategic level, such as the SDG compass (GRI, UN Global Compact, and World Business Council for Sustainable Development 2016) and the SDG impact assessment tool (Chalmers University of Technology and University of Gotheborg 2020). Following the process suggested in the SDG Compass, a starting point for implementing the SDGs on a strategic level is first to understand the goals and create a baseline for how the business currently performs in relation to the goals, followed by prioritizing goals and selecting relevant indicators (at this stage the SDG impact assessment tool and SDG Capture (Niras 2019) can support the process).

Then, the goals should be anchored within the business (GRI, UN Global Compact, and World Business Council for Sustainable Debelopment 2016), and in relation to construction it should be considered how the goals can be operationalized on a project level, and how the impact/effect should be measured. This process can be similar for the different actors within the construction industry, however, the prioritization of the goals will differ depending on where in the building design process the companies are involved, as seen in the results. The Danish supplementing SDG indicators (2030-panelet 2020) are a step in the direction of making the goals more relevant and measurable in a Danish context. Along these lines, the construction companies need to consider how they can measure their contribution to the SDGs. The authors argue that the professional building owners and their advisors play an important role in integrating this in building briefs, tenders, and contracts.

However, the Danish indicators need to be interpreted from a construction perspective to sufficiently support the actors within the construction industry. In this study, the respondents highlighted goals 7 (affordable and clean energy), 12 and 13, as the ones most often contributed to construction projects. The results align with Goubran *et al.* (2019), who also highlighted goals 7, 12 and 13, where the construction industry can primarily contribute. In another study, Goubran (2019) analysed the level of dependence of the construction industry on the SDGs and concluded that goal 11 (sustainable cities and communities), goal 6 (clean water and sanitation), goal 7, and goal 15 (life on land) are directly dependent on construction activities. Opoku (2016) investigated the impact of the sustainable built environment on the SDGs. Opoku (2016) emphasized goal 3, goal 6, goal 7, goal 9 (innovation and infrastructure), and goal 11 as goals where construction activities have the highest impact and highlighted the interlinked and intertwined nature of the SDGs. Gade and Opoku (2020) investigated the challenges and barriers experienced by Danish professional building owners and their prioritization of SDGs in construction projects. Gade and Opoku (2020) highlighted goal 7, goal 11 and goal 13 with the highest priority, followed by goal 12, goal 8 and goal 17 (partnerships for the goals).

The World Green Building Council (2017) emphasises goal 12, 11 (sustainable cities and communities) and 13 as goals, which green buildings can mainly contribute to. These are followed by goal 15, goal 17, goal 9, and lastly, goal 3, 7 and 8. The general consensus of these studies is that the construction sector can particularly contribute to goal 7, 11, 12 and 13. However, the SDGs should be approached as a whole to ensure a balanced approach to sustainability. Also, it should be emphasised that the construction industry involves multiple actors who can contribute to the SDGs in different ways and at various stages of the building design process and throughout a

building's life span. The authors argue that the SDGs should be implemented both on a strategic level within the companies, but also as a design tool and for early goal setting and prioritization within construction projects to spark transformative change.

## CONCLUSIONS

This study investigated the current state of the SDGs in practice within the Danish construction industry and provided indications on the state of implementation on both a strategic and operational level among different actors within the construction industry, counting architects, engineers, building owners, contractors, suppliers and manufacturers, and academics. The results indicate that most of the companies surveyed (79%) had implemented the goals on a strategic level, while only 29% had implemented the goals on a project level. Goals 7, 12 and 13 were the ones most contributed to construction projects by the respondents. The main barriers to implementation were lack of measurability and limited time and resources. Additionally, the paper findings contribute to international research and building projects when implementing the SDGs in construction by gathering some experiences and identifying the perceived barriers. It also contributes to construction management on how organizations must change their strategies to enhance the SDGs in construction. Based on the results, the authors suggest the following directions for future research: 1) further development of tools and methods to support the actors within the construction industry, mainly focusing on measurability, operability and prioritization, 2) in-depth investigation of the state of implementation of the SDGs for the different actors within the construction industry, and, lastly, 3) further studies on the challenges and barriers for implementing the goals in the construction industry.

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# THE QUANDARIES OF DESIGN DEVELOPER COMPETITIONS

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Public clients in Western countries, including Sweden are currently under pressure to create sustainable housing and urban environments and mitigate climate change. This calls for new types of societal planning and governance. In Sweden both architectural and design developer competitions is in use. In design developer competitions, the public client has allocated a particular piece of land, and requests responses to certain possibilities and limitations. The participants are developers or contractors who aim to develop business through winning the competition and constructing buildings on the land. The question is whether design developer competitions can deliver more sustainable housing at a fair cost. Theories of innovation, sustainable transition, and governance all contribute to the framework of understanding. The method is a critical reading and analysis of two design developer competitions scrutinizing them for sustainability aspects. All steps of the competitions, program, competition, jury verdict, and implementation, involve particular dilemmas for the actors. Sustainability aspects vary widely from singular to comprehensive solutions, reflecting a dilemma between creative designs versus controlled outcome. Competitions turns out to be less of an instrumental tool for societal planners with sustainability goals.

Keywords: design developer competitions; dilemmas; innovation; sustainability

## INTRODUCTION

Municipal planners and developers attach specific expectation to Design Developer Competitions (DDCs). Such competitions are also called land allocation competitions, however translating the Swedish 'markanvisningstävling' into DDC is appropriate from an international perspective. In DDCs, proposals are presented as architecture and urban designs through drawings, illustrations and schemas together with a short text. In this study, proposals are visualised as in traditional architectural competitions. The aspiration is that these competitions will function as innovative governance tools that can address some of the dilemmas present urbanization involves such as cost versus sustainability, location versus affordability, collaboration versus independency, and affordability versus architectural quality. In DDCs, the public client allocates a piece of land, and tenders for proposals for using the land within certain barriers and enablers. The participants in such competitions are typically

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developers or contractors who aim at developing business through winning the competition with an architectural design and construct the buildings on the allocated field. From a sustainable transition perspective, this raises the question whether DDCs deliver what societal planners hope for, i.e. sustainable housing and other values such as architectural quality at a fair cost.

The paper draws on a framework of understanding combining theories on innovation processes, sustainable transition, adaptable architectural design and governance. The method is a critical reading and analysis of two DDCs scrutinizing their sustainability aspects. The result reveals how each step of the two competitions (program, competition, jury judgement and realization) involves particular dilemmas for the participating actors. The contribution of the paper is to identify and analyse these dilemmas, such as freedom for the bidder versus precise direction of the competition. In scrutinizing the competitions' results, we e.g., find that the sustainability aspects vary widely, from very singular proposals, such as proposing a charging pole for electric cars, to offering a comprehensive solution through a sustainability certification such as Miljöbyggnad (a Swedish environmental building certification).

## METHODS

The study examines two cases of competition processes. Case study methodology is a method for examining cases in their natural context (Groat, 2002). This is suitable for studies of competitions due to the clear connection to practice. Competence in architecture and urban planning is based on concrete experiences from assignments. Cases form a repertoire of examples that are reused in new projects in reworked form. According to Stake (1995), it is the case and its unique properties that define the object of study. He moreover suggests that cases can be used as an opportunity to learn rather than for parametric comparison. Flyvbjerg (2006) presents the case study as a scientific method, emphasizing its use for developing theories, testing hypotheses and presenting instructive stories. We use Flyvbjerg's insights about information-oriented case selection strategies in order to maximize the utility of information from the two cases that form the basis of our study. We have accordingly chosen two critical cases where the winning proposals are expected to display high degrees of innovation, as they build on experiences from completed R&D projects that have been part of a government push for innovative housing. Critical cases produce information permitting "logical deductions of the type, 'If this is (not) valid for this case, then it applies to all (no) cases" (Flyvbjerg, 2006: 230). We do thus not suggest that we are able to produce statistically generalizable results. Instead, we aim to contribute towards theory development by developing analytical generalizations from the cases.

Case descriptions, results and conclusions are based on written documents received from the National Board of Housing, Building and Planning, Botkyrka Municipality and the City of Stockholm. Based on a review of decisions on support for innovative construction by the National Board of Housing, Building and Planning, two R&D applications was used as guideline for chosen two DDCs that was then selected for in-depth analysis. Upon request, the National Board of Housing, Building and Planning provided application documents, decisions and companies' reports. Botkyrka municipality and the city of Stockholm have submitted supplementary data about the competitions on request. This applies to documents such as land allocation policy, competition programs, competition proposals, jury statements, assessment templates, design programs, agreements and detailed plans. Information retrieval via the web is

also included in data collection. Please note that the substantial number of primary documents studied are written in Swedish and therefore not part of the reference list.

## Framework of Understanding

The overall framework understands DCCs as a part of a governance framework. An interpretive sociological approach is used to bring several theoretical components together. Governance theory provides and understanding of how a public unit, the municipality, can act under particular conditions of a legal, political and juridical framework (Koch and Buser, 2006; Torfing and Triantafillou, 2016). This is becoming prevalent in particular due to societal attempts to mitigate climate change and create sustainability. A central concept is innovation as it is the intention of the competitions to bring about new creative and innovative solutions. One understanding of innovation comes from The Oslo Manual (OECD, 2018) where four categories of innovations are defined: product, process, market and organisational innovations. Orstavik *et al.,* (2018) defines innovation as "humanly created changes in established ways of creating value." Innovation often takes places in a tension between value and costs. Innovation is measured and identified in a context (Tidd and Bessant 2009) and may thus be valuable in one context and mainstream in another. The concept of innovation has developed from a focus on competition improvement to service, public sector, business models and social innovation (Fagerberg *et al.,* 2004). Innovation process approaches are helpful in understanding and conceptualizing the competitions' processes (Van de Ven 1999). Further theory and concepts on competitions, housing architecture and sustainability is used in order to underpin the framework. This includes transition theory, sustainable building developments, architectural quality, competitions in architecture and urban design, and housing and adaptability. On this background, we tentatively identify the following main dilemmas in this field:

1. Organiser's dilemma: How to set a frame for innovation in the program phase?
2. Design team's dilemma: How to understand the brief and translate requirements into design-solutions in the competitions?
3. Professional's dilemma: How to support design teams' work with innovations?
4. Jury's dilemma: How to develop and appraise identified innovative solutions in the evaluation of proposals?
5. Client's dilemma: How to maintain innovative solutions throughout project implementation?

## Case Study 1: Botkyrka

Case study 1 concerns A-Architects (pseudonym), which is a large Scandinavian architecture company that entered a competition in Botkyrka. Botkyrka is a typical suburb to Stockholm developed as a part of the so-called 'million program' a large social housing program. Since 2015, the municipality has had a land allocation policy stating that the municipality is required to prioritize housing in areas, which have good access to public transport. The land must be sold to developers on market terms, and the municipality must primarily allocate land for apartment buildings through direct provisions, tenders or DDCs. In the policy, DDCs are described as suitable for testing ideas and selling land. It is the local politicians who decide if the municipality should arrange a competition. They determine the direction, evaluation criteria and assign land to the winner. The officials in the municipality then produce documentation and draw up agreements with builders who meet the requirements.

In 2014, Botkyrka municipality announced a DDC for new homes in Alby. The competition site is located next to Alby centre with access to a metro station. Co-

utilization of existing infrastructure appears to be a driving force. Through the DDC, the municipality aims for proposals for creative solutions with a high degree of utilization, where design and choice of materials create conditions for environmental, social and sustainable housing construction. The homes will be condominiums, a form of lease that is absent in the area. This is believed to contribute to diversity in a district characterized by apartment buildings. The municipality promises to assign the land to the first-prize winner. The best project idea wins land allocation on all or parts of the area and the opportunity to buy or dispose of the future plot with a plot right. The final extent and design of the buildings will be determined in a future detailed plan, which will be drawn up after the winner has been chosen. The competition site is estimated in the competition program at 20,000 sqm. and the land price at a minimum of SEK 1,000 / gross sqm. including street costs. In the area, there are elderly affected by the plans. Proposals must therefore show how a care home can be integrated into the new buildings. Builders must inform the municipality of their financial background in an expression of interest.

The first part of the competition proposal must be quite short (6 pages). Then the following documents is included: (1) description of the project idea, (2) sketches, reference pictures, situation plan, illustrations with scale, (3) two alternative solutions for care housing, (4) description of the company's environmental ambitions, (5) assessment of number of apartments, (5) offered land price, (6) general description of implementation and estimated schedule, (7) presentation of reference projects. Interested builders are informed that the proposals will be evaluated using a template, available on the municipality's website. According to the competition program, the criteria in the valuation template must be weighted in percentages and scored based on the following order of priority: (1) Social sustainability, (2) Architectural quality, design and innovation, (3) Location (4) Environmental sustainability, (5) Economic sustainability, (6) offered land prize. How the criteria are weighted in the assessment is not reported in more detail in the program. However, they show what the organizer regard as important values in the competition and their measures (weight) tells us how valuable these criteria are in this specific case.

Competition was limited with Botkyrka municipality receiving four proposals. The winning proposal was submitted by the T-Build contractor in collaboration with A-Architects. Their proposal included 426 apartments in houses of 4-8 storeys and 30 homes in terraced houses. In the proposal, the urban space is divided into zones that have different characters, respectively a public, a common and a private zone. The private zones are areas that have space for cultivation. Playgrounds are located in a common zone. A square is the public zone. The buildings will be built in prefabricated frames with cast-in reliefs. The proposal aims at creating variations over a theme based on the topography of the land. The buildings vary in height, colour scheme and location. Saddle roof with steep angles break down the scale of the houses. It is a new design language introduced in a district dominated by functionalist principles. T-Build offers to buy the land for SEK 35 million, corresponding to SEK 1,297 pr. sqm. An expected sales rate of 70% of the apartments governs the housing construction. The buildings must be produced according to an environmental certification system.

The competition proposals are evaluated by four officials with no other interest groups being represented. The officials were a development manager from the public building administration, a project manager from the unit for land and development, a planning architect and a landscape architect. All four competition proposals meet

requirements. The jury sees the following strengths in the winning proposal: "Dense residential area but good level on the scale: does not feel like the area is too large-scale but adapted to the human scale. Complementary architecture in Alby: point-house talks well with existing architecture, the houses are placed so that further development on the Alby square is possible, the houses bring something new to the area's architecture in the form of roof slopes, colour and relief on the concrete, and they fit into the topography. Flexible floor plans for the apartments and a flexible number of rooms for businesses. T-Build has good reference objects. They have experience in building these types of projects. Good price and BTA" (Project group assessment and recommendation, p. 2).

In 2016, the municipal board instructs the city planning committee to proceed with the urban development project and produce a detailed plan for the implementation of winning proposals. The detailed plan increases the number of homes. The point houses may now be built in 6-11 floors. The terraced houses in the competition proposal will be replaced with apartment buildings in 4-6 floors and the square will be supplemented with another point house. The external environment must be clarified in a special design program in connection with the land being made available for housing construction in the detailed plan. The design program contains detailed guidelines developed in collaboration between A-Architects and partners with the city planning administration. It is a comprehensive and richly illustrated document that sets out design principles of land, conservatories and buildings. It deals with the facades, balconies, roofs, ground floor and entrances, basement, courtyards, street spaces, outdoor environment, squares/parks, lighting and signs and artistic decoration.

**Case Study 2: The Competition in Stockholm**

Stockholm City has a land allocation policy from 2015. It contains four methods for allocating land to companies including DDCs that are used when the city wishes to fulfil special ideas about the design or use. Competitions are marketed on the city's website. According to the policy, the competition proposals must be evaluated by a jury with a composition specified in the conditions of the competition and pricing takes place through a fixed price model at the assessed market value or leasehold. The idea of reporting a fixed price is that the design teams should be guided by internal quality ambitions in the development of competition proposals.

The DDC in Stockholm has cheap and "square meter efficient" housing for young people as its goal. The competition is organised by the city through the Development Office and is situated in a district from 1926 with mixed housing and metro stations from the 1960s. Also in this competition, densification and joint utilisation of the infrastructure appear as an underlying driving force for urban development. The City of Stockholm demands innovations, and the competition is predicated on the hope to find an innovative, smart and innovative solution. The winner may implement their proposal in collaboration with the development office and the city planning office. It should be housing that young people can afford. The development office estimates that the competition site will house 25 normal-sized apartments. The rent reported in the competition proposal will be written in future land allocation agreements.

The competition is open to all companies that meet the requirements. The client must show in the application that they have the competence and financial resources for the task. Competence must be reported as completed reference projects. The following information must be included in the proposal: (1) average rent including heating and hot water, (2) description of the project, (3) report of parking and noise management,

(4) situation plans and at least one facade and a perspective on the buildings; and (5) organisational plan for the management of the homes. The jury is informed of which companies are behind the proposals. The organizer does not require anonymous reporting of the proposal. According to the competition program, the proposals are assessed on basis of the following criteria: (1) average rent, (2) innovation and "square meter efficient" innovations, (3) adaptation to conditions, (4) architecture and design. The jury must make a balanced assessment of the proposals. Directed method of ranking is a form of architectural criticism. The winner will be chosen after an overall assessment of the qualities and shortcomings that the jury sees in the proposals. Also in this competition, there is no political participation in the evaluation. The proposals will be judged by a jury of five named members.

The DDC in Stockholm generates 15 competition proposals. All proposers meet the qualification requirements. The jury notes that the proposals vary in focus, quality and there is a wide range in housing costs. The rent varies from 1490 SEK to 2550 SEK per sqm. The number of apartments varies from 24 to a maximum of 55 homes. Some of the proposals are considered to contain new thinking, but we do not receive any further information about what the innovative solutions are. A critical aspect of the jury's evaluation is whether the proposals have apartments that are 'homes' or just 'rooms' for temporary accommodation. Some solutions are perceived as student housing and apartments with a hotel rather than home-like character. Therefore, the jury develops the assessment criteria in the program to include living qualities such as furnishability, flexibility, spaciousness and daylight.

A developer (U) and partners present a competition proposal containing 49 apartments in two attic corridors with an average rent of 1812 SEK / sqm. The proposal is the result of an R&D project that has been supported financially by the National Board of Housing, Building and Planning. The apartments have a "function wall" with kitchen equipment. The solution corresponds to the competition requirement for square meter efficiency with hidden storage spaces and other space-saving solutions. All apartments have access to a balcony. The green roofs provide a smoother flow of rainwater to the surrounding sewers. It is also possible to have terraces that used for cultivation plots. The apartments are placed in two slatted houses with attic corridors and a corridor with access to all homes. The slatted house is stepped down on each side to better suit the surrounding buildings. Street-facing apartments have glazed balconies to minimize noise. The design team emphasizes low rent through quick assembly of modules that have been equipped with maintenance-free materials and systems for heat recovery. Apartments are delivered at the construction site as complete modules, mounted in a steel frame, with kitchens, bathrooms, floors and storage. The installation time is estimated at two hours per apartment. The construction will be carried out according to the Gold standard, which is the highest Swedish environmental certification level.

U Developer and partners proposal was not included in the jury's final assessment. Their proposal received the following review: An architecturally fine proposal where, however, the ambition to bring in many apartments has led to excessive developments. The buildings are close to the nearby villas. Apartments have good housing qualities and well-studied functions. Balconies and good daylight conditions provide an indoor-outdoor relationship. Green roofs with patios replace yards. Premises in the street corners contribute to city life. On the company's website, U Developer presents the proposal for the competition in Stockholm as "very successful". It was the first time that the construction system was tested in competition. Building systems have

since been used in 2019 in a DDC arranged by Järfälla municipality, which is located in the Stockholm region, where U Developer was successful and won with a new proposal. The winning proposal includes 140 condominiums. The homes will be built as modules in an industrial production system to minimize operating and management costs. First prize in the Stockholm competition was awarded to a proposal with 30 apartments and an average rent that is 9% lower compared to the apartments from U Developer and partners. Obviously, it is neither the number of apartments nor the rent level that decides the competition. First prize is awarded instead to a proposal with an architecture that stands out, and which the jury perceives as innovative and exemplary without further specification. This proposal also includes modules to reduce cost. In the selection of winners, the jury's ideas about architectural quality thus appears as a decisive criterion when used in the assessment of competition proposals.

## DISCUSSION

A comparison between the two competition processes shows several interesting similarities and differences making the cases instructive (Stake, 1995). There is no clear coordination between the competitions' objectives, the submission requirements and the assessment criteria. The program in Botkyrka contains the evaluation criteria: social sustainability, architectural quality, design and innovation. The municipality demands creative solutions and a high degree of utilization. The competition will contribute to diversity, in terms of form of lease, size, design and price of housing. The link to social sustainability is unclear. The land is offered for sale and the apartments must be leased with tenant-ownership. The governing goal for the competition in Stockholm is cheap and space-efficient housing for young people. By inviting to the competition, the organizer hopes to find an innovative, smart and innovative solution for apartments at affordable rents. The city places the same demands on competence and finances for participation as in Botkyrka municipality.

The assessment of the proposals is based on open, interpretable criteria that give the jury room for manoeuvre in selecting winners. The differences between the two DDCs do not lie primarily in the design of criteria but in the application, i.e., in the way of ranking the proposals and reporting the outcome of the evaluation. In Stockholm, the jury reports the evaluation results in an architecturally critical statement (Lundequit, 2002). The ranking is presented as evaluative descriptions and assessments, typical of jury statements in architectural competitions. In Botkyrka municipality, the proposals are scored on the basis of weighted criteria. Qualities are transformed into quantities. The assessment is based on the idea of a rational decision-making process (Svensson, 2009). First place is given to the proposal with the highest score. This strategy with measured criteria conveys a vision that the winner is chosen objectively. Architectural values and building properties represent two different scientific traditions and ways of understanding knowledge. However, a common problem for both is that the criteria are applied in judging visualized solutions showing what the future environment may look like if the proposals are implemented, and not qualities in a built environment.

The organizers' information to the participants varies in the competition programs. In Botkyrka, interested companies in the consulting, construction and real estate sector are not allowed to know who will assess the quality of the competition proposals and their professional domicile. Potential proposers are left in uncertainty. It is only in the jury's statement, after the winners have been chosen that the design teams see who

has evaluated the competition proposals and their competence for the task. The City of Stockholm, on the other hand, informs and reports in the program, which persons are included in the jury, their names, titles and organizational affiliation. The review shows that the competition process in Stockholm has a higher degree of transparency compared with Botkyrka. The program is more informative.

The jury's ranking of the competition proposals is affected by how the assessment is organized and how the solutions are categorized. The evaluation in Botkyrka is based on an individual assessment of the proposals. In Stockholm, the proposals are seen as representatives of two different ways of solving the task. Dividing proposals into categories is necessary when there are a large number of solutions to be assessed, but it is not important in competitions with only 15 proposals. It is particularly clear in the Stockholm case that the organization of the assessment process affects the outcome. The competitions in Botkyrka and Stockholm have different approaches to price and quality. Botkyrka municipality has land price and financial sustainability as one of five assessment criteria in the competition. The City of Stockholm applies the principle of a fixed price. In Botkyrka municipality, companies are forced to use the land price as a means of competition, which can be assumed to result in more expensive housing and counteract the organizer's wishes for proposals that promote social sustainability. This makes it more difficult to create affordable housing for low-income citizens. In Stockholm, the organizer wants the design teams to compete with quality and low rent instead of with tenders on the ground. From this point of view, a fixed price can be seen as a quality-enhancing strategy in competition processes.

The submission requirements are loosely linked to goals and evaluation criteria. The submission requirements in Botkyrka municipality prescribe that the proposers must describe the project idea and environmental ambitions. The homeowners, size and apartment types are up to the builders to decide. To leave the solution for the housing issue to the proposers in this way is surprising with regard to the municipality's stated desire for social sustainability and variation of housing. The program in Stockholm is clearer in terms of the number of apartments and their design. According to the submission requirements, the proposals must contain a description of the project, including the average rent. The homes must be presented as a situation plan, type plans for floors, illustration plan, suitable sections, at least one facade and perspective on the buildings. Submission requirements have a significantly higher level of detail in Stockholm. However, there are no specified requirements for participants to report on what is innovative in the proposal.

The competition proposals reinforce the differences in focus that the competition programs already established. The competition in Stockholm has a clear focus on “square meter efficient” apartments for young people. The jury clarifies this focus by extending the assessment criteria to the evaluation of the proposals to include housing qualities such as furnishability, flexibility, spaciousness and daylight. This means that proposals with minimal flats receive criticism relating to shortcomings in terms of housing qualities. The jury's assessment of the proposals means that they partially reinterpret evaluation criteria in the program in order to clarify differences in the way in which design themes solved the task. The competition in Botkyrka focuses on the urban planning level, which in this case is strengthened by linking a comprehensive and detailed design program for the external environment to the implementation. The focus on urban development in Botkyrka leads to the external environment being further developed when the land is made available in the detailed plan.

The DDCs do not have the same attractiveness. Botkyrka receives only four proposals. Only construction and real estate companies are presented as proposers. Participating architectural firms are invisible in the evaluation. The fact that competition in this case is limited to four proposers may be due to several factors. One possible explanation is the location. There might be uncertainty among developers about the possibility of selling the homes at a profit and to new tenant-owner associations. Another possibility is that the competition was marketed within a too small circle of potential construction and real estate companies. The DDC in Stockholm attracts 15 proposals. All design team companies are named in the jury statement. Despite stricter requirements, more participants are competing. Why does this competition appear more attractive? A first explanation is the plot, its size and location in the city. There are more companies able to build as specified. A second explanation is the attractive location of the competition site. A third possible explanation is that the invitation was marketed to a large number of potential consulting, construction and real estate companies. It has also been possible to get a clearer picture of the evaluation in the competition program.

The municipal organizers are blind to the role of innovator. Creative, innovative thinking and innovations are seen as a matter for the design teams. This applies to both Botkyrka municipality and the city of Stockholm. The innovation in the competition process is attributed to the companies in the consulting, and construction and real estate sectors. Since innovation and new thinking are explicit evaluation criteria, the jury members should have the task of identifying and highlighting creative and new solutions when evaluating the proposals. However, there is no information in the competition program and jury statement that shows that the organizer sees himself as an active player who tests his own ideas. A "hidden" news from the organizer in Stockholm, however, is the requirement in the program that the stated rent in the competition proposal must be determined in an agreement with the city.

## CONCLUSIONS

This paper set out to scrutinize whether DDCs deliver what societal planners hope for: more sustainable housing and other values at a fair cost. The case results produce five conclusions, which revolve around the four of the five dilemmas identified previously, showing challenges and opportunities for improving DDCs as a tool for innovation.

The first, involves the organiser's dilemma and how to set a frame for innovation in the program phase. Here we illustrate how underdeveloped competition rules leads the municipality to provide highly simplified descriptions of the competitions. The potential for generating creative and innovative solutions for accommodation needs are not exploited by the municipality in the competitions. We also illustrated that the municipalities do not perceive their own role as innovator in the process from program to implementation of the winning proposal. The second main finding addresses the design team’s dilemma of how to understand the brief and translate requirements into design-solutions in the competitions. Here we illustrate how the lack of transparency makes it difficult for the competition teams to get a clear picture about what is supposed to be contained in the competitions proposal and how the evaluation is done. The relation between goal demands at hand in, evaluation criteria and the jury's judgment of the proposal would need clarification in the program. Third, in relation to the professional’s dilemma of how to support design teams’ work with innovations, we show how topics such as team building and compensation are left entirely to the companies. Compensation for design work and establishment of the teams are viewed

as a question for the companies in the sector. The organisers do pose demands for the composition of the design team, but they do not demand specific competences or documentation. Fourth, concerning the jury's dilemma of how to develop and appraise identified innovative solutions in the evaluation, we point to the problematic of a lack of knowledge and experience exchange in the building sector. We found that there is no documentation of the competitions by the organisers to support experience exchange and diffusion of such documents as the competition program, the proposals and the jury judgment.

These are conclusions we will bring with us in a research project that will follow the competition process and focus on the fifth dilemma, namely, how to maintain innovative solutions throughout project implementation. The current critical conclusions nevertheless clearly shows that there are room for improvement when using design competitions as a governance and innovation tool.

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# A RISK FRAMEWORK FOR THE DELIVERY OF LONG-TERM PERFORMANCE THROUGH THE LARGE-SCALE ENERGY FOCUSED RETROFIT OF HOUSING

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The 2019 Climate Action Plan (Ireland) seeks to retrofit approximately 500,000 existing homes to attain a B2 Building Energy Rating by 2030. Although not without merit, this presents a number of risks. The authors, through a review of relevant literature and a survey of leading experts in the field of domestic retrofit, set out to explore if and how the implementation, execution, and performance of retrofit strategies that utilise a uniform approach to the retrofit of the decidedly non-uniform existing dwelling stock could create un-intended consequences. It is demonstrated how issues related to indoor air quality, comfort and overheating may occur due to the narrow focus of housing retrofit on regulated energy. It also established that the application of theoretical modelling can affect dwelling performance. These issues could have significant health and wellbeing impacts on occupants and, furthermore, could be exacerbated by the impacts of climate change. The research incorporates a risk assessment which examined the interdependent factors, including areas that require further research, that present a risk in large-scale deep retrofit. The findings have implications for the policy framework. Without action, there is a risk that the retrofitted dwellings of today become the 'hard to treat' dwellings of the future.

Keywords: retrofit; performance gap; building fabric degradation; ventilation

## INTRODUCTION

Consistent with the European Union's ambition to achieve a net-zero target carbon emissions by 2050 (European Union, 2019) Irelands Climate Action Plan 2019 (Department of Communications, Climate Action and Environment, 2019) details a roadmap of measures that seeks to achieve this goal. The residential sector in Ireland accounts for both 25% of the energy and related CO2 emissions (SEAI, 2018). To meet the goals set out above, significant decarbonisation of this sector must occur. In this context Ireland has set an ambitious goal of retrofitting 500,000 existing homes to a Building Energy Rating (BER) of B2 by 2030 (Department of Communications, Climate Action and Environment, 2019). This equates to almost 30% of all residential buildings in Ireland (SEAI, 2020). Whilst such an approach is necessary, it should not be pursued in isolation.

The paper utilised a review of existing literature coupled with a survey of leading participants in the housing retrofit market in Ireland to explore the potential un-

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intended consequences that may arise from a retrofit strategy that is based upon the large-scale reduction of regulated energy. Un-intended consequences can vary from those affecting occupant health and well-being to those that affect the dwelling structure.

The authors note that occupant behaviour can adversely affect the indoor air environment. However, this is true for all dwellings and not just those under review. This paper focusses on current retrofit policy and strategy. Future research will focus further on the impact that occupant behaviour may have.

# LITERATURE REVIEW

## Performance Gap

The Energy Performance of Buildings Directive (EPBD) (European Parliament, 2010) mandated all EU Member States to adopt a methodology to calculate the energy performance of buildings resulting in the production of an Energy Performance Certificate (EPC) (European Union, 2002). In Ireland, the model used is the Dwelling Energy Assessment Procedure. This model incorporates default values for elements that are utilised when it is too labour intensive or invasive to determine the actual value (Arkesteijn and van Dijk, 2010). Such default values are based on the regulations that were applicable at the time of construction as opposed to empirical data (Gram-Hanssen, 2014). The use of these pessimistic defaults ensures that dwellings do not achieve greater ratings than warranted whilst promoting the positive benefits of carrying out energy upgrade works (Arkesteijn & van Dijk, 2010). The current use and application of such theoretical modelling contributes to the aptly named performance gap, the differential between the expected versus. actual energy consumption.

The performance gap can manifest as the prebound effect (Sunikka-Blank and Galvin, 2012), arising due to the over-estimation of pre-retrofit energy consumption (Gram-Hanssen, 2014) where elements of the building perform much better than the default value suggests or as the rebound effect (Sorrell, 2007) where the energy that is saved as a direct result of low energy retrofit measures is offset by increased use. Realised energy savings can be 10-30% lower than those predicted by theoretical models (Liang *et al.,* 2018).

This presents a risk in large scale retrofit as deeper upgrades than necessary may be specified, leading to additional cost for the homeowner. In addition, not achieving predicted energy, and cost savings may affect ability to repay loans taken for energy upgrade works. In turn, this may limit the ability of the national retrofit strategy in achieving its energy saving goals.

## Indoor Air Quality and Ventilation

We now spend over 90% of our time indoors (Klepeis et al, 2001), as a result there is a growing awareness of the importance of Indoor Air Quality (IAQ) in energy efficient buildings along with increasing concern regarding the impact of air-tight dwellings on the health and well-being of occupants (Shrubsole et al. 2014). Inadequate air change rates have a significant impact on IAQ (Yang *et al.,* 2020). Ensuring fresh, clean air together with appropriate temperature and relative humidity are key factors in creating healthy indoor environments (Kraus 2016). Studies have previously linked severity of asthma symptoms to lower air change rates in dwellings (Ucci *et al.,* 2011) with higher indoor concentrations of air pollutants such as volatile organic compounds (VOC's) leading to an increased occurrence of mould growth and condensation

(Kraus, 2016). Research has shown that whilst VOC levels change significantly based on the season, appropriate ventilation strategies can be successful in reducing total levels (Turunen *et al.,* 2019). Demand-controlled ventilation (DCV) systems that do not supply airflow continuously but are controlled by humidity sensors to save energy can pose potential problems for exposure to VOC's (De Jonge *et al.,* 2019). Research by Sharpe *et al.,* (2016) across 85 dwelling typologies that represent 3300 homes found that only 16% of Mechanical Ventilation with Heat Recovery (MVHR) systems were commissioned correctly with respect to air flow and balancing. The reliance on a mechanical ventilation strategy is also predicated on the dwelling occupant's awareness of the system and its service requirements. A case study by Brown and Gorgolewski (2015), showed that dwelling occupants that switched off their MVHR units reported greater satisfaction with the IAQ within their apartment despite quantitative data proving the opposite was the case.

These issues present a risk in large scale retrofit as the adequacy of IAQ is dependent on the implementation of a correct ventilation strategy. Systems need to operate correctly so that they can maintain the appropriate levels of ventilation required. Dwelling occupants need to be aware of maintenance schedules. Airtightness is closely related to this risk as the reduction of unintended air leakage further emphasises the ventilation requirement.

**Airtightness and Building Fabric Degradation**

The presence of an airtight external envelope can lead to increased internal temperatures (Mavrogianni et al. 2013) and higher concentrations of CO2 (McGill *et al.,* 2015), VOC's and PM2.5 (Derbez et al. 2018) and mould growth (Crump *et al.,* 2009). The Durabilit'air Project (Leprince *et al.,* 2017) reviewed and analysed existing studies on the long-term durability of airtightness measures. In almost every study, the air permeability of part of the dwelling under test had decreased.

Decreases in airtightness may, dependent on the location and the envelope build-up, cause the air permeability to increase leading to uncontrolled ventilation. Leakage of moist air in the opposite direction allows hygroscopic materials within the structural envelope to pick up water molecules at the inner surfaces of their pore system until they reach a water content at equilibrium with the humidity of the ambient air (Kunzel, 1995). This can lead to mould growth and materials degradation depending on construction methods and dwelling typologies (Campbell *et al.,* 2017). In turn, this can have negative implications for occupant health and wellbeing (Shrubsole et al. 2014).

The presence of this issue presents a risk in large scale retrofit where elemental performance takes precedence over hygrothermal performance. This risk is exacerbated in solid wall traditional dwellings but exists in all dwellings where moisture may condense in an uncontrolled fashion across the internal/external elemental divide.

**Radon**

It is estimated that 9% of deaths associated with lung cancer throughout the EU are due to radon exposure in the home (Crump *et al.,* 2009). However, research regarding radon concentration in dwellings, specifically in retrofitted dwellings, remains limited, particularly in Ireland and the UK. A computational evaluation by Mc Grath et al. (2021) predicts radon concentration increases of up to 107% following an energy retrofit that seeks to remove all uncontrolled ventilation. Europe wide monitoring

campaigns that looked at the relationship between indoor radon concentration and low energy upgrades showed that thermal retrofitting can cause increases in indoor radon concentration (Collignan et. al. 2016). Modelling by Akbari *et al.,* (2012) demonstrated that radon concentration falls as relative humidity increases from 30% to 60% whilst an increase in relative humidity above 70% correlates with an increase in air density which prevents radon from moving upwards in the room and escaping through planned ventilation channels. Therefore, it would appear that the presence of a functioning and effective ventilation system in retrofitted dwellings is important. This is furthered by McGrath *et al. (*2021) who found that the addition of dwelling specific ventilation strategies has a positive effect on radon concentration levels.

The presence of this issue presents a risk in large scale retrofit as approximately one-third of Ireland is designated as a high radon area (Radiological Protection Institute of Ireland, 2010). It is not clear at present how the presence of a retrofitted radon barrier and matters such as occupant behaviour may relate to radon levels in retrofitted dwellings. Unintended increases in internal radon levels have the potential to cause serious and long-lasting consequences for dwelling occupants. This is an area requiring further research.

**Overheating**

The current drive in both new build and retrofit dwellings is focused on heat retention as a climate change mitigation strategy. Although this is not without merit, the dwellings that we design build and retrofit today need to consider the potential impacts of climate change or they risk becoming the hard-to treat dwellings of the future. As such, they need to incorporate adaptive capacity to ensure long-term performance and avoid the 'locked-in' impacts of climate change (de Wilde and Tian, 2011). One of the key climate change related risks to be considered is overheating.

Low-energy dwellings have been associated with an increased overheating risk particularly in warm climates such as Australia, the United States, the UK, and part of Southern and Continental Europe (Jenkins *et al.,* 2014, Hatvani-Kovacs *et al.,* 2018, Sailor *et al.,* 2019, Salthammer *et al.,* 2018). However, overheating has also been identified as a risk in cooler and more temperate climates (Dengel and Swainson, 2012 and Mulville and Stravoravdis 2016). To date, limited research has been undertaken in relation to the overheating risk in low-energy dwellings in Ireland. Washan (2019) found that, in Ireland, single aspect dwellings and dwellings with south and west facing glazing were most at risk and called for further analysis. Mulville and Stravoravdis (2016) found that increasing levels of insulation and air tightness was correlated to overheating risk. Therefore, this issue is particularly relevant in the context of large scale retrofit.

Overheating in dwellings has been associated with negative impacts on occupant health (Dengel and Swainson 2012) whilst occupant adaptations could lead to potential safety concerns. For instance, Baborska-Narożny *et al.,* (2017) found that in a retrofitted apartment block, occupant adaptations included wedging fire doors. As such the research gap regarding overheating risks in cooler climates remains.

## METHODS

This paper is part of an ongoing research project that explores the risks associated with the retrofit of housing in Ireland because of the narrow focus on the reduction of regulated energy. It incorporates an exploration of the existing research pertaining to the risk factors identified throughout the literature followed by a survey of leading

experts in the field to identify and rank the highest risk factors emanating from the large-scale energy focused retrofit of housing.

The survey was administered online, targeting experienced professionals in the field. Respondents were asked to note overall, and specific housing retrofit experience, any with limited retrofit experience were excluded from the final analysis. An initial pilot of the survey took place with five respondents and some minor amendments were made to the survey following this to aid comprehension. Respondents were asked to note their awareness of the potential risk factors associated with large-scale energy focused dwelling retrofit. An opportunity was provided to add further clarification or additional comments, if required. Respondents were then asked, based on their experience, to note the likelihood of the previously identified potential risk factors occurring in respect to large scale energy focused dwelling retrofit and the magnitude of the impact should they occur. 60 responses were received which allowed the authors to analyse and rank the risk factors identified.

## ANALYSIS AND DISCUSSION

Fig 1 demonstrates that experienced retrofit professionals are aware of the potential risk factors associated with large-scale energy focused dwelling retrofit. The greatest awareness is associated with negative impacts on IAQ (Mean 4.07; St. Dev 0.92). This risk factor also has the narrowest standard deviation, demonstrating a high level of agreement across all respondents.

This is followed by the Performance Gap Rebound Effect (Mean 3.85; St. Dev 1.01) showing a similar level of agreement. The position of Overheating Risks (Mean 3.8; St. Dev 0.98) and the level of overall agreement associated with it as a risk factor is surprising. Respondents were aware of and in general agreement in respect to Building Fabric Degradation (Mean 3.50; St. Dev 1.03). This is an important recognition on the part of experienced retrofit professionals.

There is a lower awareness and a greater deviation associated with the Performance Gap Prebound Effect (Mean 3.48; St. Dev 1.21). This may show that whilst there is general industry-wide awareness of pessimistic BER assumptions, respondents may be unsure as to what risk(s) may arise from same.

The largest deviation is associated with Increase in Internal Radon Levels (Mean 3.31; St. Dev 1.55) showing quite a variability of responses, quite possibly due to the limited research available on the subject, however, respondents seem to have an awareness of the link between reduced air movement and its possible effect on radon levels. Presumably, this position is held for VOC's, PM2.5, humidity, etc. as it is also reflected in respondent's position on the risks associated with IAQ.

MVHR Performance over time (Mean 3.19; St. Dev 1.48) also shows a wide range of responses, though some respondents proffered that they were disinclined to specify or use MVHR due to the perceived difficulties associated with commissioning, maintenance, and operability by end-users.

The position of and large deviation associated with Airtightness Reduction over time (Mean 3.17; St. Dev 1.44) suggests that it is also an area that is under-researched in an Irish context. It is also a risk factor that would not arise with any immediacy.

The least level of awareness among retrofit professionals is associated with DCV Performance over time (Mean 2.93; St. Dev 1.25). The relationship of DCV

performance to VOC and PM levels is under-researched in an Irish context, as such, widespread acknowledgement of this issue may not exist.

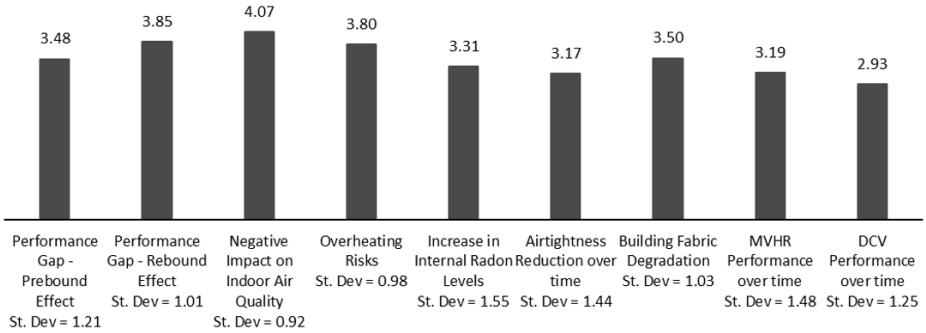


*Fig 1: Mean awareness of risk factors among survey respondents*

Fig 2 illustrates the likelihood of occurrence of the risk factors under review and the magnitude of the impact should they occur. The data suggests that respondents feel that the impact of each risk factor would be significant, were it to occur. Interestingly, respondents consider that the magnitude of impact associated with the occurrence of Negative Impacts on IAQ (Mean 4.07; St. Dev 0.92) and Increase in Internal Radon Levels (Mean 3.31; St. Dev 1.55) is large, reflective perhaps of the significant effects that the occurrence of both would have on occupant health and wellbeing.

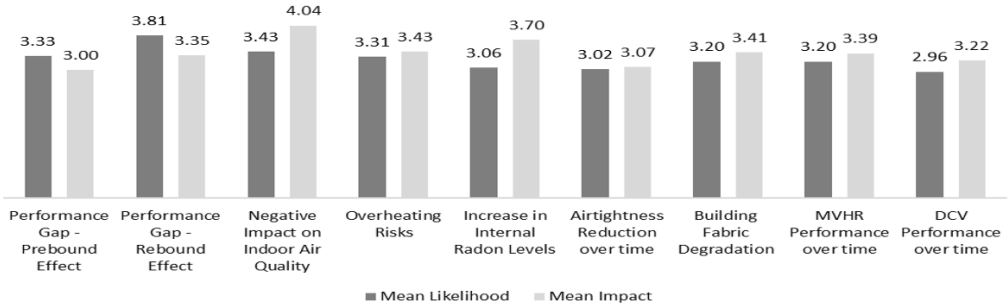


*Fig 2: Mean likelihood of occurrence and magnitude of impact*

Fig 3 demonstrates the individual rating of each risk factor (mean likelihood of the risk occurring x mean impact), therefore indicating the total amount of risk attached to each factor in respect to large scale energy focused dwelling retrofit.

Negative Impacts on IAQ (Mean 4.07; St. Dev 0.92) is perceived as the greatest risk associated with large-scale energy focused retrofit. This is not surprising given the level of research available (Ucci *et al.,* 2011; Shrubsole et al. 2014; Kraus 2016.).

The risk rating associated with the Performance Gap Rebound Effect (Mean 3.85; St. Dev 1.01) is interesting insofar as it reflects the position of experienced industry professionals if energy focused dwelling retrofits fail to achieve predicted energy targets. This would have serious repercussions in respect to both the overall viability of large-scale energy focused retrofit measures and the required outcome of the scheme in general.

Overheating Risk (Mean 3.8; St. Dev 0.98) and Increased Internal Radon levels (Mean 3.31; St. Dev 1.55) are also rated highly. As noted previously overheating risk and radon levels remain under explored in the Irish context. The presence of overheating risk as being significant is perhaps somewhat surprising as there is limited

recorded instances of overheating in Ireland. Potentially this points to underreporting, this could be further exasperated over time due to the impacts of climate change.

Building Fabric Degradation over time (Mean 3.50; St. Dev 1.03) and MVHR Performance over time (Mean 3.19; St. Dev 1.48) are perceived, by survey respondents, to exist in the mid-range in respect to risk. The survey demonstrated that there was general awareness of these risks, with respondents indicating a relatively high impact factor should they arise. Research has shown that these risks have eventuated, following low energy retrofit measures, in other jurisdictions (Leprince *et al.,* 2017; Sharpe *et al.,* 2016; etc.). It may be only a matter of time and further research before we start to see like effects in an Irish context.

The Performance Gap Prebound Effect (Mean 3.48; St. Dev 1.21) is perceived by survey respondents to be a lower risk. However, research has shown that this does exist (Sunikka-Blank and Galvin, 2012) so it may be that general industry awareness is lacking. The survey found that the awareness of this issue is mid-range in respect to the other factors under consideration.

DCV Performance over time (Mean 2.93; St. Dev 1.25) and Airtightness Reduction over time (Mean 3.17; St. Dev 1.44) were also perceived as lower risk by survey respondents. However, the survey also found less overall awareness of these issues. Given the recentness of widescale adoption of DCV within the Irish Construction Industry and the unseen (at least for a considerable period of time) and incremental nature of fabric degradation and air tightness reduction, it is perhaps not unsurprising.

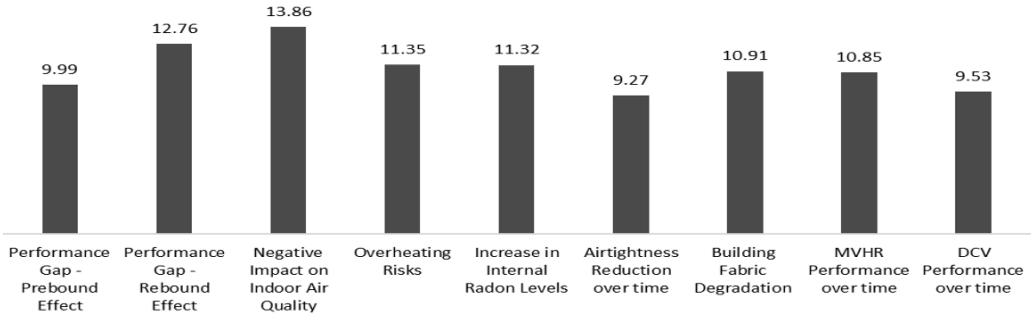


*Fig 3: Risk rating - mean likelihood x mean impact*

It can be argued that IAQ, Overheating Risk, and Radon Levels can all be associated with ventilation. Research has shown that these risks can be somewhat mitigated by a suitable mechanical ventilation strategy (for instance see McGrath *et al.,* 2021). Whilst welcome as a potential solution, it is important to note that such a strategy is also not without risk. Passive ventilation can be influenced by occupant behaviour (blocking of vents), with purge utilisation based on the occupant's consideration of the indoor environment. DCV can monitor humidity (some monitor CO2) but would need to incorporate VOC and PM sensors, room specific filters for incoming air, and purge capacity. The continuous activation of MVHR systems can ensure that the correct levels of airflow and air management are maintained. However, survey respondents reinforced the literature findings in respect of under-performing systems, lack of awareness among dwelling occupants in respect to operation and maintenance, and poor commissioning of MVHR systems (Brown & Gorgolewski, 2015; Sharpe *et al.,* 2016). All are valid arguments that can be mitigated by the introduction of a regulatory framework in respect of MVHR installation, operation, and maintenance.

## CONCLUSIONS

This paper set out to explore if and how the implementation, execution, and performance of retrofit strategies that utilise a uniform approach to the retrofit of the decidedly non-uniform existing dwelling stock could create un-intended consequences for the dwelling and/ or occupants.

The research has confirmed the existence of risks associated with large-scale energy focused dwelling retrofit. These risks can be exacerbated by (but not limited to) poor design, dwelling typology, ventilation strategy, occupant behaviour, theoretical modelling, and building fabric degradation over time leading to airtightness reduction. These risks can negatively impact the indoor air environment in respect to air quality, increased internal radon levels and overheating and can affect the structural integrity of specific dwelling typologies. Further research is required to ascertain the un-intended consequences that can arise or have arisen as a result of the current retrofit strategy in Ireland.

Considering the interdependent risk factors that present a risk in large-scale deep retrofit, it is advisable that a policy framework is created in respect to the specific requirement for mechanical ventilation in dwellings that have undergone low energy upgrade works. The framework must regulate requirements in respect of the regulation of PM, VOC (all types), CO2, humidity levels, and purge requirement. It must also regulate procedures for installation, operation, and maintenance of ventilation systems.

Performance gaps (prebound and rebound) must be viewed as a risk that can affect the viability, therefore the success, of Irelands ambitious goal of retrofitting 500,000 existing homes to a Building Energy Rating (BER) of B2 by 2030.

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# CIRCULAR PREQUALIFICATION AND BIDDING PRACTICES AT CONTRACTOR FIRMS

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Developing new prequalification and bidding practices are paramount to the implementation of circular building and refurbishment. Understanding these practices are essential as prequalification and bidding represent the two most important competitive parameters for contractor firms. However, little is known about the actual prequalification practices and bidding practices at contractor firms due to the sensitivity and confidentiality of the subject. The purpose of this paper is to investigate through activity theory how practices of prequalification and bidding in contractor firms may support or hinder a circular transformation of refurbishment and new building. It is based on an integrative literature review that will review, critically appraise, and synthesise representative literature in an integrated way to generate new frameworks and perspectives on the research question. The study points at the barriers and levers for a circular transition of contractor firms. The main findings are related to five central dilemmas that contractor firms are facing in the process towards circular prequalification and bidding practices identified from the activity system. The five dilemmas include: 1) scalability within the organisation and knowledge sharing, 2) interpretation of sustainable requirements, 3) narrow profit margin and poor business cases, 4) underdeveloped circular markets and 5) the traditional practices of tendering. In conclusion, this paper will generate new insights on prequalification and bidding practices for both researchers and practitioners into the possibilities and obstacles for renewing the building industry and transforming it towards a circular future.

Keywords: sustainable building; bidding; competitiveness; contractor selection

## INTRODUCTION

The construction industry faces substantial sustainable challenges. In response, sustainable initiatives in the Danish construction industry are emerging such as: 1) an increase in Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) certifications, 2) the launch of a voluntary sustainability class in the Danish Building Regulations, 3) the European reporting system Level(s) for sustainable buildings (Birgisdottir and Haugbølle, 2019) and 4) a number of pilot and development projects (Huovila *et al.,* 2019; Leising *et al.,* 2018). The sustainable trends are further amplified by the significant increase in the global population growth and thus, straining the available natural resources. As a result, current practices need rethinking towards the aim of

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achieving a circular economy and by that take greater social responsibility to reduce the negative environmental impacts. The term circular economy includes principles related to the increase of material productivity, eliminating waste, maintaining the value of materials and enable systems for closed-loop processes of materials and energy (Adams *et al.,* 2017). The potential is immense, as the construction sector is responsible for generating 35% of the world's total waste as well as producing and consuming around 40% of all materials on a global scale (Faezi, 2014).

New sustainable trends enhance the pressure on construction companies to change their business models. Several studies emphasise that the development towards a circular construction industry requires new business and ownership models (Adams *et al.,* 2017; Leising *et al.,* 2018; Hart *et al.,* 2019). However, the literature points to the fact that it remains unclear which changes are needed and how innovation of business models can translate into practice (Hart *et al.,* 2019; Adams *et al.,* 2017). The past decade of research concerning business models has focused on establishing a theoretical grounding (Teece, 2010), developing models and tools e.g., business model canvas and value proposition design (Osterwalder and Pigneur, 2009; Osterwalder *et al.,* 2014), and mapping the diversity of business models (Gassmann *et al.,* 2014). Other research in the field has focused on developing sustainable and circular business models (Schaltegger *et al.,* 2016; Boons and Lüdeke-Freund, 2013; Lüdeke-Freund *et al.,* 2019). Still, the majority of the studies are focused on consumer goods or new digital products and services, while few studies are focusing on long-term capital goods such as buildings nor contractor firms. Circular economy business models rethink traditional business models, but the perspective is product-oriented aimed to break the shorter life cycles by suggesting that products must be long-lasting, reusable or recycled (Lüdeke-Freund *et al.,* 2019). The construction industry must be considered with a different logic to encompass the longer life cycles of capital goods, flexibility in building design, the procurement of unique "products", and services that include several repairs or refurbishments during buildings' lifetime.

Focusing on the practices and processes of the contractor firms are therefore paramount to the implementation of circular construction both in relation to refurbishments / renovation projects and new building projects. In particular, understanding the tendering practices are essential, as prequalification and bidding represent the two most important competitive parameters for contractor firms. Therefore, contractor firms must be prepared to visualise the planning of sustainable and circular issues from the early process of prequalification for the specific building project to the hand-in of the final bidding material. The focus of contractor firms is chosen; thus, the delimitation is not to include the activity system of building clients with the awareness that the inter-organisational activities are also highly relevant in terms of understanding the contractor firms' practices.

The research objective of the paper is to synthesise current findings within the academic literature in order to generate new understandings and frameworks on contractors' prequalification and bidding practices through the application of activity theory.

## RESEARCH DESIGN

This study applies activity theory as the theoretical basis for the data collection and processing, which is conducted as an integrative literature review. Activity theory is applied as a framework to structure and synthesise the main concepts and ideas retrieved from the integrative literature review. Activity theory (Engeström, 2018) is

chosen, as the analysis of the integrative literature study will encompass an activity system aimed to illustrate the process-related descriptions of contractor firms practices within prequalification and bidding.

*Activity theory*

The strength of activity theory is the application of an organisational perspective on changes of practices in organisations (Engeström, 2018) rather than an institutional or a political perspective. Thus, the organisational perspective allows for a deeper understanding of which practices counteract and enable certain objectives with the perception that organisations are dynamic and flexible, where institutional conditions do apply. However, the practices of contractor firms are not necessarily determined solely as a result of a governed institutional framework. Activities and practices within prequalification and bidding described in the academic literature are categorised into activity theory's six dimensions in order to identify the internal levers and barriers for a circular transition. An analysis of the contractor firms' activity system will examine the dominant interactions between the organisational activities, hence the possibilities for participating, influencing and contributing to circular building projects.

An activity system consists of a triadic relation between a "Subject" and an "Object" mediated by "Tools and signs" and controlled by "Rules", "Community" and "Division of Labour". Changes in an activity system are driven by internal tensions and/or tensions in relation to other activity systems. Activity theory differentiates between four types of development dynamics: Primary and secondary tensions internally in an activity system as well as tertiary and quaternary tensions externally between activity systems (Engeström, 2018).

*Integrative literature review*

The integrative literature review applies a systematic approach for evaluating the available research that is relevant to the research objectives. The process includes identifying, assessing and interpreting selected academic literature within the subject. Thus, the following overall five-stage integrative review involves (Russell, 2005): 1) research problem formulation, 2) literature search, 3) assessment of data, 4) data analysis and 5) interpretation and presentation of findings. The methodology of the integrative literature study is chosen to critically review and synthesise the represented literature in an integrated form to demonstrate new conceptual frameworks (Torraco, 2016) by application of activity theory. Furthermore, the integrative literature review comprises less information about the individual papers/studies in detail, because the emphasis is on the presented common ideas, concepts and relevant findings stated in the papers. As a result, the quality assessment is essential to critical review and identify the general trends of the research (Khoo *et al.,* 2011).

The delimitation of the literature search focused on key findings towards three main directions when searching for articles online in the databases of the university library and Google Scholar: 1) Contractor firms' prequalification and bidding process, 2) sustainable building transition, and 3) business models and innovation. The method of the quality assessment was to evaluate the individual articles in terms of relevance to the research area including omitting studies conducted in countries differing excessively from Nordic construction practice e.g., developing countries. In addition, the chosen literature is based on recent research within the past ten years to avoid "out-of-date" publications and include peer-reviewed articles to ensure content quality. Moreover, the examination consisted of accentuating the most frequently

identified barriers and potentials for circular bidding processes mentioned in the academic literature. 56 articles were selected as "primary studies" for full review and evaluated in terms of research objective and motivation, chosen methodology, important findings and reflections on relevance/research quality. 29 studies were eliminated, and the remaining 27 studies constituted the chosen data sample for the presented results.

## FINDINGS AND DISCUSSION

*Potentials of Circular Tendering*

Transforming business models in contractor firms are subject to special circumstances due to ambiguity in performance requirements, non-linearity in project execution, an increasing level of emerging complexity throughout the project phases and a strong project focus. Therefore, innovative initiatives usually only translate into practice in the individual project without any possibility for repetition (Orstavik *et al.,* eds. 2015), which is further hampered by complex supply chains (Van den Brink *et al.,* 2017). The strong project focus of firms and buildings as capital goods are challenging the contractor firms both internally as a result of their own tendering practices and externally as a result of the current set of rules assigned to the contractors (Fig 1).

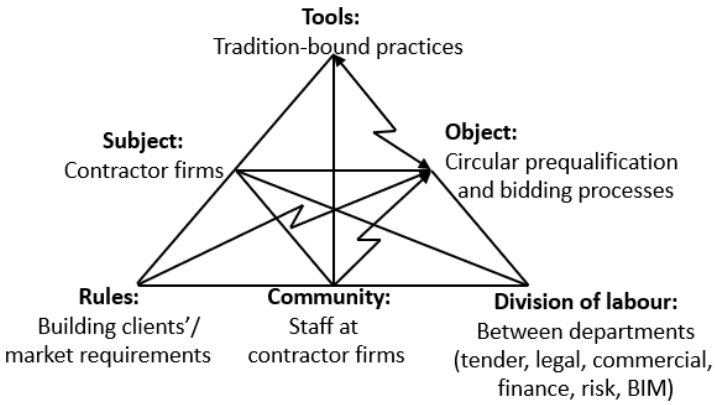


*Fig 1: Activity system of contractor firms (Modified from source: Engeström, 2018)*

The complexity of the amount of information and stakeholders involved in today's building projects combined with a focus on short-term goals in individual project execution (Van den Brink *et al.,* 2017) are hindering innovative processes. Tradition-bound predefined mechanisms of cost-efficient driven and risk-minimising decisions in the early project phases characterise the practices of contractor firms (Hartono and Yap; 2011; Urquhart *et al.,* 2017). Circular solutions require extra investments (Kozminska, 2019) and funding together with unforeseen costs and risk (Brooks and Rich, 2016) in which contributes to the majority of current building projects resorting to traditional standard procedures.

While current practices in the construction industry are mostly demonstrating barriers to implement circular tendering processes, there are new emerging trends in which rethink the traditional practices. In the following, five central dilemmas towards a circular transformation of construction are identified based on contradictions in the activity system of contractors.

*Scalability within the organisation and knowledge sharing*

The first dilemma is connected to the constraint between the community and the objective (Fig 1). The community for contractor firms consist of the internal staff in

the organisations and a contradiction to the objective includes a knowledge gap concerning sustainable construction (Hwang *et al.,* 2018; Adams *et al.,* 2017; Häkkinen and Belloni; 2011). Thus, participating in sustainable projects entail contractor firms to possess other competencies in addition to their core competencies. Traditionally, sustainability has served as an additional consulting service in the construction industry among designers and engineers. Nonetheless, the increased amount of sustainable building projects is initiating other stakeholders to participate in the sustainable agenda (Hwang *et al.,* 2018). The growing demands from building clients and the importance of contractor firms' function and role regarding circular implementation in practice, obligate contractor firms to acquire knowledge and skills within sustainable practices (Brooks and Rich, 2016). Examples include practices related to certification schemes, testing of materials, and waste handling (Kozminska, 2019) to maintain a competitive advantage in the bidding processes of sustainable building projects. However, this raises the dilemma of ensuring production teams at the building site having adequate knowledge and skills in order to follow the speed and be well-prepared for the implementation of the solutions written in the tender. Correspondingly, there is a balance of aiming to win sustainable projects as a winning strategy, but also guarantee that all parts of the organisation through education and valuable knowledge sharing can deliver the promised results.

*The interpretation of sustainability requirements*

The second dilemma is related to the constraint between tools, rules and objective (Fig 1) as the interpretation of circular construction and sustainability may reflect in vague descriptions and difficulties with adapting methods and tools. Hence, sustainability in the construction industry remains at the development stage. The lack of standardisation is generating confusion in two ways; 1) the building clients' ability of setting accurate and clear sustainable requirements and 2) the contractor firms' ability of responding to the requirements regarding cost estimations and time planning. The applied rules for the contractor firms include great dependency on building clients' requirements. Therefore, contractors must accommodate a myriad of needs and considerations (Winch and Cha, 2020) combined with high flexibility in terms of providing service to different types of building client organisations (Haugbølle *et al.,* 2015). The literature highlights the importance and necessity of increased legislation in the area (Brooks and Rich, 2016; Nordby, 2019). Furthermore, contractor firms are not, in principle, a passive stakeholder who is solely dependent on other stakeholders choosing to operate in a circular direction. Cooperation with building clients is essential for driving the circular agenda, but the contractors can also help to shape the market as active players by providing relevant inputs to building clients and legislative bodies. Hence, contractor firms can profitably visualise their innovation potential to influence and challenge the building clients' standpoint by moving from reactive to proactive innovation as a response toa changing environment (Meng and Brown, 2018).

Moreover, current tools and methods available for sustainability assessments generate difficulties for contractor firms to incorporate in tenders. There are several uncertainties in the methods (e.g. Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) calculations) for demonstrating the expected operational costs and environmental benefits by choosing sustainable building projects due to the lack of standardisation (Häkkinen and Belloni, 2011). In addition, calculating circular tenders increases the complexity in terms of predicting the actual building project costs and, consequently, associated unforeseen costs and risks (Brooks and Rich, 2016). The

risks include e.g., extra investments due to additional tests and permissions of reused materials (Kozminska, 2019).

*Narrow profit margin and poor business case*

The third dilemma concerns the constraint between tools and objective (Fig 1). The tradition-bound practices (Pardalis *et al.,* 2019) are playing a significant role in contractor firms' activity system, which work against the change in a circular direction (Kozminska, 2019). Contractors are focused on short-term aims of winning the subsequent building project (Van den Brink *et al.,* 2017) and therefore, practices are influenced by establishing winning strategies (Tan *et al.,* 2010). The strong focus is on evaluating the bidding from a profitable perspective determined by risk assessments (Hartono and Yap; 2011; Urquhart *et al.,* 2017). Moreover, "project strategic importance" is also playing an important role, when contractor firms are choosing to bid (Hartono and Yap; 2011). The chosen strategy ensures the right positioning in the market e.g., by aligning potential projects with the track record or entering a new market opportunity.

The traditional perception of a contractor firm is characterised by strong market forces, profit optimisation and competitive adaptation. However, it is equally important to understand that contractors are subject to certain terms and conditions. Contractor firms are responsible for handling a large number of cash flows, which typically need to generate a net profit margin of at least 5% for each completed building project (Zhang *et al.,* 2020). Thus, scrupulous planning of the production to avoid budget overruns is crucial. There is consequently a great risk associated with changes in practices because the financial margin profit is a condition of existence. As a result, both young and experienced contractor firms are reticent about adopting innovations. Hence, younger firms are afraid that changes will damage their business and experienced firms are focusing on increasing their area of expertise (Pardalis *et al.,* 2019). The literature suggests the need for developing new sustainable business models to enhance the economic incentives among the stakeholders (Adams *et al.,* 2017; Leising *et al.,* 2018; Hart *et al.,* 2019; Kozminska, 2019). Nevertheless, the literature does not provide concrete suggestions on how circular business models should be implemented in practice including the role of the involved stakeholders in the construction industry value chain nor the necessary adaptations of the contractor firms' internal and external practices. Furthermore, the literature fails to explain how innovative solutions can demonstrate a sustained impact on the overall processes within the construction firms' organisations instead of focusing on innovation in individual case studies (Brockmann *et al.,* 2016; Chegut *et al.,* 2019; Martiskainen and Kivimaa, 2018).

*Underdeveloped circular market*

The fourth dilemma relates to the constraint between rules and objective (Fig 1), as the status quo in the construction industry is generating difficult conditions for circularity. The circular market is underdeveloped due to the lack of economic incentives among stakeholders in the value chain combined with unsuitable building regulations (Nordby, 2019; Zhao *et al.,* 2018) as well as technical challenges related to material recovery (Hart *et al.,* 2019). Consequently, the business case is poor for contractor firms to reuse or recycle material streams, as the construction industry follows the linear economy which supports a market of acquiring virgin materials at lower costs, more readily accessible and the assurance of meeting required building regulations or certifications (Hart *et al.,* 2019). Many studies also refer to the need for

a new circular service provider/recovery market to drive the transition (Van den Brink *et al.,* 2017; Nordby, 2019; Leising *et al.,* 2018).

Contractor firms must respond to the conditions of procuring building materials, which meet the building regulations in terms of load-bearing ability, toxic compound levels and "Conformité Européene" (CE) marking. Reused materials contain the complicated documentation process of meeting several requirements, tracking the suitable materials including sufficient amounts, testing and recovering the materials, and finally, planning for the correct storage of the materials (Hart *et al.,* 2019; Kozminska, 2019). The circular market terms for contractor firms to manage in practice are associated with great liability risks as there is no security of material supply, no formal authorisation procedure in place, and not the least, the market for reused and recycled materials is currently non-existent (Nordby, 2019). Thus, circular initiatives entail many additional resources, and expenses compared to the alternative option of purchasing virgin materials.

*The traditional practices of tendering*

The fifth dilemma refers to the constraint between rules and objective (Fig 1). The construction industry's tender and contract forms generate difficult conditions for applying a circular economy in practice (Aarseth *et al.,* 2017; Pomponi and Moncaster, 2017). The traditional closed and controlled approach only allows few main stakeholders to drive the project objectives and by that hampering the flexible open dialogue among multiple stakeholders needed for co-creating sustainable initiatives at an early project stage (Aarseth *et al.,* 2017). The literature emphasises that the procurement of contractors must prioritise different aspects than only cost or price (Loosemore and Richard, 2015) and non-traditional procurement systems such as integrated project delivery and partnering might be considered as sustainable drivers due to the increased level of integration and collaboration (Tang *et al.,* 2019; Häkkinen and Belloni, 2011).

Although contractor firms' individual considerations for self-survival should not be underestimated, there are trends towards the creation of shared value with the aim of combining market competition and at the same time serve fundamental societal needs. By creating shared value, contractor firms must address societal issues from a shared value perspective and invent new practices in the organisation to address them. In addition, the traditional role of contractor firms is being challenged because the benchmark is not solely focused on efficiency and profit within in-house production, but the perception expands the link between societal and economic progress (Porter and Kramer, 2011). In the academic literature, the awareness is mainly concentrating on the building clients and designers for driving the sustainable agenda (Häkkinen and Belloni, 2011; Zhao *et al.,* 2018). Nonetheless, contractor firms are often functioning as the key stakeholder to all the other stakeholders in the value chain from the building clients, designers, engineering consultants to the subcontractors, procurement partners, waste management companies and demolition companies. Moreover, contractor firms possess valuable knowledge of building material characteristics and practical experiences in construction solutions.

Building projects with untraditional contract forms create a new platform for contractor firms' involvement in the very early dialogue together with the project stakeholders to address the project's sustainable objectives (Tang *et al.,* 2019). Also, these types of projects allow contractor firms to complete projects where other parameters are considered instead of the narrow focus on the lowest pricing and time

optimisation. General contract forms often result in contractor firms entering the project at the late planning phase. Consequently, allocating almost no room for contractor firms' input and participation in the decision process. Excluding contractor firms' involvement in relation to the fostering of innovative and sustainable solutions is criticisable, because contractor firms are ultimately responsible for implementing the chosen solutions.

## CONCLUSIONS

The main findings of this study include five central dilemmas that contractor firms must address within their own practices in the transition towards circular prequalification and bidding. The five dilemmas represent a substantial part of the complex reality that contractor firms face in the circular transition of traditional bidding practices. Although, the preparation of tendering is the foundation for contractor firms, the understanding of the bidding processes is limited due to the confidential and commercially sensitive nature of the subject.

The first dilemma is about the acquisition and scaling of sustainable knowledge within the organisation. The second dilemma relates to the interpretation of sustainable requirements and the associated uncertainties of available methods and tools. The third dilemma focuses on the contractors' problematic terms and conditions of handling large cash flows and generating a reasonable net profit margin for each completed project. The fourth dilemma refers to the underdeveloped circular market, which is currently inadequate to compete with the existing market. The final and fifth dilemma discusses the traditional practices of tendering and how alternative tender and contract forms can accelerate circular implementation.

This study is limited to examine the activity system of contractor firms. However, further research could gainfully include the activity system of building clients to expand the field of knowledge within enablers and barriers for circular bidding processes. The procurement methods of building clients are particularly valuable to investigate further, as the culture of procurement helps to dictate the green agenda and the contractor firms' level of flexibility towards adopting circular initiatives.

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# HEAVY-DUTY CONSTRUCTION EQUIPMENT: DINOSAURS OF BLACK ENERGY?

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Construction equipment emissions in civil engineering are a major sustainability issue. However, the industry continues investing in diesel (and/or biodiesel) machines - which, even if compliant with EU regulations, are far from "clean". Cleaner technologies in construction equipment, like electrical engines, are considered more expensive investments; moreover, they are dependent on the available power supply while operating in confined areas. So, transitioning these machines sustainably involves changing technologies, business models, and public regulation. In Scandinavia, heavy-duty engines (over 25 tons) have only recently become (limitedly) available. Therefore, the current paper analyzes enablers and barriers for a sustainable transition of civil engineering construction equipment to on-site electrical machines in Scandinavia. The sustainable transition theory, combined with sustainable business models, serves as the framework of understanding. Empirically, a desk study of governance and regulation is combined with material from four fossil-free test building sites in Norway, Denmark, and Sweden. The results highlight the importance of a public-private business model, where public client-driven transition is subsidy-supported (e.g., making electrical equipment available through concession, and encouraging small innovative machine manufacturers to develop electrical equipment), while waiting for international construction equipment players to become transition-ready. Recommendations for the transition thus include strengthening public-private collaboration.

Keywords: heavy-duty; electrical engines; sustainable transition; Scandinavia

## INTRODUCTION

Over 2018-2021, emission-free civil engineering projects have been introduced within the core of various European cities - e. g. Oslo (2018), Copenhagen (autumn 2019), Bergen (summer 2020), Helsinki (autumn 2020), Amsterdam, Brussels, Budapest, Lisbon, Vienna (BBI 2021, SPP 2021). Construction equipment manufacturers are also in the process of providing electrical machines. According to BBI (2020), electrical machines up to 2.5 tons are now available all over Europe. But it is also documented that it is the heavy-duty machines, above 10 tons, that are the heaviest contributors to $CO_2$, $NO_x$, PM, CO, and other emissions (DNV GL 2018). Despite this, over 2018-2020 we have witnessed an unprecedented investment rate in

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traditional diesel-driven machines. In Sweden, about 10000 new machines bought in 2018-2020 are probably at a high environmental standard (EU step 5) but are still diesel-driven; some 20000 diesel machines from 2011-2018 are at a somewhat lower standard (Maskinleverantörerna 2021). For the same period, the sales of electrical machines up to 2.5. tons can be counted in hundreds, and above 2.5 tons are close to absent. The sustainable transition is thus very slow and only recently have heavy-duty engines (over 25 tons) become available in a Scandinavian context, and only in a limited amount.

The research aim of this paper is therefore to investigate enablers and barriers for a sustainable transition of civil engineering construction equipment in Scandinavia. The sustainable transition theory is adopted as the framework of understanding, combined with contributions on sustainable business models (Schot and Geels 2008, Koehler *et al.,* 2019, Schaltegger *et al.,* 2020).

The empirical material combines a desk study on the material of three national settings (Norway, Denmark, and Sweden), with interviews and material from four test projects of emission-free building sites. The contributions of this paper include the documentation of an absent and emerging sustainable transition. There is a co-existence of a traditional incumbent regime of diesel engines, and a commencing niche of an emission-free constellation of particular public-private stakeholders. Those employ a new resource-economic business model, where public client-driven transition is supported with subsidies (like making electrical equipment available through concession in a particular area and encouraging small innovative machine manufacturers to develop electrical equipment) - while waiting for the large international construction equipment players to become transition-ready. Recommendations for the transition thus include strengthening public-private forms of collaboration.

## METHOD

We hereby adopt a sociomaterial interpretive understanding of sustainable transition (Orlikowski and Scott 2008, Schot and Geels 2008), viewing sustainable transition as a negotiated process of interaction between actors and materiality/technology. The sustainable transition perspective requires a broad elaboration on and coverage of stakeholders, from niches of companies over national incumbent regimes (i.e., government and corporations) to an international landscape of stakeholders (Koehler *et al.,* 2019). Here, the coverage is somewhat more modest and predominantly focuses on three national contexts, Sweden, Denmark, and Norway - and even more narrowly, on the cities of Gothenburg, Copenhagen, and Oslo, respectively. In these contexts, city policy (i.e., municipality and public client strategy) turned out to be central.

Moreover, the sustainable transition perspective asks for a longitudinal processual perspective; however, here this is limited to the period of 2018-2021. The empirical material combines a desk study of the three aforementioned national settings, with interviews and material from four test projects of emission-free building sites. This involves governmental announcements, municipality investigations, planning and strategy documents, contractors company websites, rental companies, and machine manufactures. When identifying relevant actors, a snowballing approach was adopted. This became particularly expansive in the Norwegian context, where far more stakeholders were active in the sustainable transition than expected - as emerged from a relevant Oslo City project entailing a cluster of the state, four municipalities,

two machine manufacturers, four rental companies, five contractors and more. Particularities of the three city studies are entered below.

**Gothenburg**

No emission-free building projects have been carried out so far. The empirical material includes dialogues with City Procurement project members (WSP 2020), and site measurement project members (Bernholdsson *et al.,* 2020) and documentation gathered through the collaboration and retrieved from the net.

Copenhagen (Denmark)

No emission-free building projects have been carried out so far. The empirical material includes dialogue with a representative of a large-scale research project about "green building sites" and documentation on governmental climate initiative (Klimapartnerskab 2020).

Also, two specific projects are mentioned:

1. City Center electric cabling substitution (video footage documentation retrieved from the Internet encompassing the municipality, the electricity company, the contractors, and the rental companies).
2. Day Care institution in suburb (one interview with the sustainability manager at the contractor, and documentation retrieved from the Internet).

Oslo (and beyond)

Four emission-free building projects have been carried out so far - all elaborately documented. The empirical material includes:

- A series of government and municipal reports and documents.
- Interview with a municipality representative.
- Dialogues with two machine manufacturer representatives.
- Interview with the measurement research project representative.
- Documentation gathered through the dialogues and retrieved from the Internet.

It should be noted that the paper relies mostly on documentation material and to lesser degree interviews. Moreover, no site measurement was carried out. Most of the documentation was available in the respective national languages only. Most of these references have not been included in the references list here. Also, at present most in-depth studies of emission are ongoing and not prepared for sharing results yet.

**Framework of Understanding**

The main framework of understanding is the sustainable transition theory, within which the multi-level perspective (MLP) is coined (Schot and Geels 2008, Koehler *et al.,* 2019). Approaches within MLP look upon innovation in a sector as a sociotechnical phenomenon and identify three levels of sociotechnical interaction within which sectorial innovation can be explained in the micro-, meso- and macro-levels and interactive domains (Schot and Geels 2008). We here extend this argument to understand the intertwined linkages between the social and the technological as sociomaterial (Orlikowski and Scott 2008). Moreover, adopting a sociomaterial lens implies cautiousness in accepting levels too readily - as "classic" MPL does. In a sociomaterial multilevel perspective, niches form the micro-level, where radical novelties emerge. The sociomaterial regime forms the meso-level, which accounts for the dominant stabilized sociomaterial pattern of interaction, which is reproduced by institutionalised learning processes. The macro-level is formed by the sociomaterial

landscape, an exogenous environment beyond the direct influence of niche and regime actors (e.g. macro-economics, deep cultural patterns, macro-political developments).

According to Scott and Geels (2008), researchers within sociology of technology and evolutionary economics have stressed the importance of niches as drivers of innovations, from where a new sociomaterial regime can be developed. Niches work as incubation environments for new ideas, by being protected from the traditional selection mechanisms of the marketplace. By distinguishing between market and technological niches, Schot and Geels (2008) explain the way innovation can be achieved through institutional learning processes, which link technological niches to niche markets. These changes could potentially lead to a regime shift. According to MLP, the central dynamic of sustainable transition is the regime being challenged by emerging technologies from niches. This occurs in "classic" MPL as: (1) technology maturing in some closed technological niches, (2) these technical solutions addressing a limited market need, and (3) the technologies further maturing through the growth of the markets, thereby winning wider acceptance in the entire regime. This understanding is extended here to think of the constitutive element as sociomaterial, i.e., a constellation of social actors, methods, materials, and technologies, rather than just technology alone.

An important premise for the development and maturation of ideas within niches are learning processes and the building of social networks that support new innovations and investments (Schot and Geels 2008). The development of niches through these activities is achieved through ongoing project-based learning processes, which over time provide a certain direction and rationality. In early versions of MLP, the transition was expected to originate in niches of emergent clean technologies. However, as studies of transitions flourished, cases of incumbent regimes driving sustainable change emerged (Schot and Geels 2008, Koehler *et al.,* 2019). The incumbent regimes also turned out to be capable of driving sectors and/or nations in a sustainable direction. Travelling from niches to an altered incumbent regime is not particularly specific in transition theory. Within the expectation of a niche growth, we therefore distinguish between punctual and clustered niche activity, denoting a continuous occurrence of single projects without agglomeration. This transition can occur through micro-steps over a long time (Sovacool 2016).

**State of the Art**

The emission of large civil engineering machines has gradually been better understood and also reduced (Krantz *et al.,* 2017, Hajji *et al.,* 2019, Masih-Tehrani *et al.,* 2020), including the important impact of the idle time of the engines (Lewis *et al.,* 2012). But many interests still keep the focus on diesel-driven engines, i.e., the machine manufacturers, the rental companies and the contractors. The investment in such traditional machines has boomed over the last four years. The investment binding in the relatively young machine portfolio is considerable, and a barrier for sustainable transition. Medium-old machines are however at larger challenge (bought 2011-2018) due to their emission of $CO_2$, NOx, PM, CO a.o. An interesting alternative path is to rebuild diesel engines. Rebuilt machines have been calculated to reach the same lifecycle costs after 10 years (Wiik *et al.,* 2020). But despite these substantial barriers in a series of countries, projects and activities are ongoing were manufacturers, municipalities, contractors and others are collaborating on emission-free building sites (BBI 2020, Bernholdsson *et al.,* 2020, Gill 2020, Hajji *et al.,* 2019, Masih-Tehrani *et al.,* 2020, WSP 2020, Riemer Sørensen 2020, mfl). Moreover, manufacturers of

machines are gradually offering electrical machines. According to BBI (2021), electrical machines up to 2,5 tons are available all over Europe.

**The Case of Gothenburg: Still Waiting**

The sustainable transition of the transportation sector has received a lot of state, public, and private enterprise attention over the years. In 2018, a government-business initiative issued a plan for fossil-free construction and civil sectors. This plan was backed by important industry interests - but focused mainly on cement and steel production (constituting a substantial transition issue) and did not include heavy construction machines. In 2019, the government announced a premium for investors in electrical machines as a symbolic gesture, as well as a new research initiative for sustainable transition of construction machines. It focused on fossil-free engines - but not necessarily electrical, thus leaving the biodiesel option open.

The municipality of Gothenburg was active in this national development, launching a series of initiatives with local stakeholders - introducing electrical buses, electrical machines for road and park maintenance, and other. In 2019, a project was launched to investigate the possibilities of raising a demand in public procurement of civil works. This involved market dialogues with civil contractors and resulted in a demands proposal reported in August 2020. The municipality of Gothenburg has still not announced its first fully emission-free building or civil project, but the local stakeholders are getting ready to take up the challenge when it arrives. In 2018-2020, a large project measured the emissions on 22 civil works sites around Gothenburg, estimated electrical charging scenarios, developed a business case for the economy of electrical machines, and mapped the way electrical machines can be used in the near future (Bernholdsson *et al.,* 2020). All 22 sites encompassed excavation, 13 involved stone paving, and six included asphalting. Each site used one to three machines; in total, seven wheel-loaders, 15 belt excavators (six larger than 20 tons), 25 wheel-excavators (21 11-20 tons, none above 20 tons), were used (Bernholdsson *et al.,* 2020). Another pilot and demonstration project will be launched in late spring 2021, carrying out pilots of electrical machine usage in urban sites.

**The Case of Copenhagen: Punctual Transition**

Emission-free building sites and civil machines entered the Danish government's tripartite initiative (the "Climate Partnerships") in the spring of 2020, and since then the national institutional context is on the move. However, the municipality of Copenhagen initiated its practical projects before the national agenda emerged. At least four projects have been carried out - two are described below. The first project concerns the municipality framing an electricity cable renovation project in central Copenhagen in late 2019, as emission-free. The direct client was the electricity company. The contractor hired was a well-known collaboration partner to the municipality, however not having worked with electrical machines before. An alliance with a machine rental company enabled the use of electrical Wacker Neuson machines, some only just introduced by the manufacturer; this was an estimated 20% extra cost for the contractor. The project was relatively small and short, placed on four central streets, including the Strøget pedestrian main street. It encompassed 5 to 600 m. of cabling, dismantling existing pavement, excavating, removing existing cables, establishing the new, and reestablishing pavement. The machines used included a dumper, a wheel loader, an excavator, and compactors - all small machines, with the wheel loader having a charging capacity of 0,3 $m^3$. A charging station nearby was established, and changeable batteries in the compressors were also used. The

transportation to and from the site was not included in the project. Apart from using electrical machines, a further innovation was to operate on-site during the night. The noise reduction also marked the daytime operation. The project was monitored in a measurement program with a view to future post-project evaluation: "The Municipal Environmental Department permitted longer hours worked, which decreased the project timeline by 50% overall and resulted in savings that compensated the 20% higher initial investment for emission-free equipment" (BBI 2020). The second project is a daycare institution in a suburb close to the city center, initiated in the autumn of 2020. This project is carried out under the auspices of a strategic partnership between the municipality of Copenhagen and building companies. The contractor employs fossil-free and electrical machines only for the groundworks. The municipality supports economically the on-site $CO_2$ reduction efforts with around 25000 €. The building period is estimated to be 16 months. As with the previous project, the transportation to and from the site was not included, there was on-site operate during the night, the noise reduction also marked the daytime operation, and the project was monitored in a measurement program for post-project evaluation.

**The Case of Oslo: Clustered Transition**

Transitioning to electrical vehicles (also including civil construction machines) has long been in the Norwegian state agenda. From around 2016, the Norwegian state has issued a series of support programs and subsidies for promoting fossil-free and electrical machines. In 2016-2018, a number of Norwegian municipalities (e.g. Bergen, Stavanger, Trondheim, Tromsö) carried out pre-investigations and dialogues with the civil construction sector; several of those pre-investigations concluded that electrical machines were not on the market, and biodiesel was the realistic alternative. Nonetheless, the Norwegian state's rigorous support for innovation led two machine suppliers with local offices in Norway to commence rebuilding more heavy civil machines.

In 2018, Pon Equipment, a reseller of CAT machines, had a 25 tons electrical belt excavator ready for testing. Around the same time, NASTA announced their first rebuilt Hitachi machine, and several equipment manufacturers (including Volvo Construction Equipment, Kramer, and Wacker Neuson) launched small machines (less than 2.5 tons) on the market. The electrical CAT machine was sold to both large and small contractors in Norway (including Veidekke, Betonmast and Firing and Thorsen), as well as the municipality of Østfold Fylkeskommune, which commenced renting out the machine. The Hitachi NASTA so-called ZERON machine was sold to Skanska Rental, as well as Marthinsen and Duvholt. The municipality of Oslo became "green" after the local election in 2015. The city council commenced a strategic process of sustainability, focusing on construction and civil engineering emissions in Oslo city center. It was claimed that 30% of the $CO_2$ emissions in Oslo came from building sites. This was later modified to 8% (DNV 2018), but the focus was maintained. The municipality continued planning their policy of emission-free building sites, and in 2018 they tendered the site of Olav V Gata and Klingenbergsgata in central Oslo as a pilot for the demands of emission-free building sites. The project included the renovation of three strings of a street crossing, each with a length of ca. 250 m. The VA works of cloaks, pipes, and cables, needed to reach a depth of three (occasionally 3.5) m. The project involved some site concrete molding with steel reinforcement, while the substitution of masses went to a depth of 88 cm. The two strings of the crossing were fitted with broader pavement and one string became a pedestrian area. The municipality carried out a market dialogue with

contractors and clearly got the impression that the project was doable, including it in the climate budget of 2019. The tender entailed strict procurement demands, placing a weight of 30% on the environment (with about half of it on the construction equipment), 40% on quality, and merely 30% on price. The winner was a previous collaboration partner, a small contractor specialized in parks and gardening. When finalizing the contract, the municipality had not only gotten good and qualified bits, but also many of the wished machines - through a concession agreement with a rental company (Servi). The machines cost roughly 2-3 times more than conventional ones, but with a 40% public state support from ENOVA, this was reduced to a double price. Eventually, the construction works were carried out from October 2019 to summer 2020, and the resulting $CO_2$ reduction was measured to be over 90% (Wiik *et al.,* 2020). The electrical equipment included a wheel excavator ZERON/NASTA with rotor tilt and three buckets (eight tons), a big track cable excavator ZERON/NASTA (16 tons), and a Hitachi ZX 160 with rotor tilt and three buckets. Later, a PON Equipment/CAT 353 (25 tons), and two wheel-loaders Kramer 5055e with a bucket and pallet fork, were rented. However, the project did not receive a wished wheel excavator (15 tons), a dumper, and a compressor. Nonetheless, the role of subsidies should be noted: the municipality signed a concession agreement with an equipment supplier/rental company (Servi) that provided the electrical machines for the contractor at reasonable costs. The contract between the municipality and the contractor implied that the latter was obliged to use these machines.

The machines were ready by September 2019, while the municipality was ready to provide sufficient electrical power supply by the October of 2019. Some deviances between what was planned, and the actual practical experiences are worth noting. The electrical wheel loader (Kramer) was too weak to lift pallets with pavement stones. The contractor had arranged for repacking the pallets with stones in smaller portions on a buffer site operated by them. Also, the two electrical wheel loaders had too low a capacity, and so an extra biodiesel wheel loader had to be rented. Similarly, the electrical compressor tested did not have enough compressing power, so a biodiesel version was chosen instead. Apart from the above, four more fossil-free projects are found in Greater Oslo (in Fornebu, Gjøvik, Asker, and Tonsen) (Wiik *et al.,* 2020). According to the municipality's strategy, buildings sites in Oslo municipality must be emission-free before 2025 (BBI 2020). However, roughly 80% of sites are state- or private-driven and the municipality currently lacks the regulatory instruments to control those. Further initiatives in Norway include at least two projects in Bergen and four projects in Trondheim. In Bergen, the utility company Kraftselskabet BKK is responsible for two building projects (a nursery home and a wardrobe facility). The rental company CRAMO is part of this set-up, with a mobile charger (battery container) system. One of the projects in Trondheim included demands about emission-free personal transport to and from the site but faced challenges as the electricity supply was not in place.

## DISCUSSION

The cases described in the three national contexts inform us about the barriers and enablers of a sustainable transition of heavy-duty construction machines - which is a complex sociomaterial setting with somewhat contradictory dynamics. Gothenburg represented a sociomaterial constellation preparing for the transition, Copenhagen represented the first paradigmatic pilot constituting a new niche, and Oslo represented the clustered sociomaterial constellation where the niche has commenced influencing the incumbent regime - especially municipal policy, but less so the machine

manufacturers, even if two major manufacturers have designed and implemented electrical machines sold in the greater Oslo area. In the Copenhagen electric cabling case, the municipality tendered a civil project to a contractor backed by their usual equipment supplier (a rental company that had invested in a series of Wacker Neuson machines). The exception for this punctual innovation was nighttime work, enabling the works to be done in a very short time and with minimum pedestrian nuisance. But where this pilot appears as punctual innovation, the Norwegian cases represent important clustered innovations of financial, technological, and organizational character. The Olav V Gata case stands out as an internationally radical innovation, even if it simply was about bringing existing elements together. This case drew directly on at least three manufacturers (Kraemer, Hitachi and CAT) having developed their machine technology. CAT and Hitachi directly benefited from the state's support. The municipality could make an agreement with a machine rental company, contractually demanding that the contractors operate the electrical machines. The case represents a public-private partnership and a joint business model for doing emission-free building project. In Sweden and Denmark, the incumbent large machine manufacturers, rental companies, contractors, and public clients (e.g. municipalities, the Swedish Transport Authority) are hesitant in taking the more far-reaching steps of electrification. This might stem from a lack of public client demand and the massive investments in diesel engines in both countries. The Danish state can be understood to not challenge the present "glass ceiling" of large machines, claiming these are not market-available (similar to what is reported in Helsinki (BBI 2021)), whereas Sweden invests massively in the sustainable transition of their automotive industry (including heavy-duty construction engines and trucks). A further barrier is the interpretation of investment and operation costs.

In Norway, a full business case is established for the transition (Wiik *et al.,* 2020), whereas in Sweden only certain conditions (e.g. over 7000 hours of operation) would make the investment economically sustainable (Bernholdsson *et al.,* 2020). Both the Swedish and Norwegian cases come with uncertain repair and maintenance costs - but the latter is now backed by several cases operating longer than a year. In one of those, a Hitachi 38 tons excavator used a bare 24% of the energy that a corresponding diesel engine would do (Wiik *et al.,* 2020). In Denmark a business case is lacking and sorely needed, as electricity is more expensive there - but a possible link could be made to the surplus production of electricity by wind power. Connected to these considerations, Wiik *et al.,* (2020) translated the (larger than 90%) $CO_2$ reduction into economic value, through adapting the $CO_2$ trading price in Norway. As such, environmental and economic sustainabilities get integrated in a resource-economic business model (Conrad 2020). It can be noted that while EU has been successful in driving down particle emissions of diesel engines, this relative improvement now tends to legitimize the sector's investments in diesel engines, which in turn become a barrier for the transition to electrical engines). A backlog of traditional - albeit low-emission - engines is the resulting present status of 2021. This can be seen as a lack of transition - continued acceptance of (mostly larger) diesel engines, and too little articulated demand for electrical machines.

This analysis thus points to a coexistence of an absent sustainable transition (a continued diesel regime), and an emerging sustainable transition of electrical machines. The commencing niche of an emission-free constellation of public-private stakeholders is at the moment clearly strongest in southern Norway. Therefore, recommendations for the transition include strengthening public-private forms of

collaboration. When subsidizing sustainable innovation like the electrical rebuilt of machines, the societal and private investment is a bit longer-term. But it is not an unlikely scenario that the continued adoption of electrical machines will lead to standardization, efficiency improvement, and even mass production - meaning that the cost of rebuilding may fall to an economically feasible level for a private business. The Oslo case also showed the way the municipality systematically planned and realized the needed electrical power infrastructure, which in other attempts of electrification had actually led to unnecessary barriers (e. g. see the case of Helsinki (BBI 2020)). Posing the demand in public procurement also exhibits a curious apparent paradox. When municipalities carry out a market dialogue about electrical machines, they are frequently met with the argument that the machines are not on the market. But as soon as Oslo and Copenhagen actually raised the demand formally in a tender, the contractors and rental companies became ready rather quickly. Finally, when the impact of these projects on the climate is conceptualized independently from the economic cost, there is a risk that the $CO_2$ reduction becomes a qualitative benefit. A more direct resource-economic appreciation of the impact on the climate (Conrad 2020) might help these initiatives on their way. As such, sustainability development measurements are coming increasingly to the fore.

## CONCLUSIONS

The objective of this contribution was to investigate what kind of enablers and barriers there are for a sustainable transition of civil engineering construction equipment in Scandinavia. Among the three investigated cases, the Norwegian case has shown how public subsidies and municipal client demand during the project procurement can drive a commencing sustainable transition, as well as the fact that private players contribute significantly in rebuilding, investing, and operating the machines. The analysis points to a situation where, at a time, there is an absent and emerging sustainable transition. There is a coexistence of a traditional incumbent regime of diesel engines, and a commencing niche of an emission-free constellation of particular public-private stakeholders - a niche clearly strongest in southern Norway. Here a new resource-economic business model is emerging, where public client-driven transition is supported with subsidies (i.e. making electrical equipment available through concession in a particular area, and encouraging machine builders to develop electrical equipment) - while waiting for the large international construction equipment players to become ready for the transition. The resulting $CO_2$ reduction in these cases has been measured at over 90%. Recommendations for the transition therefore include strengthening public-private forms of collaboration, like subsidizing sustainable innovation, supporting electrical power infrastructure, and posing the demand in public projects. A resource-economic appreciation of the impact on the climate might further help such initiatives.

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# VALUE INTEGRATION THROUGH SOCIAL INNOVATION IN BLUE-GREEN INFRASTRUCTURE PROJECTS

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Blue and green infrastructure (BGI) projects such as rain gardens, green roofs and water squares, embody a variety of values such as technical (drainage), environmental (biodiversity), economic (property development) and social (health and wellbeing). Because these values have proven to be challenging to integrate, local governments are increasingly experimenting with social innovation (SI) as a bottom-up form of value integration. Because we lack knowledge about different ways of how value integration is achieved, we compare four BGI city projects in North-Western Europe that share the ambition to realise BGI through SI. The findings reveal that social innovation leads to four ways of value integration: materialistic, human, organisational and process. These value integration arrangements unfortunately seem to mainly contribute to greater alignment between values rather than true value integration. Our research helps to better detect where and when public values are dealt with in BGI projects.

Keywords: adaptation; value integration; social innovation; blue-green infrastructure

## INTRODUCTION

To integrate multiple interests in various construction related challenges, such as climate change, the green deal, digitalisation, achieving circularity, new forms of collaboration between public, private and societal stakeholders are needed). Especially in climate-proof and sustainable urban planning projects, interdependency grows, and actors must coordinate their activities in seeking for interventions that integrate multiple objectives and values (Van Broekhoven, Boons, Van Buuren, and Teisman, 2015). One of the current urban developments that is seeking value integration are Blue and Green Infrastructure (BGI) projects. These are nature-based solutions such as green roofs, water squares or raingardens that aim to make cities more climate resistant (Willems, Kenyon, Sharp and Molenveld, 2020). The multi-functional nature of blue and green infrastructure projects brings goals from different policy arenas together: it does not only offer water management benefits (e.g.,

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improvement of urban drainage), but can also improve the quality of life in cities (e.g., urban regeneration, biodiversity, economic development). Yet, value integration in BGI projects has proven to be difficult, underscoring the need for better coordination in this domain. Coordinating the actions of government organizations across policy sectors has always been an important task in safeguarding the quality of our built environment (Molenveld, Verhoest, Voets, and Steen, 2020). This coordinating responsibility has only become more urgent because society is increasingly faced with complex, multi-dimensional challenges such as climate change and resource scarcity (Candel and Biesbroek, 2016). Hence, these challenges cannot be addressed by one governmental organization or policy domain alone (Molenveld *et al.,* 2020) but require collaboration with private or societal parties in order to align or integrate the different interests and translate these interests into values for a project.

A recent, promising form explored by local governments for better value integration is social innovation (Pel, Haxeltine, *et al.,* 2020). Social innovation (SI) combines technical, social and economic objectives through which governments strive to achieve broader goals for both public and private parties (Karré, 2018). It refers to new approaches for dealing with social challenges that come about through networks and joint action in social domains, outside the systemic world of government and the business logic of the corporate industry. Social innovation goes further than crossing various governmental boundaries and can offer different pathways regarding value integration by involving different stakeholders and engaging with various value systems; from public institutions under public procurement law, public and private organisations in their socio-technical environment, to residents in their societal context (Karré, 2018). However, the convergence of different values of stakeholders also means a greater likelihood of value conflicts, due to the incommensurable and incompatible nature of values, making value integration more difficult (Kuitert, 2021).

Previous research has argued that no consensus exists on what value integration actually is and how it is achieved. In this context Keast, Brown, and Mandell (2007) argue that a failure to understand the attributes of the various integration modes and adequately match their mechanisms and processes with the stated purpose and context has contributed to the limited success of integration strategies. We do know quite a lot about top-down bureaucratic innovation to strive for value integration, such as through policy integration (Candel and Biesbroek, 2016). Because we lack knowledge about different ways to organizing value integration in the context of social innovation, this paper aims to understand how the multiple values of Blue Green Infrastructure projects can be captured and sustained in the process of social innovation.

Our research question is: How can the multiple values of BGI projects be integrated through the process of social innovation? To answer this question, we combine theoretical insights from social innovation literature (Karré, 2018; Wittmayer *et al.,* 2020) and literature on hybridity and public value management (Christensen and Lægreid, 2007). These insights are brought together to analyse four BGI projects in three different European countries. A cross-case comparison led to the identification of four arrangements - materialistic, human, organisational, processual - that local authorities are experimenting with to integrate value by utilising different ways of the hybrid features of social innovation. Findings, however, also show that these value integration arrangements appear to lead to increased alignment of different functionalities rather than true value integration.

# THEORY

*Value integration for BGI project*

Blue Green Infrastructure, such as green roofs, water squares or raingardens, is usually a responsibility of the domain of urban water management at a local government level. A pitfall is, however, that wider benefits of BGI are often added as an additional goal to existing ambitions, and then to some extent lost to other goals, such as financial feasibility and construction goals (Pel, Wittmayer, Dorland, and Søgaard Jørgensen, 2020). For example, the employment of local youth in green space management may be hampered by strict social return regulations. This 'adding on' is also recognized in a recent study into commissioning in the construction industry, in which new values were often achieved through existing value systems rather than establishing new value systems (Kuitert, 2021). e.g., when social return objectives have been achieved through a physical redevelopment project. In addition, public actors have limited tools except stimulation or dedicated managerial actions, to actively implement new values to adjust their value pallet (Meynhardt, 2009). Moreover, existing management approaches, such as contractual mechanisms, create hard boundaries to limit risks, for example, and thus offer little room for new values that require greater cooperation (Kuitert, 2021). So, despite their often-commendable intentions, governments continue to struggle to distance themselves from old rational-technical approaches to value decision-making and adopt approaches that does justice to the dynamic interests of the entire network and contribute to the larger system (Keast *et al.,* 2017).

One reason for this is that new approaches are at odds with established bureaucratic norms and practices, leading to trade-offs between values instead of balancing or integrating values (Kuitert, 2021). This also has implications for the spectrum of value integration, ranging from alignment to true integration. To understand the different degrees of integration, Jørgensen, Remmen and Mellado (2005) studied different approaches to integration in management systems and distinguished three levels of integration: aligned, coordinated and integrated. First, alignment concerns a parallelisation of the systems using the similarities of the standards to structure the system, in which compatibility is increased and standards are combined in a management document (Jørgensen *et al.,* 2005).

This compatibility element corresponds with Besharov and Smith's (2014, p. 365) framework that demonstrates that both the nature and extent of conflict depends on the type of logic multiplicity within different categories of organizations. One of the dimensions that delineate heterogeneity in organizations is the compatibility - the extent to which the instantiations of multiple logics within an organization are suggestive of consistent organizational action. This degree of value integration combines values, but separate procedures remain. Second, the next step towards integrated management is through internal coordination aiming to reduce the possible trade-offs. This leads to a 'weighted balance' in values, which could be quickly degenerate into the pursuit of the sum of individual customer wishes (Stoker, 2006). Third, full integration is achieved by creating a culture of learning, stakeholder participation and continuing improvement (Jørgensen *et al.,* 2005). This is where added value is sought, going beyond the formal rationalities and thus the classical economic view with its typical cost-benefit and multi-criteria approaches (Kuitert, 2021). Added value is achieved when the integration of values leads to enhanced value for each objective within the integration (Stoker, 2006).

*Social innovation as a counterpart of bureaucratic innovation*

Value integration can be achieved through different forms of innovation: top-down bureaucratic innovation, followed by implementation, and bottom-up social innovation aiming to create organisational support during the process of project delivery. Social innovation (SI) includes various non-technological innovations and active contributions from consumers, citizens and organizations that go beyond the actors of a traditional construction project (Wittmayer *et al.,* 2020). SI for BGI projects is primarily aimed at improving social outcomes and creating public value by combining technical, social and economic objectives that together form new functionalities that move beyond urban drainage (Karré, 2018; Willems *et al.,* 2020) . This kind of multi-functionality gets achieved through internal and external hybrid relations (Willems *et al.,* 2020).

Hybrid organizations are multifunctional entities that combine different tasks, values and organizational forms (Christensen and Lægreid, 2007). In this paper, hybridity is approached in terms of "the ability of organizations to incorporate elements from contradictory institutional logics over time, and thus as the organizational processes through which this incorporation is managed" (Fossestøl *et al.,* 2015, p. 290). Internally, SI means cutting across boundaries, the integration of different policy domains within local governments. Externally, SI means creating compelling new relationships through higher stakeholder involvement (Mulgan *et al.,* 2007). Kraatz and Block (2008) argue that, because the hybrid organization is a composite of multiple institutional systems, its internal functioning is thus reflective of the contradictions between the larger systems themselves. Actors must coordinate their activities and seek for interventions that integrate multiple objectives (Van Broekhoven *et al.,* 2015).

Social innovation may be seen as the counterpart to bureaucratic innovation. In bureaucratic innovation, value integration often takes the form of policy integration. Tosun and Lang (2017, p. 559) define policy integration as "policy-making in certain domains that take policy goals of other, arguably adjacent, domains into account". The question remains whether integration is only a strategic concept, or whether it can also take place operationally, tactically, or even between individuals within a firm. We consider policy integration as an activity taking place at the strategic decision-making level, so value integration as bureaucratic innovation takes place here and has subsequently to find a way through the organisation and the project network. Value integration as social innovation, in contrast, can occur at different levels. SI may start either top-down or bottom-up - either within the organisation or in an (internal-external) network - and strives to ensure that the value integration being pursued is picked up by the organisation and is mainstreamed throughout the organisation.

Therefore, SI for complex social issues quickly becomes challenging when confronted with traditional forms of subsystem policymaking within hierarchical systems of governance that have more narrowly defined value systems (Candel and Biesbroek, 2016). Looking at pathways to value integration, one has to incorporate the process of pursuit better. We therefore adopt a dynamic, relational perspective in order to take into account the value dynamics present in SI. More static approaches to value management consider how are managed are deliberate and purposeful (Stewart 2006; Williams *et al.,* 2020), which dismisses the value dynamics that Pel *et al. (*2020), for example, focused on when studying how SI initiatives renegotiate both organizational and institutional boundaries in a relational framework and with a process-theoretical approach respond to the emergent, distributed and institutionally hybrid characteristics

of social innovation. In this case, changes to the way values are managed can be emergent (Stewart 2006). This connects to literature on adaptive governance, where it gets explained that changes in the ways values are managed can be emergent, e.g., new patterns of organizational or individual action reflecting shifting societal values, or purposeful, e.g., deliberate policy changes in response to new understanding of values (Williams *et al.,* 2020).

## RESEARCH APPROACH

To analyse which value integration approaches are used in the social innovation process, we performed an explorative comparative case study of four Blue and Green Infrastructure projects in different cities of three different North-Western European countries - Dordrecht and The Hague (both in The Netherlands), Antwerp (Belgium) and Goteborg (Sweden), see Table 1. The cases share the ambition to realise multiple goals of BGI through SI. In addition to achieving their urban water management and green space management goals, the cases aim to obtain social and economic objectives as well, such as fostering public health, facilitating recreation opportunities, and city branding. In-depth case study research allows for acquiring in-depth, context-specific knowledge (Yin, 2003), which is crucial for understanding value integration in practice.

*Table 1: The Blue and Green Infrastructure cases*

| Project | Vogelbuurt<br>multi-functional park | Cromvlietpark<br>multi-functional park | Sint-Anneke Plage<br>Living lab | Jubilee Park, Frihamnen<br>Temporary land-uses |
|---|---|---|---|---|
| City, country | Dordrecht, NL | The Hague, NL | Antwerp, BE | Gothenburg, SE |
| Period of time | 2018 - current | 2017 - 2021 | 2017 - current | 2013 - current |
| Value integration Project goals | Goals related to climate adaptation, biodiversity, recreation and public health. | Creating greening in which goals related to social return and climate resistance. | Combining climate adaptation measures with socio-economic redevelopment. | Climate awareness-raising, social wellbeing and city branding. |
| Participating actors | Municipality, housing association, neighbourhood organisation, Sports Council | Municipality, A group of local small and medium-sized enterprises, a resident panel, intermediaries | Municipality, Waterway Agency, local entrepreneurs, designers, nature preservation NGO | Municipality, River City Company, designers, residents |

In total 24 semi-structured interviews with various public and societal stakeholders have been audio taped, transcribed verbatim and analysed in Atlas.ti. To explore the different value integration pathways, we looked into what happened with both climate adaption goals and wider societal goals when delivering the multi-functional BGI projects through social innovation. Existing ambitions regarding climate adaptation may be complemented with new goals that, for example, improve health and wellbeing or provide recreation facilities. Applied to BGI, core values in urban water management, such as its technical orientation and cost-effectiveness, have to be connected to different commercial and social values. Using an inductive coding technique (Locke, Feldman, and Golden-Biddle, 2020), engaging with data first before subsequently looking for patterns, allowed us to capture the way in which value integration. We distinguished four arrangements that local authorities are experimenting with to integrate value by utilising different ways of emerging, distributed and institutionally hybrid features of social innovation - materialistic, human, organisational, processual value integration. These arrangements were analysed in the context of the potential of achieving social and sustainable value

through more traditional existing value systems in comparison with achieving these goals by building new value systems. We coded where, when and how societal, environmental, economic and technical values came together and analysed what this meant for the degree of value integration as identified by Jorgensen *et al. (*2005): single value, combined value, balanced value, or added value.

## FINDINGS

Our analysis demonstrated that local authorities are experimenting with different ways of integrating value by utilising the emerging, distributed and institutionally hybrid features of social innovation in different ways. We inductively identified four ways of value integration in the BGI projects, which we call a materialistic, human, organisational and processual arrangement. Each arrangement will be discussed further below.

*Materialistic value integration*

We recognized several materialistic ways to achieve value integration through social innovation. In Dordrecht, for example, the municipality and housing association leaned on a social organisation located in the neighbourhood who strived for more green space to prevent heat stress and support water storage. This intermediary was very involved with the residents and, in order to stimulate residents taking out pavement in their garden and plant green, they lent out garden tools. This was mainly done because they could not expect residents to buy a lawn mower or pruning shears for this kind of small green spaces but also occurred because of the limited financial situation of most of the residents. In Gothenburg, the municipal project team co-developed prototypes of green infrastructure with local residents in order to raise awareness and get people involved with the design and maintenance of their environment.

*Human value integration*

Another set of value integration arrangements was more human in nature. Most municipalities and other involved semi-public organisations used intermediaries to integrate system world logics and life world logics. These were mainly social organisations that also had an (intrinsic) motivation for climate issues. Some of these organisations were sometimes already a partner of the municipality, but now took on a different role as intermediary in these SI processes. Both in Dordrecht and The Hague the intermediary was used as a 'connecting' figure - the eyes and ears in the neighbourhood with a strong local network and also a network in the system world. In Dordrecht, the squatting past ensured that there was an intrinsic motivation to improve the climate, and in The Hague, this merely came from the external connections. In Antwerp and Gothenburg more established sustainable entrepreneurs were used. In Gothenburg, a group of more holistic thinking colleagues came together in a freestanding municipal department which aimed at the construction of blue-green infrastructure projects, yet always combining this with a human perspective (broader goals vs. climate goals). In Antwerp a non-profit but (partly) publicly subsidised local entrepreneur advised on sustainable construction, residence and living. Their campaigns proved to be especially useful in raising awareness for climate change.

*Organisational value integration*

New organisational arrangements were also recognized introducing different ways of working. In Dordrecht, a programmatic approach has been chosen that transcends the various departments. A specific group with the responsibility to create more "Blue and Green" throughout the city had the task to "work themselves jobless", ensuring

that their perspective was widely supported and integrated into the organization. Collaboration was pursued both within and outside the municipal organisation, which led to an increase in coordination considerations. For example, one of the interviewees mentioned that when a certain way of organising worked better for the sports clubs, it was chosen. Yet, this today still leads to a lot of alignment, rather than true integration by collaboration. In Antwerp, the municipality worked with integrated work groups on urban renewal, and especially the dedicated participation department breaks into other policy arenas, while in The Hague, the innovation was merely found in the composition of the multi-perspective project team.

*Processual value integration*

Finally, our analysis showed how different innovative processual elements can lead to new ways for value integration. In Dordrecht, workshop sessions to pile up all tasks and contextual conditions were organized from where opportunities are indicated per neighbourhood. In the other cities, different ways of communication were also visible. Another processual integration option was seen in the combination of old and new forms of participation. The practicality of the physical output of the innovative participation trajectories in The Hague and Antwerp made it easier to get the municipal organization on board, whereas the general participatory regulations remain quite abstract. The exploration of new participation methods within the current participation regulations was also sometimes limiting. Especially the temporary nature of some experiments, for example in Antwerp and Gothenburg, allowed for broader exploration, with the risk of never getting embedded.

*Impact of value integration arrangements*

Looking at the impact and degree of value integration of the different arrangements, in each of the four cases it became clear that despite the aim for value integration, one value or goal remained to be leading. We found that when the main goal comes from the technical department, acting as the 'owner' or asset manager of the water tasks, the management approach was often more traditional mono-value oriented. In Dordrecht, for example, the municipality affiliated with the demolition and new construction of the housing association using their sewer replacement to also urge greening. The local sports council, in turn, then used this to 'go with the flow' and to 'riding the wave of water storage' in order to improve their sports park and make it more attractive to non-members as well. In Antwerp, the water issue was central, and it was discussed that one could 'load things integrally'. Water was seen as a 'good entry point'. . Alternatively, when the social perspective was leading, e.g., creating climate awareness, the pursuit of common goals was more natural, and a broader view was taken. Furthermore, an intermediate form of impact on value integration was seen when the climate goals were strived for with a spatial department in the lead.

Although in a quite pragmatic way, the spatial challenges generally proved to be approached integrally, leading to explicit value trade-offs with regard to functionalities and other aims. In Goteborg, the Gotenborg2021 and Jubilee-park were located in the former harbour area Frihammen, where the temporary character offered increased 'space' for value coordination. In The Hague, social goals like social return on investment were especially strived for by aiming to involve for example apprenticeships for local residents in the execution of spatial development, trading off against other types of values than normally in the social domain. The case of Antwerp centred on the private safeguarding of green through 'uplifting' rules about accessible square meters of green per resident. The canopy was used as a lever to 'surf along' with the current initiatives. This shows that the social innovation was either initiated

from the perspective of water infrastructure, or from the perspective of green infrastructure, which appears to influence the degree of value integration.

The findings also show the dependence of higher organisational levels to achieve value integration. We found that formal value integration mainly took place at strategic levels, while being aware that the operational impact was kept unsure until today. In Dordrecht, for example, a specific vision was created which was picked up by directors and explained to be important for the alignment with the city of Dordrecht as a whole. However, it was also expressed that the translation into the neighbourhood level remains a challenge that still needs to be taken on. In Gothenburg, interviewees indicated that it was also all about the coordination of visions and learning their partners how to work in accordance with the new vision. In Antwerp, it was discussed that civil servants needed to 'sell' the climate adaptions by emphasising the flooding in certain neighbourhoods from a safety perspective. Safety was one of the core municipal values in Antwerp.

Their rather progressive spatial structure plan with a 'soft spine' was in line with their blue-green ambitions and therefore provided these aims with a serious position on a strategic level. Because the elaboration of a green and water plan was a must-have of this spatial structure plan, this resulted in looking at water in a spatial way, emphasising liveability and heritage of the city. In the Hague, the combination of the construction of a city park with high social return ambitions even came from the political sphere, initiated by a local alderman who wanted to boost the relatively poor neighbourhood. Furthermore, we found that when the opportunity had risen to find additional finances that would cover a gap in the project budget, a climate adaption section was added to the climate plan. Getting in at the right time also appeared to be important when looking at the possible impact on value integration. For example, in Antwerp a discussion was going on about the canopy of a road that also offered opportunities for green roofing. This was easier to enforce now due to the existence of regulations about the proximity of several square meters of green space per inhabitant. In Gothenburg, the 400-year anniversary brought opportunities to see where things are already happening and get involved, and to find out during the timeframe what is needed and what is required.

## CONCLUSIONS AND DISCUSSION

Based on our study of four case studies of Blue and Green Infrastructure projects in different Northern European cities, we saw that overall social innovation opens up new ways of value integration in addition to already established top-down bureaucratic ways. These value integration arrangements, however, seem to mainly lead to increased alignment of different functionalities so far rather than true value integration. Hence, integration does not always mean added value for a city because the wider benefits seem often considered to be add-ons: they are often added to BGI project as an additional goal to existing ambitions and then, to some extent, lost to other goals. Due to accountability structures of a specific main value, the decision making often remains from a single or dual value perspective. The pattern of bumping up against systems is similar to the trend we see in the implementation of new values in project commissioning of public construction clients (Kuitert, 2021). The conflicting nature of values makes it increasingly complex to manage projects that contribute to today's transition issues such as climate adaption.

This paper provides insights in the barriers of how to go from add-ons to integrated value decision making, and thus how to move towards systematic Blue and Green

Infrastructure. Overall, in the long run, this could mean that new value systems do not replace dominant institutions, but they do challenge and sometimes even alter dominant logics in governmental decision-making. In that case, there will not be transformative change (Pel *et al.,* 2020). Yet, values have been said to be a good entry point for investigating changes in the contemporary public sector.

Like Ford *et al.,* (2019), we argue that a first step in the task of incorporating public values in planning is to detect where and how values are already dealt with in decision-making processes, whether policy makers are conscious of considering values, or not. Further research could look into this kind of long-term institutional change. The findings also suggest that the problem with blue and green infrastructure projects seems to be that insufficient stakeholder integration leads to suboptimal value integration. The shift from a relatively static outcome-oriented approach to a differentiated dynamic understanding of integration allows for further research to deepen understanding of when integration is fully realised, what elements constitute integration processes, and how they can evolve over time (Candel and Biesbroek, 2016). Further research could address to what extent different modes of stakeholder integration led to types of value integration throughout the process of public service delivery, and vice versa. This contributes to knowledge on how local governments combine conflicting value systems, which is especially important for public managers who should be able to balance and reconcile conflicting objectives in realising societal challenges in the built environment.

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# DOES INDUSTRIALISED HOUSING DRIVE SUSTAINABLE TRANSITION? SWEDISH EXPERIENCES

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Industrialised Housebuilding (IH) in Sweden have grown within Multi-Storey Housing made of Timber (MSHT) and most of the producers rely on this approach. Business models for Industrialised Housebuilding, often start with prefabrication. With the rapid growth of sustainability demands and circular construction as an uprising theme, a central question is, what is the sustainability element in Swedish industrialized housebuilders business models regarding MSHT? Sustainable transition theory is adopted. The method is a desk study of existing research, websites, annual reports and other material. The sustainability element in the business models of industrialized house builders is explored, with focus on circular construction. MSHT is described as reducing environmental impact compared to concrete and provides social values, enabling its diffusion, however with less apparent cost advantages. However, with the growth of circular thinking, IH may have potential to further develop. The findings show that sustainability is overall present in the development of IH within MSHT, where the companies show a homogenous picture with varying challenges and contribute to sustainable transition. Regarding circular construction, the study shows potential in additional steps needed from a life-cycle perspective.

Keywords: circular construction; industrialised housing; sustainability; Sweden

## INTRODUCTION

Due to changes in building regulations in 1994, multi-storey housing in timber (MSHT) became allowed. Since then, this niche has grown, and MSHT-systems have developed. According to statistics from TMF (2020) apartments in building with 3 stories and more have increased from 1000 in 2015 to 1700 in 2019. There has also been an increase in available producers of MSHT, with industrialised housebuilding (IH) as a key component for the manufacturing and production. Increased volumes of MSHT, with its assumed positive environmental impact, has also been lifted as a key issue to reach climate goals by 2030, as well as a key to meet societal challenges (Brege *et al.,* 2017). The building sector is in this setting of high interest due to its huge environmental impact (see for example Manley and Rose 2017). In this setting, MSHT is a highly interesting alternative, with its environmental advantages in

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comparison with the current dominating structural material concrete (Erlandsson *et al.,* 2018, Penaloza 2015).

Over time the concept of circular economy has also been of rising interest. No common definition exists of the concept, but a relevant example is "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (Kirchherr *et al.,* 2017: 229). This statement was based on an analysis of 114 definitions of the concept. Hence, this uprising concept clearly pushes sustainability forward, introducing higher ambitions and goals and subsequently also more pressure on society and the building sector, being a major source for negative impact on the climate.

Studies have also been made regarding business models of IH and MSHT, highlighting prefabrication as a starting point to which other elements should be adapted and related to (Brege *et al.,* 2014). Prefabrication is also a part in IH according to studies by Lessing (2006) who besides this element highlights seven others; planning and control of the process, developed technical systems, off-site manufacturing of building parts, long term relations between participants, supply chain management integrated into the construction process, customer focus, use of information and communication technology and systematic performance measuring and re-use of experience. Due to the developments since the work by Brege *et al. (*2014), with the rapid growth of sustainability as a key ingredient society and with circular construction representing an emerging new set of sustainability demands, a central question is, what is the sustainability element in Swedish industrialized housebuilders business models? A main point is also as the title of the paper entails, if this drives sustainable transition. The approach builds on sustainable transitions research since this allows for a broad approach to understanding (see Main approach later in this paper).

**Sustainability, Circularity and Business Models**

Regarding sustainability, this research uses the work by the Brundtland report "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987) and emphasises the three dimensions of economic, social and environmental sustainability, where all three dimensions are given equal value and should be emphasized.

A main point in this paper is also what the sustainability element is in IH´s Business Models (BM). This paper aligns with Brege *et al. (*2014) view of business models, where the business model construct defines alignment between the environment, the company offering, internal and external resource base and activity systems. This covers three central building blocks: market position, i.e., roles taken in the market; offering, i.e., the value proposition toward customers; and operational platform, i.e., the resource base and its organisation. Brege et al-s' review of BM in relation to MSHT identify five elements: prefabrication mode (operational platform), role in the building process (market position), end-user segments (market position), system augmentation (offering) and complementary resources (operational platform). Based on their frame of reference they identified seven different BM's and this research builds on these results. However, the sustainability dimension as well as the theme of circular construction is not included and as they also point out BM´s change over time. This motivates a continuation of their research.

To update and include circularity and sustainability in the business model discussion, work by Lüdeke-Freund *et al. (*2019), who makes a review of circular business models, is included. They state that "The overarching goal of CEBMs is to help companies create value through using resources in multiple cycles and reducing waste and consumption" (pp 41, in line with previous references). Waste is avoided or reused in the best scenarios and only renewable energy is used and that all the process must be taken into consideration. They show several different options revolving around the key areas of value proposition, value delivery, value creation and value capture. Therefore, these concepts are used when reviewing sustainability and circularity of MSHT, especially since they present a number of different typical CEBMs where different areas are expressed in detail, based on the four key areas.

# METHOD

## Main Approach Used

A framework on the move forward in sustainability research is transitions research (Köhler *et al.,* 2019). A main driver in this type of research is that many environmental problems require radical shifts to new socio-technical systems. These shifts are called "sustainability transitions" (Elzen *et al.,* 2004; Grin 2010) and "a central aim of transitions research is to conceptualize and explain how radical changes can occur in the way societal functions are fulfilled" (Köhler *et al.,* 2019:2). A stream of interest that this paper focuses on is "businesses and industries in sustainability transitions", focuses on "how firms and other organizations contribute to (or slow down) transitions and how changes in the organizational and business dimension affect transformation more broadly, i.e., institutional, political, societal change" (Köhler *et al.,* 2019: 11). This is useful in understanding changes taking place. For the paper, the Multi-Level Perspective (MLP) of sustainable transition by Schot and Geels (2008) is used.

Theories inside MLP view innovation in a sector as a socio-technical phenomenon and identify three levels of socio-technical interaction, in which innovations in sectors can be explained: micro, meso and macro (Schot and Geels 2008). A main point is that niches form the micro-level in which radical novelties develop, in this case the theme of MSHT. A socio-technical regime forms the meso-level, i.e., the dominating stabilized socio-technical pattern of interaction reproduced by institutionalized learning processes. The socio-technical landscape forms the macro-level (e.g. macro-economics, deep cultural patterns, macro-political developments). Sociology of technology research and evolutionary economics have highlighted the importance of niches as driver of innovations, where new socio-technical regimes can develop (Geels and Kemp, 2007; Schot 1998 and Levinthal 1998). Through the niches, new ideas can develop with less influence from traditional selection mechanisms of the marketplace. In this setting, MSHT can be regarded as a possible uprising new socio-technical regime with a growing market and increased acceptance, challenging concrete as a main structural material. To show this in the approach in the paper, we go through changes in the context, i.e., increased pressure on increased sustainability, how MSHT has developed and in specific how sustainability and circularity are visible in the current situation of the studied companies and then we reflect on what has happened regarding these levels in the analysis and discussion.

Since the cases selected for the study has grown from established timber companies, where other business areas have financed the development, they have been able to finance the development and maturation of ideas taking place over time (cf Lindgren

and Emmitt 2017) and hence with building of social networks and learning processes occurring, all essential for these activities to take place (Schot *et al.,* 1994; Kemp *et al.,* 2001). The development of niches through these activities is achieved through ongoing project-based learning processes which over time provides a certain direction /rationality. As Schot and Geels (2008) and Koehler *et al. (*2019) highlight, regimes can be capable of changing sectors and/or nations in a sustainable direction.

**Method - Selection and Studies of Companies**

The method is a desk study of existing research, websites, annual reports and other material useful for describing MSHT, business models and business model development. Google Scholar was used to find relevant literature regarding existing research, and authors prior knowledge and material was useful for finding relevant material on the companies. Google and the company homepages were also used. The method relates to an argumentative literature review (see for example Coleman, 2017), following the steps 1) formulating a valid and interesting research question 2) reviewing literature based on the research question 3) collecting and assessing relevant findings in literature and based on this write, describe and formulate the paper leading up to the conclusions made. The framework by Brege *et al. (*2014) is used in order to describe the business models of the studied companies, and the cited work by Lüdeke-Freund *et al. (*2017) is used to study the circular elements in specific detail, specifically used in the discussion and analysis of the findings. Of the companies selected, three of them were studied in Brege *et al.,* while the fourth, Derome bought Setras production, which was studied in Brege *et al.*'s research.

Besides this, the organisations studied were also suitable due to their size, i.e., being the larger producers of industrialised MSHT-systems. They are furthermore naturally developed from a timber-focused company and have been in the area more than 15 years, providing a fair possibility of developing businesses that consider all three elements of the sustainability concept. Furthermore, the companies have a published sustainability report, which was central for the desktop-study. To discuss transition, the growth of MSHT is reviewed in general and short, and the cases studied provide detail of their current status, to enable a valid analysis according to the approach used.

**Multi-Storey Housing and Studied Companies**

*The growth of MSHT and its characteristics*

As stated in the introduction, the rise of MSHT, has resulted in a niche being established on the market. This niche is dominated by IH, and it can roughly be divided into a number of different sub-niches basically from three types of structural systems: column-beam systems, massive wood elements and timber frame systems (Stehn *et al.,* 2008). These are combined into on-site construction, prefabricated elements and prefabricated volume elements (Stehn *et al.,* 2008), where On-site construction becomes more and more rare (Swedish Wood 2016). It is mainly used as a part of a learning process when moving towards IH (see for example Lindgren and Emmitt 2017). In addition, there has been huge investments in production of Cross-Laminated Timber (CLT), enabling the use of massive elements, finished in factories with holes for windows, doors etc. (See for example, Dagens Industri 2018).

Altogether, modular housing systems dominates the market with the others as sub-niches (Swedish Wood, 2016). There is also a substantial amount of production taking place with one to two story buildings, dominated by timber as structural material. The advantages of MSHT have mostly been directed towards lower environmental impact by using timber as the structural material. A report by IVL

comparing five different building systems show that timber-based systems have the lowest environmental impact, but there is still work to be done, like using climate improved concrete in the foundation, transportation with HVO-fuel and using energy-efficient sheds on site. Life-cycle studies by Penaloza (2015) also conclude that timber has the lowest environmental impact and the biggest challenge for timber to lower impact further, is to reuse the material more after demolition.

Many traditional efficiency parameters have also been raised about MSHT but there has however been a debate taking place about the cost for MSHT, for example in the magazine Betong (Betong, 2019), but the current expansion at least indicates MSHT as cost competitive. As stated in the introduction, there has also been an increase with 70 % regarding MSHT over a five-year period. There has also been a discussion about the stability and usefulness of timber is as a material in relation to concrete (the existing regime, see for example Engström, S and Hedström 2012).

Looking back at the development regarding MSHT, Stehn *et al. (*2008) reported on three-year observations of MSHT and concluded that the development between 1995-2008 is characterized by a start in using the material, increased prefabrication, use of weather protection, new actors on the market, development of technology both in terms of the systems as a whole and their technical details. This development is also typically described in Lindgren and Emmitt (2017), where the resources and width of a major company enabled development of MSHT through a broad portfolio of business areas generating resources for development. It would be suitable to call this a start-up and learning stage in the development. Main development areas highlighted here relates to coordination of the process and technology development. The MSHT-sector had a turnover already at this stage of 2,4 BSEK, with an increase from a market share of 5 % (2004) to 10-12 % (2008). It is also quite evident that there are many technical issues that are at hand to manage, but projects were driven by environmental and quality arguments, with specific considerations regarding fire, acoustics, installations, moisture/weather protection and the no of stories.

A later review by Brege *et al. (*2017), points out that in 2015 MSHT had a turnover of 3,5 BSEK and in this forward-looking report, they highlight that the share of MSHT must increase to 50 % given that traditional concrete stays the same to have a chance to make the climate-goals. The concrete industry is also pointed out as working hard on being climate-neutral by 2030 mainly through a more efficient use of energy in cement-manufacturing (transfer to bioenergy), optimisation of cement-recipes for different areas of use and catch and store the carbon-dioxide that is created in manufacturing. A main point in their report is that a heavy expansion is needed within MSHT, highlighting that timber is in an expansion stage, becoming mature and stable, while there are uncertainties regarding expanded concrete production since the climate issue at the moment is insecure.

These current advantages with MSHT, especially the lower environmental impact, has also most likely put pressure on current building methods (concrete) and this also shows in how they display themselves as well as in their development of solutions. Strängbetong has for example introduced Strängbetong Studio, a combination of precast elements with a subfloor system in metal, reducing environmental impact as well as providing more flexibility in the erection process. There has also been a growing interest in hybrid-solutions, where different materials are combined to get the best result in terms of all sustainability dimensions.

*Business models of industrialized housebuilders*
In this section of the paper, the studied organisations are described, and then regarding the five elements of the business models based on Brege *et al. (*2014).

Derome has a long tradition of working in timber, which has developed over the years and now the company has 6 Business areas covering businesses from sawmills to real estate companies with a turnover of 7,6 BSEK. Through this, the company as a total has many different roles in the market and regarding IH, they deliver to their own business areas as well as to external customers. Moelven byggmodul, belongs to the larger forest company Moelven with a turnover of 11,8 BSEK but they also have more flexible solutions coming from a building system using CLT (Moelven Töreboda). Byggmodul, active in modular housing has a turnover of 1091 MSEK and Töreboda has one factory and a turnover of 295 MSEK. The level of prefabrication differs between the two areas, where Byggmodul has a clearly higher level of prefabrication. Lindbäcks stems from a sawmill but has continuously developed into a producer of modular housing and owner and manager of buildings, with a turnover of 1,7 BSEK and the company as a whole consists of the producer and real estate companies. Martinson was recently bought by the larger company Holmen, a large forestry-centred company with a turnover of 16,3 BSEK. Martinson, with a turnover of 1,9 BSEK has a business areas covering saw-milled products, building products in CLT and Glulam and building systems covering different types of buildings.

Moelven and Lindbäcks are producing and supplying volumetric modules, while Derome supplies both volumetric modules and elements. Martinson makes elements in CLT and thereby is a frame-system for MSHT. Regarding the offering and end-user segments Derome, Moelven and Lindbäcks at large address the same type of customer with similar offerings. Brege, *et al. (*2014) address this as medium level living in typical suburbs, for medium income earners and students or elderly people (but a review of conducted projects however indicates that Moelven moves towards Martinsons customer-segments). Martinson targets both the customers that the others focus on, but also high-income earners in city centres. Regarding prefabrication mode, all suppliers have a high degree of prefabrication level.

*How do the selected companies currently express sustainability and circularity?*
After studying the latest information from the companies (websites and sustainability reports), all of them highlight all three sustainability dimensions, however to different extent. They all in different ways highlight fast erection time, lowered amount of transportation, social aspects with a sound living environment and what they do to create good social living spaces and solutions, for example mutual social areas and car-pools. They especially highlight the positive environmental effects with timber, how they replant trees and invest in the forest and also the positive sides with timber as a construction material. A main issue in the manufacturing is to use raw materials from the nearby surroundings, with both CE and FSC/PEFC-classification, which guarantees a sustainable forestry holding. They also emphasize local values, for example having production-sites in the countryside (a heritage from the past when being close to water and forest was important) thereby enabling societies to continue and develop in the countryside. All companies emphasize a safe and sound work-environment.

They also highlight that they have a good control of their supply chain. They continuously reduce waste throughout the construction process, by sorting and reducing waste and a resource-efficient design. Different examples of how they also

try to develop in the supply chain are given. Moelven for example, are mapping their use of plastics, to lower costs and environmental impact. The plastic is made to 95 % by reused plastics and trials are done with a PE-laminated fluid-carbon to lower impact. Derome have a transportation fleet of their own that is run to 60 % with fossil-free fuel (with the aim of increasing with 5 % each year), they decrease the use of road transportation and increase on railroad, trials are made with trucks that run on biogas and also 74 tonnes-trucks (can take 8 tonnes more than conventional trucks) are used. The companies also express how they work with bioenergy and Lindbäcks for example show how they work with solar panels. The use of reused materials is also apparent at all companies. A main issue when it comes to the sustainability reports is that these to a high extent contain much of the same focus areas and major similarities are found, but there are differences in where they are and what they work with. They provide measurements covering all sustainability dimensions and how they progress within all these areas. They also highlight which of the UN sustainability goals that they are working with. Moelven has an overall focus on objectives 3, 4, 8, 13, 15. Derome on 5, 11, 12, 13, Martinson 5, 7,8,9, 10, 11, 12, 13, 15 and Lindbäcks 3,5, 8, 9, 11, 12 13.

When it comes to circularity, a main issue is that the companies show a lot of focus on the process from the raw material timber from the forest, through production/manufacturing and over into real estate management. Moelven though, highlight that renovation and extension of building life cycles is good for the environmental impact and that much work is needed here. They have for example developed office-solutions that can be modified and used for new needs, and they highlight that current buildings can be developed by adding extra stories in timber. This is also highlighted by Martinson, but not in relation to circularity. So, in this area there seems to be a potential in working with solutions that reduces the need to tear down buildings and instead prolong their lifecycle.

## ANALYSIS AND DISCUSSION

### What is the sustainability element in the BM of IH? Do they drive sustainable transition?

Reviewing the development so far, the change in building regulations opened up for a window of opportunity with MSHT. This is the starting point. The first years characterised by technical development was at large enabled by the developing companies' resources in combination (micro-level) with an increasing pressure on more sustainable alternatives in building (macro-level). This start consisted of development in which technical and processual issues were developed and improved, i.e., better and more stable products, leading up to more stable systems, enabled by internal development at large timber-based organizations. This reflects what happened on micro-level and can be viewed as basic factors needed for further development. In the stages following, there are two seemingly strong drivers, a stronger focus and pressure on sustainability (macro-level) and an increased acceptance for MSHT shown by an increase in turnover (meso-level). BMH It is however a point of discussion regarding what drives what? but after this an interplay takes place between different levels, undoubtedly important for future development and for sustainable transition.

As can be noticed, sustainability and all its dimensions are visible in all the businesses and business models studied. The growth of MSHT imply financial feasibility, as well as the visibility of the other dimensions and they seem to have been strengthened

over time, but the environmental dimension is a key driver initially (even if the timber companies also saw a possibility to expand their business). In the forward-looking work by Brege *et al. (*2017), MSHT must expand and drive development forward to reach climate goals, but this also creates a need for increased capacity. Hence, a challenge is therefore to manage a heavy expansion in a controlled way, with an increased pace regarding sustainability. It can also be concluded that circularity can be developed in many different areas. As of today, much of the focus is on the actual production and on the real estate management part, but there is a need to find solutions for renovation and development of already existing buildings, to increase their life cycles and put greater emphasis on the final parts of the life cycle of buildings, otherwise it comes to focus on how to use the waste that comes from buildings that are tear down.

If we return to CEBMs, the focus areas in the sustainability work are in the majority to reduce waste and switch to more environmentally friendly solutions, thereby reducing environmental impact. The companies continuously try to reduce and reuse material in different forms. However, when reflecting on the reuse and consumption, the lifecycle concept comes into focus. There are basically two ways that come into question when addressing the end of a building in use; tear it down and use the scrap material in other settings or prolong the lifecycle by adjusting or developing the building. The latter is to a minor extent addressed by Moelven (and not outspoken by Martinson) and the first area is not addressed at all at this stage (if one cannot generously see that reuse of material is occurring in the process). The use of scrap material can be processed again into other products but requires a systematic approach in the demolition of buildings to sort and reuse the scrap material. Hence, a conclusion to make is that the final steps show a potential to develop, at least in how the companies express this issue and then work with it, in line with Penaloza (2015).

So, does industrialised housing with regard to MSHT drive sustainable transition? Reviewing the changes taking place with a development in cycles, it is taking ground and winning more of the market shares available, and it should thereby put pressure on the existing regime of housing built by concrete in a similar manner as depicted in transition theory (Schot and Geels 2008). The systems have for some time been well developed technically and the growth with regards to market share, delivered apartments and turnover, indicate that the cost level is competitive and the work taking place on improving sustainability indicates that it does contribute to sustainable transition, and is challenging the incumbent regime. As its often seen in transition studies it is however not only a new more sustainable product that challenges the incumbents, but it is also other dynamics such as macro level legislation (ie from EU) that pushes the development (Köhler *et al.,* 2019) But more focus is needed on prolonging the life cycle of buildings in terms of developing buildings and solutions that enables reuse of the material.

## CONCLUSIONS

The contribution set out to answer two main questions: What is the sustainability element in Swedish industrialized housebuilders business models? And does this drive sustainable transition? The findings show that sustainability is overall present in the development of industrial housing (IH) with regard to Multi-Storey Housing made of Timber (MSHT) and the studied companies show a fairly homogenous picture in their work. Depending on company the sustainability dimensions and work and development areas differ. Hence, the research conducted indicate that IH with regard

to MSHT contribute to sustainable transition, but in tandem with other dynamics such as renewed legislation coming from macro actors on national and European level. Regarding circular construction, the companies show a clear focus on working with the supply chain in their control with using and reusing products and materials in an efficient way. But many other aspects of circularity are not covered. The study shows that additional steps need to be taken, mostly when it comes to prolonging the life cycle of buildings and in terms of how demolished buildings come into further use.

This being a desk-top study, several interesting ways to move forward arise. There is an expectation that things might be hidden beneath the surface, i.e., it is fairly likely that the companies conduct activities, even of less sustainable character, that are not presented here. Interviews based on the results with the companies involved would shed more light on the findings and if and what the companies are working with in a circular direction, i.e., future plans. It could be suitable to present this study as a basis and study reactions from the involved organisations to see if and what more is in the development plans by the companies.

Furthermore, views from concrete industry representatives would be of interest to validate findings and find opposing arguments not least from the existing regime. It is also evident in this short paper that the meso-level needs to be both described and expressed more thoroughly, in order to deepen the analysis of what happens. One key factor of interest to retrieve a better answer for the main question here, is to more deeply describe and analyse what happens on the meso-level. Does MSHT drive the concrete-industry forward, or is it a result of the general development on macro-level?

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# SOCIAL SUSTAINABILITY IN PROCUREMENT OF CONSTRUCTION PROJECTS: A LITERATURE REVIEW FROM A NIGERIAN PERSPECTIVE

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Sustainability in procurement is gaining popularity and subsequent momentum globally. However, the aspect of social sustainability, particularly from a Nigerian perspective, is given little, if any focus. Based on this premise, this paper reviews the literature on the subject, which sets out the landscape in the context of social sustainability in procurement. From the review carried out, a gap in knowledge is identified that shows an imbalance in implementation of the triple bottom line on construction projects; namely environmental and financial factors are given more attention than social. In a Nigerian construction industry context, this is accredited to sustainability policies being skewed towards environmental and economic sustainability, with social sustainability lacking. To address this, an insight into social sustainability in procurement from an international context is provided, subsequently turning the lens on Nigeria. The absence of social sustainability factors within Nigeria's policies, amplified by poor implementation of existing policies, limit the implementation of sustainable procurement in construction in the country. This subsequently results in making the industry's output uncertifiable by globally accepted standard measures of sustainability. The imbalance in content of policy instruments and poor implementation, heightens the barriers to the integration of the social factors of sustainability by stakeholders. However, sustainability is shown to deploy procurement to support implementation of the wider social, economic, and environmental objectives. The paper concludes by recommending the development of model-based recommendations that culminates in theories which will enforce implementation strategies on stakeholders within a Nigerian context.

Keywords: procurement; social factors; stakeholders; sustainable development

## INTRODUCTION

Sustainability, as a concept, began with focus on economic efficiency of output and growth. It also includes other hidden considerations which associate with environmental impact, societal and governmental requirements. These together form a triple bottom line that make up the founding elements of sustainability, namely environmental security, cost-effectiveness, and social sustainability (Romodina and Silin 2016). The construction industry is a crucial sector for economic development and has a significant impact on its environment and society. There is, however, a consensus among authors that the industry is under-performing in all three dimensions

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of environmental, economic, and social sustainability (Bratt *et al.,* 2013; Kahlenborn *et al.,* 2010; Myers, 2013). There is also agreement that the integration of sustainability initiatives into construction practices is driven by the role played by public procurement (Adetunji *et al.,* 2003; Brown *et al.,* 2012; Sierra *et al.,* 2018; Walker *et al.,* 2012). Thus, sustainability deploys procurement to support the wider social, economic, and environmental objectives in ways that offer long-term benefits (Sims, 2006).

Although the construction industry impacts on society, environment and economy, the existing sustainability studies in the industry are only largely related to the environmental and economic contents. The social aspect of sustainability appears to have been given less attention (Zuo, *et al.,* 2012). Since sustainable development consists of social and economic growth that protects and enhances the natural environment and social equity (Diesendorf, 2000), it therefore illustrates the importance to study the social components of sustainability in procurement in the construction industry. Andrecka (2017) Reports that environmental and social policies have been encouraged in many countries in tendering procedures to ensure sustainable performance. However, the correct implementation of sustainable construction procurement is hindered by barriers of lack of knowledge about how to consider sustainability criteria in procurement procedure (Carter and Fortune, 2007; Testa *et al.,* 2016). This is furthered by the lack of objective methods to assess and monitor these sustainability criteria (Ruparathna and Hewage, 2015b; Wright, 2015). These become aggravated if analysis is focused on social sustainability (Ruparathna and Hewage, 2015b; Sierra *et al.,* 2017). In a Nigerian context, such issues are amplified, and concerns raised; however, little by way of investigation is given to the subject of social sustainability in procurement; hence the development of this paper.

**Sustainable Construction and Policies**

Sustainable construction is the application of sustainable development principles to a building life cycle, from planning, through to construction; from mining raw materials to production and becoming construction products, usage, destruction of construction products, and management of wastes. It is a holistic process which aims to sustain harmony between nature and the constructed environment, by creating settlements which suit human and support economic equality. Sustainability policy is a statement of environmental actions or principles proposed or adopted by government, organisation or individual. Yin (2005) Views the subject of policy options from three perspectives: Policy priorities, policy instruments, and institutional arrangements. Policy priorities refer to clear statements of policy objectives to be accomplished. Policy instruments are the set of techniques by which government and organisation enforce policies for the society's greater good (Mickwitz, 2003). However, it has been established in the literature that the existence of a sustainability policy within an organisation does not necessarily imply that the content of sustainability activities within the policy is being implemented (Carpenter and Meehan, 2002; Price *et al.,* 2011).

Baker (2006) Explains that many international organisations and agencies like the European Union (EU), the United Nations Environmental Programme (UNEP) And the World Bank, have focused on the objectives of sustainable development. National governments, sub-national, regional, and local authorities, as well as groups within the civil society and economic actors, have gone further, by making declaratory and practical commitments, to the goals of achieving sustainable development. For

instance, the United Kingdom (UK) Has enacted laws and policies that requires the construction industry to adjust the way they operate, by being innovative to embrace the concept of sustainability in their operations (Opoku and Ahmed 2013). Similarly, Coulson (2014) Observe that in the UK, there is strong legal obligations, guiding the procurement of timber and wood-derived products. Correspondingly, Naoum and Egbu (2015) Report that in the UK, it is now mandatory that all newly built and refurbished buildings demonstrate compliance with "Target Carbon Emissions Rates" as well as with the Building Energy Model (Part L) Of the Building Regulations 2006. With the call for innovation in the industry, Berry and McCarthy (2011) Report that large construction companies in the UK are beginning to make the promotion of sustainability, a focal point in their operations. However, to provide context, a survey on Quantity Surveyors' awareness and preparedness in adopting renewable energy technology for buildings in Nigeria, found that the level of understanding of renewable energy technologies is still at its lowest ebb (Ewuga and Molwus 2015).

The construction sustainability certifications that are globally accepted are LEED (Leadership in Energy and Environmental Design) And BREEAM (Building Research Establishment Environmental Assessment Method), among others. BREEAM which was developed and put into practice in England in 1990, is the first example of systems which make assessment, based on environmental standards. With LEED, developed by United States Green Building Council (USGBC) In 1998, the focus is giving information about possible effects of construction on the environment, people, and organisations in construction and to minimise such impact. However, these standards of certification for sustainability are a true reflection of the imbalance of the triple bottom line, as they clearly demonstrate the dominance of the environmental and economic aspects over social sustainability; thus, demonstrating the need for further focus.

**Social Sustainability**

The term social sustainability continues to evolve (Valdes-Vasquez and Klotz, 2013). McKenzie (2004) Defines social sustainability as "a life-enhancing condition within communities, and a process within communities that can achieve that condition". Andrecka (2017) Claims that the concepts of social sustainability and corporate social responsibility are connected in the context of public procurement, because they are based on the same topics which cover labour issues, human rights protection, and ethical issues. Popovic *et al.,* (2018) States that aspects related to health, safety, human rights, child labour, labour issues, community initiatives, and employment benefits, are generally accepted within social sustainability.

According to Gates and Lee (2005), social sustainability is made up of three components: Basic needs, individual or human capacity, and social or community capacity. The intangible subject of social value, which revolves around human issues, have been developed and approached from various perspectives. One of the perspectives reflects in the definition of social sustainability by Abdel-Raheem and Ramsbottom (2016), as fulfilling needs of the present, without compromising the ability of future generations to meet their own needs. Although these social benefits can be intangible to developers, community experts highlight that they are as important as the economic and environmental benefits (Valdes-Vasquez and Klotz, 2013).

Social issues in sustainable procurement practice have been noted to be addressed more in the manufacturing sector, when compared to that of the Architecture,

Engineering and Construction (AEC) Sector (Kalubanga 2012). The construction sector in industrialised countries like UK, USA, Germany, and Canada, employs approximately 6-10% of the workforce, but accounts for 20-40% of the occupational fatal accidents. This trend is amplified in developing nations, where it is estimated that a total of 60,000 construction fatalities occur per year around the world, equating to one construction fatality every nine minutes (Raheem *et al.,* 2014). This indicates that construction workers are three to four times more likely to die from accidents at work, than workers from other industries (López-Valcárcel 2001).

Social sustainability is about minimising the negative impact while maximising the positive effects that developmental activities have on people and society. The creation of social indicators in construction, which can interact with environmental and economic indicators, is therefore an important task that deserves attention; thus, making it imperative that the industry works towards the well-being of society. This is attainable through generating factors which contribute towards a 'quality of life'. The main benefits associated with the implementation of social sustainability in the construction industry, are based on improving the quality of human life, increasing transparency, implementing skill training, and seeking intergenerational equity, fair distribution of construction social costs, and capacity enhancement of the disadvantaged (Popovic *et al.,* 2018; UNEP 2009).

Every economic activity impact on society in three broad ways. First, there is the impact on those involved in the activity itself, notably the workforce. Secondly, there is the impact on the local community where the activity takes place. Third, there is the impact on the wider global community (Ndimele *et al.,* 2018). However, construction corporations, while working in a strict profit focused economic system, find it difficult to relate to targets of social sustainability, where social issues are drawing their due importance in businesses across various industries. It is evident that most of the resources used are public resources (Zhu *et al.,* 2013). The sector has a duty to be accountable to the society on how they use such resources (Ndimele *et al.,* 2018). The construction industry also needs to understand and address the social issues pertaining to its production processes and products from inception to completion of the procurement process.

**Procurement of Construction Projects**

Construction, being at the very heart of development, is inexorably linked to shaping our society. As a concept, social sustainability is increasingly gaining focus in the construction industry. This is partly because the criteria for procurement of construction projects are now moving from the traditional emphasis on quality and price of the product, to increasingly address the secondary issues of environmental and social objectives (Ruparathna and Hewage 2015a).

Applying sustainable initiatives is essential for the construction industry to achieve sustainable development through the procurement process. Walker and Brammer (2009) Define sustainable procurement as the process of applying the principle of sustainable development, which ensures a strong, healthy, and just society within ecological limits, while promoting effective management in procurement. Sustainable Public Procurement, according to Marrakech Task Force (2011), is a process where organisations meet their needs in a way that are evaluated in terms of money, based on the life cycle of a product or service, while minimising damage to the environment. This is beneficial not only to the organisation, but also to the society and the economy (Romodina and Silin 2016).

In the context of procurement of construction projects, sustainability involves various issues in the life cycle that impact the applicability of the sustainability philosophy in general or its social agenda (Chasey and Agrawal 2012). Barraket and Weissman (2009) Identifies "the use of purchasing power to create social value" as social procurement. This encompasses a range of issues and goals relating to various dimensions of social value, like health and safety, buying from local small and medium enterprises, buying from minority owned businesses, and employment creation for disadvantaged groups like, ethnic minorities, the disabled or the long-term unemployed (Walker and Brammer 2012; Zuo *et al.,* 2012; Loosemore 2016).

**The Nigerian Perspective**

In their study of social sustainability in delivery and procurement of public construction contracts, Montalbán-Domingo *et al.,* (2019) Found that country and contract size are the most influential variables for the inclusion of social criteria in tendering procedures. The construction industry in Nigeria consists of a small number of multinationals, with a larger proportion being small and medium construction firms. Most large multinationals have hundreds of employees, and are responsible for large-sized contracts, while the smaller firms have less than ten employees in their workforce, focusing on smaller contracts (Jimoh 2012). Okoye (2016) Describes the construction workers in Nigeria as being hardly literate, poorly paid, and having to work long hours under poor workplace conditions, which is often dangerous manual work. The Nigerian national industrial revolution plan report of 2014 reveals that the construction sector is a fast-growing sector of the economy, which between 2006 and 2007, recorded a growth rate of more than 20%. Using Nigerian data, Okoye (2016) Reveals that there is a very strong relationship between the Nigerian construction sector and the GDP, with about 50% of the proportion of variations in the real GDP attributed to the Nigerian construction sector. Although the relationship between the construction sector and the actual GDP was found to be significantly and strongly positive, the overall contribution of the Nigerian construction sector to the GDP has remained very low at 1.83% (Okoye 2016).

Despite the relationship between the construction sector and GDP, notable sustainability policies operating in Nigeria, focus mainly on the environment, and less on the economic and social aspects. Section 20 of the 1999 constitution of Nigeria mandated the Federal Government to "protect and improve the environment and safeguard the water, air, land, forest, and wildlife of Nigeria". Other environmental protection provisions identified by Adewunmi *et al.,* (2012) Include the Harmful Waste (special Criminal Provisions) Act Cap 165, which is a response to the illegal dumping of toxic waste in Nigeria in 1988, the Environmental Impact Assessment (EIA) Decree 86 of 1992 which was a by-product of the provision of Principle 17 of Rio Declaration (Anago 2002). However, the National Energy Policy (NEP), enacted in 2003, remains the most direct national legal framework on sustainability by Nigeria. It is designed to articulate the sustainable exploitation and utilisation of all energy resources (Oyedepo 2012). An investigation on policy direction and drivers for sustainable facilities management practice in Nigeria by Ikediashi *et al.,* (2014) Identifies health and safety, waste management and flexible working environment, as the three main sustainability policy directions, in that order, while sustainability policy on biodiversity, urbanisation and forestation were the three least rated. All of these are policies on environmental sustainability. While Nigeria is making consistent improvements towards enacting and implementing policies on sustainability, much more needs to be done. Infrastructural and building projects must not just focus on

being environmentally sustainable, but also socially sustainable. Health and safety as an aspect of social sustainability, needs to be implemented from the procurement process, and not confined to facility management alone, as is often the case.

Furthermore, the Nigerian construction sector is still saddled with inherent challenges, despite the call for innovative practices through the promotion of sustainable construction (Mbamali and Okotie 2012). These challenges range from inadequate human, material, and equipment resources to weak regulatory framework which constitute barriers to innovative practices in the sector. Apart from these internal challenges facing the industry, other external factors that pose a challenge to the built environment in Nigeria are the deficit in housing supply (Dania *et al.,* 2013); climate challenge (Okereke and Yusuf 2013); and energy and power challenges (Ajayi and Ajayi 2013). All these challenges culminate to make outputs of the Nigerian construction industry uncertifiable by either of the BREEAM or LEED standard measures of sustainability, which in themselves have been shown to reflect an imbalance of the triple bottom line, due to failure to address social sustainability.

In a qualitative assessment of practitioners' experiences with the drivers and practices for implementing sustainable construction in Nigeria, Tunji-Olayeni *et al.,* (2020) Conclude that the most appropriate policies for implementing sustainable construction were government regulations, provision of tax relief and subsidies, and public awareness. This therefore implies that a combination of regulatory policies, market-based policies, and voluntary participation of stakeholders, will enhance the attainment of sustainability transformations in the construction industry. Their assessment identifies five major drivers of sustainable construction, with the clients' demand and international pressure being the most prominent drivers of sustainable construction in Nigeria. This means that the limited number of firms engaging in sustainable construction, are doing so, because of client demand. Since most of the interviewees worked in multi-national corporations, the assessment concludes that the demand for sustainable construction is mainly driven by pressure from international clients. Tunji-Olayeni *et al.,* (2020) Therefore, conclude that demand for sustainable construction is low in Nigeria, particularly amongst indigenous stakeholders.

A common problem in many project-based organisations is that central policies and initiatives fail to filter down to the project level and get transferred across projects (Loosemore 2014). To achieve social sustainability in construction projects, it is imperative to engage stakeholders in the decision-making process. This barrier to the integration of social issues by industry practitioners therefore impacts negatively on social sustainability of construction projects, which focuses on employee health and safety, impacts on societies, and goodness of life (Kamas *et al.,* 2019). In their review of construction management and economics research outputs in Nigeria, Ejohwomu and Oshodi (2014) Argue that there is a need to examine the extent to which current policies and activities pertaining to sustainability in the construction industry, is being integrated into built environment, planning, and development. Anecdotal evidence indicates that the contribution of public sector procurement to sustainability has not been adequately studied. Since sustainable construction is about realising that every procurement decision we make, or fail to make, impacts society; the industry needs to operate sustainably during the procurement process. One of the main challenges of sustainability, is to balance the triple bottom line in our decision-making process and implementation. Achieving environmental and economic sustainability without attaining a corresponding social sustainability is that imbalance. The constraint in getting procurement professionals and clients to focus on social issues requires

redress, specifically on how to handle the social aspect of sustainability in the procurement of construction projects. The Nigerian Government being the single largest client of the construction industry in Nigeria, is therefore best placed to drive the need to address sustainability issues through its procurement processes.

## CONCLUSIONS

The construction industry is renowned for underachieving and as documented, there is a consensus among authors that the industry is under-performing in all three dimensions of environmental, economic, and social sustainability. However, from a social perspective, such failings are amplified, particularly in the context of Nigeria. The review of literature shows how Nigerian sustainability policies and procedures, do not align with international best practice. This results from imbalance in the triple bottom line; environmental, economic, and social sustainability. Emphasis is placed on the environment and economy, with less focus on social sustainability; thereby making the global standard of assessment of BREEAM and LEED, less applicable in Nigeria. To address this, the findings indicate that government-led projects provide the best approach in driving such initiatives, followed by better education and enforcement at lower-level projects. The development of model-based recommendation that culminates in theories which will enforce implementation strategies on stakeholders like designers, constructors, and clients in the construction industry, is recommended for future research. These strategies can be incorporated into the procurement process so that disputes, conflict of interests, claims, and counterclaims among the stakeholders, will be reduced; thus, achieving social sustainability and in consequence, lead to a balance in the triple bottom line, by providing equal focus on environmental, economic, and social sustainability. This overview is intended to be of value to construction management scholars who want an introduction to sustainable construction in Nigeria. It provides a potential research agenda to stimulate researchers towards addressing the inclusion and effective implementation of social sustainability in construction in Nigeria.

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# PROSPECTS FOR INTEGRATED DESIGN PROCESS (IDP) IN IMPLEMENTING CONSTRUCTION WASTE PREVENTION (CWP) PRACTICES

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This study presents a preliminary proposal for the use of Integrated Design Process (IDP) at the design stage of construction projects, to implement Construction Waste Prevention (CWP). A systematic review of purposively sampled literature on IDP, waste management, and construction waste management, was used. CWP, IDP, and the theoretical angle used to relate the CWP to an IDP setting via the concept of integration are the key themes. The research process includes the formulation of a research question, definition of keywords, and selection of relevant studies from databases to arrive at findings. Content analysis was used to determine supportive practices and conditions, to arrive at propositions for implementing CWP through IDP. Being relatively new, the lack of an articulated integrated procedure for applying CWP at the design stage is a major gap. Findings suggest the possibility of using IDP to achieve CWP, and opportunity for a systematic method that uses IDP as a vehicle for CWP in projects, at the design stage. The study extends the research in CWP and explores other opportunities related to IDP.

Keywords: integrated design process; practice; prevention; waste

## INTRODUCTION

Advancements in sustainable construction exist, which demand more environment-friendly and resource-efficient operations (Chen *et al.,* 2018). Improvements in construction practices to minimise negative environmental impacts of resource depletion and waste deposition has been emphasised (Sev, 2009). However, existing practices focus on the reactive treatment of waste (Povetkin and Isaac, 2020). Traditional approaches to waste management have limited impact (Affan, 2017), handling only existing wastes, and relying on collection, treatment, and disposal of wastes (Skinner, 2004). However, some earlier studies highlight the need to improve production systems for improved waste management (Skoyles, 1976). Such improvement often refers to construction waste prevention (CWP), which is a proactive, systematic approach to construction waste management (Mbadugha *et al.,* 2021).

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Waste prevention are actions taken before an element turns to waste, including strict evasion of waste; reduction at-source; and reuse of products, excluding recycling and other measures applied to existing waste (Corvellec, 2016; Lilja, 2009). Waste prevention in construction highlights the need for a more integrated framework for sustainable consumption and production, waste management, and resource efficiency, to address waste at source (Lilja, 2009; Singh *et al.,* 2014). Therefore, CWP is viewed here as initiatives taken to prevent and eliminate the occurrence of waste in construction operations. The common approach is to develop more technologies and methods (Van Weenen, 1990). A few studies emphasise design as the main stage for CWP while noting most waste as resultants of poor design practices (Turkyilmaz *et al.,* 2019; Mbadugha *et al.,* 2021).

A design process that includes an innovative approach, active collaboration, and commitment of relevant stakeholders is needed for CWP (Chiocchio *et al.,* 2011; Turkyilmaz *et al.,* 2019). Improvements are often limited due to the fragmented and sequential nature of current design process (Fadoul and Tizani, 2017), However, integrated design process (IDP) has emerged as an alternative (Attia *et al.,* 2013), in the field of sustainable design and construction, for more integration and collaboration, and constructability and operability. The concept relies on the integration and collaboration of different professionals, collective decisions and goals, and combination of different approaches into a systematic process, without compromising flexibility in design and decision-making process (Düzgün and Aladağ, 2015). More recent discussions have highlighted the benefits of IDP for enhancing waste reduction and prevention efforts in construction (Cheng *et al.,* 2015). While not originally purposed for waste prevention, the nature of IDP and recent speculations, suggest its potential for achieving waste prevention. In the literature survey thus far, many studies on integrated approaches do not use a clear terminology that refers to IDP. Such studies resulted in ad-hoc and tool-based processes (Akinade *et al.,* 2018; Laovisutthichai *et al.,* 2020). Few studies have highlights that point directly towards CWP. Such studies sway between minimisation, reduction, and suggestions that may, or may not be articulated to CWP (Al-Hajj and Hamani, 2011). Regardless of the gaps in extant literature on CWP, reducing the possible quantity of waste produced, remains the most dominant perspective (Mbadugha *et al.,* 2021). Also, studies such as Laovisutthichai *et al.,* (2020; Osmani *et al.,* (2008), which focus on waste reduction to achieve prevention. The gaps in literature have probably added to the inhibitions of achieving CWP through IDP. There is therefore no articulation of the use of IDP for implementing CWP. This paper therefore examined existing studies and frameworks on the prevention, reduction, and management of waste, for a holistic understanding of CWP implementation through IDP.

A theoretical lens was used to conceptualise the combination of CWP and IDP in an equally operational mode. Literature on CWP points to systems integration, to view design process as a channel. This is relevant to IDP and provides adequate perspective for understanding the infusion of CWP into IDP. Integration is the framework to systematically assemble and coordinate parts, iterative with verification to form a whole or new framework (Rajabalinejad *et al.,* 2020). While the parts that are assembled into an organised whole is a system (Nicholas and Steyn, 2012). For purpose of this research, CWP and IDP are regarded as systems to be integrated, and the integration represents the process of interaction and fusion.

## RESEARCH METHODOLOGY

Based on the stated gap, the paper presents preliminary findings from a study to determine the potential of using IDP to implement CWP. The research question formulated is: 'What is the potential of IDP for achieving CWP in projects? A systematic review of extant literature was used. According to Schanes *et al. (*2018); Wuni and Shen (2020), a systematic review establishes the boundaries of existing research and highlights areas worthy of consideration in further studies. The methodology includes defining the research question, determining the required data, selecting relevant academic databases, conducting a systematic literature search, defining criteria for inclusion/ exclusion, analysing and synthesising the data.

*Table 1: Studies selection process*

| | Scope | CWP | IDP |
|---|---|---|---|
| Initial search | Keywords: By Boolean search formula | "Design" OR "barriers" OR "systems" OR "challenges" OR "developments" OR "constraints" OR "need" OR "practices" OR "improvement" AND "construction waste prevention" OR "construction waste reduction" OR "construction waste minimisation" OR "construction waste management" | "Integrated design process" OR "integrated design principles" OR "integrated design practices" |
| Identification | Database/search: keywords on titles only | Scopus - 46 | Scopus – 61, Science Direct – 3, Web of Science – 26 |
| Screening | Filters: year range (2000-2020); publication type, subject area, and English language | Scopus – 41<br>Retrieval lapses - 2<br>Total retrieved - 39 | Scopus – 42, Science Direct – 3, Web of Science – 12. Duplicates removed – 44; Retrieval lapses -5; Total retrieved - 39 |
| Eligibility | Reading abstract and full text<br>Paper quality using CASP | Redundant papers removed –10 | Redundant papers removed –12;<br>CASP removed – 2 |
| Inclusion | Data analysis | Included papers - 29 | Included papers - 25 |

To cover the greyness in the definitions of CWP and IDP identified in the initial studies, key phrases were determined in a way that gives an extensive search in the area, including other studies not discussing the topic but highlighting relevant factors. The key phrases were combined into a Boolean search formula for titles only. Three databases were selected for the search, Scopus, Science Direct, and Web of Science. Four stages of information extraction were used to arrive at the papers reviewed: identification, selection, eligibility, and inclusion. Apart from the details in Table 1, publication types were limited to conference papers, review articles, and original articles. Five subject areas were considered: Engineering, Energy, Environmental Science, Materials Science, and Earth and Planetary Science. From an initial pool of 41 titles for CWP and 44 for IDP, two and five papers respectively were excluded due to restricted access. Out of the total remaining 78 papers, 22 were excluded because of the field of interest, focus, or context of study. To address the validity and reliability of findings, reliable databases and journal sources and authoritative literature on the topic were cross validated. The quality of selected papers was assessed, using the critical appraisal skills programme (CASP), based on rigor and consistency, effective analysis and synthesis, method selection, and demonstration of contribution. This resulted in the removal of 2 papers for IDP, due to their

methodology. Ultimately, a total of 29 papers for CWP and 25 for IDP were included in the analysis.

# RESULTS

For CWP studies, between 2004 and 2020, research interest dropped thrice and peaking at intervals in 2004, 2008, and 2018. There were 17 journal publications, 11 conference papers, and 1 review papers, representing over 10 countries. For IDP, between 2009 and 2011, research interest peaked twice, slumping in 2010. Regardless, 15 out of the 25 papers were journal articles. IDP studies focused most on energy efficiency, Net-Zero, and high-performance structures, theoretical frameworks, retrofits, and prefabricated façade. The geographical distribution of the publication spans over 10 countries.

Following the research question, the objectives derived for this study are, to identify CWP practices that call for IDP; to identify the current practices, requirements, key principles, and values of IDP; to describe the opportunities in using IDP to address the implementation of CWP practices. The results of the review are presented according to the stated objectives of the study and synthesised to highlight the prospects of using IDP for CWP.

## CWP Practices and the Identified Conditions Requiring IDP

The common practice in construction waste handling mainly focuses on waste sorting, collection, and disposal (Ng *et al.,* 2018). Only few studies have considered using the project design stage for addressing waste before generation. Such studies mostly concentrate on reduction and minimisation measures (Laovisutthichai *et al.,* 2020). This study used prevention, reduction, minimisation, and other measures that are relevant to CWP, for identifying current efforts and associated factors that highlight the need for IDP. See Table 2.

## IDP and the Identified Characteristics

*Current practices of IDP*

The IDP framework is perceived differently among actors (Forgues *et al.,* 2017). This resulted in different variations of IDP that has different perspectives, orientation, and approaches peculiar to the core professions involved. This is because the existing guides are created by the agencies associated with the different professions (Landgren *et al.,* 2019). Most of the players are either engineering-focused which includes the Integrative process, Method for integrated design of low energy buildings; or architectural variants which include Integrated Project Delivery Guide, Integrating Energy Modelling.

There is contractor's perspective - Integrated Design-Build Method and industry variant - Integrated design and delivery solution (Ferrara *et al.,* 2018; Landgren *et al.,* 2019). IDP emerged as synergy between various existing variants (Landgren *et al.,* 2019), and has been described differently based on perceptions. The common features in all the variants are integration and interdisciplinary exercise (Forgues *et al.,* 2017).

The summary of the concepts of IDP revealed the level of flexibility in the framework. The concept has been described as; a collaborative and interdisciplinary work process; a whole system process; a management concept; a procedure as well as an approach; the integration of design and construction; the integration of information, knowledge management, and technology; and a discovery process. See Table 3.

*Table 2: identified CWP measures requiring IDP*

| Causes of construction waste | References |
|---|---|
| Design and construction detailing complexities and errors; poor communication, commitment and coordination, design changes, increased client's requirements | Osmani *et al.,* 2008; Dainty and Brooke, 2004; Wang *et al.,* 2014 |
| Limited knowledge, experience, and guidance; poor considerations of construction techniques and material used during the design | Li *et al.,* 2014; Wang *et al.,* 2014 |
| Identified CWP practices | |
| Standardization of design, dimensional coordination, design management, fewer design alterations, modular design, designing-out-waste principles, design review | (Ajayi *et al.,* 2017; Li *et al.,* 2015, 2014; Wang *et al.,* 2014) |
| The use of low waste technology, off-site construction, prefabricated technology and components, material optimisation, and modular construction | (Dainty and Brooke, 2004; Li *et al.,* 2015; Wang *et al.,* 2014) |
| Suggested measures for CWP | |
| Consolidation of the existing design measures, regenerative design, a combination of architectural design and technology; flexibility and adaptability of design; | (Ajayi *et al.,* 2017; Laovisutthichai *et al.,* 2020) |
| The use of improved construction methodology; integrated prefabrication and modular construction; integration of parametric design and modular construction | (Akhund *et al.,* 2019; Banihashemi *et al.,* 2018; Laovisutthichai *et al.,* 2020) |
| Facilitation of communications among stakeholders, integrated and proactive supply chain partnering a solution, integration of design and construction stages | (Dainty and Brooke, 2004; Ding *et al.,* 2018; Osmani *et al.,* 2008) |
| Innovation in technology, BIM for 3D model visualization, information transfer and management capabilities, use of the various green evaluation systems; system dynamic approach for assessing the implementation of measures | (Aleksanin, 2019; Ding *et al.,* 2018; Laovisutthichai *et al.,* 2020) |
| Education and training programmes; evidence of CWP projects; provision of legislation and policies; provision of incentives and disincentives for defaulters | (Crawford *et al.,* 2017; Li *et al.,* 2015; Osmani *et al.,* 2008) |
| Challenges of CWP implementation | |
| Inappropriate use of technologies and materials, unfair competition, lack of means to integrate existing measures into the current design process; poor consideration of waste reduction measures during the design | (Laovisutthichai *et al.,* 2020; Osmani *et al.,* 2008) |
| Construction industry's culture and behaviour towards CWP; the use of the simple linear design process; poor coordination and communication among stakeholders, and the absence of assistive tools and integrated guidelines | (Akhund *et al.,* 2019; Laovisutthichai *et al.,* 2020; Ng *et al.,* 2018; Osmani *et al.,* 2008) |
| Barriers to CWP implementation | |
| Traditional construction methods, incomplete/confusing documentation, disconnection between design instructions and construction in real-time, insufficient attention to the construction process during design. | (Crawford *et al.,* 2017; Laovisutthichai *et al.,* 2020) |
| Drivers for CWP implementation | |
| Active communication among participants; training; research and development in CWP; competence; construction process; design strategies and technology, materials management plan, legislation, policies, and regulations | (Li *et al.,* 2014; Ng *et al.,* 2018) |

# DISCUSSION

*CWP measures*

It has been noted complex decision-making processes cannot be realised in isolation but integrated (Klaassen *et al.,* 2021). Many of the current suggestions thus far on CWP are focused on integrated practices in the construction work practices which refer to a change in current design practice as noted by (Osmani *et al.,* 2008). Based on analysis of the selected studies on CWP, most issues and practices highlighted point to the need for an IDP project.

They include more flexible method; early involvement of stakeholders, stakeholder/ discipline integration, coordination, and active communication; proactive partnering in supply chain solutions; non-linear design process; integration of design and construction stages; innovative solutions; and integration of relevant methods, technologies, and processes (Laovisutthichai *et al.,* 2020). According to (Ng *et al.,* 2011) Such activities usually give rise to an iterative process, whereby all the systems

components - people, methods, technologies, and processes are integrated into the design process for effective results.

*Table 3: Identified practice for IDP*

| Requirements for IDP | References |
|---|---|
| Collaborative and interdisciplinary work culture, trust, description of the relevant stakeholders, the definition of the methodologies to apply | (Landgren *et al.,* 2019) |
| Emphasise integration; Technical knowledge during the design process | (Landgren *et al.,* 2019) |
| Early stakeholder involvement and commitment, Use of a systems approach | (Forgues *et al.,* 2017) |
| Active collaboration of the multidisciplinary design team, Clear and continuous communication; Rigorous attention to detail | (Chakraborty and Bahr, 2009; Forgues *et al.,* 2017) |
| Key principles of IDP | |
| Encouragement of an iterative process; flexible design framework; knowledge integration into the design process | (Ferrara *et al.,* 2018) |
| Active communication and collaboration among parties; attention to details | (Chakraborty and Bahr, 2009) |
| Key values from the application of IDP | |
| Evaluation of design methods and choices by the stakeholders; interactions of the interdependent systems of the building; opportunity for speeding up the design process | (Ferrara *et al.,* 2018; Ng *et al.,* 2011) |
| Innovative thinking, trust, rational decision-making; multiple systems and interrelationships over the lifecycle consideration; achievement of sustainability goals | (Chakraborty and Bahr, 2009) |
| Definition of the performance requirements | (Trebilcock-Kelly *et al.,* 2019) |
| Assessment of projects and verification of solutions; good communication framework for stakeholders; awareness of systemic measures to practice; | (Ferrara *et al.,* 2018) |
| Identified challenges to implementation of IDP | |
| Unclear roles, and boundaries among the stakeholders | (Koch and Haubjerg, 2011) |
| Lack of an appropriate decision-making tool to facilitate integration | (Landgren *et al.,* 2019) |
| Inability to simultaneously integrate technical knowledge with architectural qualities; incompetence among the stakeholders; different interpretations of goals and decisions | (Koch and Haubjerg, 2011; Landgren *et al.,* 2019) |

Brand and Hertogh (2021), have identified the need to involve different professions, and achieve knowledge transfer in a real-world application. It must also be user-or stakeholder-driven, encouraging innovation, and overcoming barriers between research and practice.

*IDP measures*

The results revealed that IDP is flexible, involves an iterative process, and can be adapted to any field where sustainability issues are of concern. Among the benefits, it allows multi-stakeholder engagement in the design process, which facilitates whole system consideration of design issues, design variables, technologies, and possible solutions with many perspectives (Forgues *et al.,* 2017; Landgren *et al.,* 2019). Although it is yet to be explored, findings suggest that a framework based on IDP, which includes identified methodologies could be targeted at better waste management outcomes in projects.

*Integration framework*

Results show a pattern, which emphasises that implementing CWP to achieve prespecified goals and objectives, requires integration at the design stage. For the CWP mechanism to be effective, conformance to certain criteria is necessary (Nicholas and Steyn, 2012). The requirements for efficient implementation of CWP align with qualities of IDP (Brand and Hertogh, 2021; Ng *et al.,* 2011). Therefore, IDP features essentially constitute the qualities that can be engineered to implement CWP, making it the more suitable design approach for achieving CWP. IDP would therefore suffice as an ideal vehicle for integrating relevant practices, which facilitate waste prevention as highlighted by (Jin *et al.,* 2019). By converging relevant waste

prevention practices in an IDP setting, exploiting the potential inherent in IDP to efficiently implement CWP, a new framework addressing waste generation is created. However, findings also highlight potential challenges, since IDP is not generally practiced, and not originally and currently waste focused. Such challenges, include a lack of predefined integrated design system and tools for adaptation and application of CWP.

## CONCLUSIONS

The current study explored the relevance and need for using IDP to achieve CWP in construction projects. Though the need has been suggested in literature, there is yet no theoretical justification for the claims. The paper presents preliminary results, which build a more comprehensive baseline of understanding, regarding the use of IDP for CWP. The relevant limitation here is the inherent theoretical nature due to the stage of study in a wider research project. However, the findings thus far show that existing efforts to improve efficiency, including the development of waste prevention measures, generally highlight the viability of the project design stage. There is a need for an approach that rises above the hindrances of traditional work practices and approaches. It should be an approach with modalities that facilitate implementation of relevant waste prevention measures, at the design stage. Current findings show that IDP has the characteristics that can be adapted to facilitate the implementation of CWP. The said adaptation is essentially to purpose IDP for CWP by using its features and adapting features from other relevant approaches. Achieving such an evolved IDP, would require future studies along, which include more detailed theoretical analysis and empirical studies, and a design approach.

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# REDUCING EMBODIED CARBON IN THE CONSTRUCTION SECTOR

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The increasing drive towards net zero carbon has thrown a spotlight on 'embodied carbon' in the construction industry. Embodied carbon refers to the whole life carbon emissions associated with the materials used in buildings, and includes emissions arising from the resource extraction, material production, transport, installation, maintenance and end of life disposal. In the UK, embodied carbon associated with new construction accounts for 20% of annual carbon emissions from buildings. Reducing this is key to meeting the UK's commitment to achieve net zero by 2050. In this study, recent academic and industry literature on embodied carbon is examined, and interviews are held with nine industry professionals with specialist knowledge on embodied carbon. The findings show that against a background of increasing academic research and industry knowledge on the topic, there remains a lack of clarity over the guidance and methodology used to calculate embodied carbon. There is no comprehensive materials database for embodied carbon and no one calculation tool or approach used by the construction industry. A more coherent and agreed approach is needed if industry is to effectively reduce embodied carbon in new build construction and refurbishment. The UK has no clear legislative requirements or policy framework on the topic. Legislation is urgently needed to drive and incentivise embodied carbon requirements throughout the industry. Since most of the embodied carbon emissions of materials occurs before the construction phase, the focus must be on understanding the implications of material choices with a preference for material reuse where possible.

Keywords: carbon; embodied carbon; net zero; life cycle; sustainability

## INTRODUCTION

*The drive for net zero*

In the UK, buildings may generate as much as 49% of total UK greenhouse gas emissions, (LETI 2020). Following commitments made at the 2016 Paris Climate Agreement, the UK Government has set a target to achieve net zero carbon emissions in the UK by 2050, (Harvey and Ambrose 2020). Prior to that, some groups had proposed that all new buildings designed from 2025, and all new buildings constructed by 2030 onwards, should be net zero carbon, e.g., LETI (2020), but the Government's announcement adds a policy impetus and has the effect of putting real pressure on the construction industry to reduce carbon emissions.

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*The importance of embodied carbon*
71% of building-related emissions are generated by heating, cooling, power supply power and other in-use activities. These are 'operational emissions'. The remaining 29% are generated in the production and supply of the materials used in the building, (WGBC 2018). Known as 'embodied emissions', these latter were produced before the product or material gets fitted or installed in a building and are therefore considered 'embodied' in the product or material itself, (Pomponi and Moncaster 2018).

For almost 45 years the construction industry has targeted reducing energy use in buildings. Spurred by the Energy Performance of Buildings Directive, (EU 2010), the UK Building Regulations have evolved to produce buildings that use less energy, and have lower operational emissions, (Pomponi and Moncaster 2018). However, until recently, embodied emissions were largely disregarded, and embodied carbon continues to be under-considered by designers, (Adams *et al.,* 2019). As buildings have become more energy efficient, the opportunities to further reduce operational carbon have reduced, and embodied carbon now represents a higher percentage of the whole life carbon emissions, (LETI 2020). This growing impetus to reduce emissions further, means increased focus on embodied carbon.

*Addressing embodied carbon during building design*
Reducing embodied carbon in new buildings means using less material, or using materials with lower levels of embodied carbon, (LETI 2020). Understanding the embodied carbon content of materials is key to this. A whole life approach considers the embodied carbon of materials and influences their selection. Such an approach is beginning to evolve, but uncertainty remains over what information and assumptions are being used, and how the calculations are being carried out, (De Wolf *et al.,* 2017). For many projects, the focus remains largely on cost and reducing operational carbon emissions during building operation, rather than a whole life carbon calculation.

The construction industry is still only beginning to account for embodied carbon, with progress evident only in some parts of the sector, (De Wolf *et al.,* 2017). Although guidance exists to calculate embodied carbon in construction, there are many variations on the approach to calculate it, (Säynäjoki1 *et al.,* 2017). The various data and approaches used make it difficult to draw comparisons between projects and may be one reason why the sector has been slow to adopt a strong approach to addressing embodied carbon. To compound the problem, there is no clear Government legislation or guidance that enforces or requires or regulates a whole of life approach to carbon, (Pomponi and Moncaster 2019). This halting and confused approach has hampered efforts to effectively reduce embodied carbon in new buildings, (Giordano *et al.,* 2015).

*Aims of the study*
The aim of this study is to examine how embodied carbon is currently taken into account in construction projects in the UK, and clarify what information and tools are available to calculate the embodied carbon content. It then identifies the steps needed to more effectively reduce embodied carbon in the construction sector.

## RESEARCH METHOD

Academic and industry literature on carbon, embodied carbon and material carbon content was reviewed. Information was obtained from publicly available information on several recent projects on how embodied carbon was approached during design and

material selection. A series of interviews was then held with nine industry professionals familiar with the topic of embodied carbon and practical experience in considering it in building refurbishment and new building design. The nine interviewees included an architect (A), a mechanical and electrical director (B), a mechanical and electrical engineering associate (C), a structural engineering director (D), a client project manager (E), a building developer (client) (F), a clients' building manager (G), a main contractor's director (H) and a design manager (I). The interviews were conducted in a semi-structured format centred around a set of key questions and allowing for follow-up to elucidate particular points. The interview responses were transcribed for coding and thematic analysis with the aid of the NVIVO software tool which uses thematic analysis to explore patterns in the data and which allows in-depth analysis of the interview transcripts. This is an established approach for drawing out information from practice and experience, (Braun and Clarke (2006).

## LITERATURE REVIEW

### Developing Industry Targets and Adopting a Whole of Life Approach

In 2017, the World Building Council set dual goals: 1. new buildings operating at net zero carbon by 2030, and 2. eliminating construction emissions by 2050 to achieve net zero carbon, (WBGC 2017). In the same year, the UK Green Building Council developed a framework called Advancing Net Zero, which emphasised the need to consider both the construction and operation stages in order to achieve net zero carbon buildings, (UKGBC, 2017).

In 2019, RIBA adopted its 2030 Climate Challenge Targets of reducing operational energy by 75%, and embodied carbon by between 50% and 70%, using a whole life carbon approach, (RIBA 2019). These aim to reduce the embodied carbon in domestic buildings from a current benchmark of 1,000 kg CO2e[2] per m2, to 300 kg CO2e by 2030. For non-domestic buildings, the target is to move from the current benchmark of 1,100 kg CO2e per m2, to 500 kg CO2e by 2030, (RIBA 2019). RIBA (2019) considers that the methods for calculating embodied carbon to address these targets are widely established although this is questioned by industry practitioners, see later.

A whole life approach to carbon emissions considers both the operational emissions and embodied carbon emissions over the life of a project, (RIBA 2019). The five main stages to be considered are usefully defined in British Standard EN 15978, namely: 1. From resource extraction to material production (which includes raw material supply, transportation, and manufacture of the product); 2. Construction (which includes transportation to site, and the construction and installation processes); 3. Use (which includes use, maintenance, repair, replacement, and refurbishment); 4. End of life (which includes deconstruction and demolition, transport, waste processing, and disposal), and 5. The emissions and potential benefits arising beyond the boundaries of the project (which address the ability to reduce the quantities of materials used, as well as the potential for future recovery and recycling).

[2] CO2 equivalent, i.e. also taking other greenhouse gases into account in addition to CO2

A best practice approach would include setting initial targets for embodied carbon taking account of how much recycled material can be used in the building, and also considering the potential for future recycling of the materials used, (LETI 2020).

**Available Guidance and Advice for Calculating Embodied Carbon**

Several organisations have produced guidance on addressing embodied carbon. CEN: The European Committee for Standardization (CEN) published two standards - in 2011 and 2012 - to provide guidance and formalize methods for calculating whole life carbon, (BSI 2011) and (BSI 2012). These remain the core standards used today, although the effectiveness of even a such a formalised method of calculation depends on having reliable and accurate data, which the BS does not provide.

RICS: In 2017, RICS produced its 'Whole Life Carbon Assessment for the Built Environment', which was the first guidance in the UK on a whole life carbon approach to reducing emissions. It details principles and supporting guidance based on British Standard BS EN 15978:2011 and was felt necessary because the 2011/2021 standard left designers too much flexibility for interpreting the guidance. Morris (2018) is among those who question how effective the RICS guidance is for industry, given the underlying unreliability and inconsistency in the approach and assumptions used to produce the core data which the guidance needs.

RIBA: In 2017, RIBA published its 'Embodied and Whole Life Carbon Assessment for Architects'. This was produced to provide guidance specifically for architects on reducing carbon emissions by considering whole life carbon during design. Although this guidance contained the most consistent and detailed approach available within the construction industry and emphasised how decisions related to carbon must be rigorously interrogated at each stage of the project, (Sturgis 2017), it remains dependent on a reliable database of material information in order to be useful.

IStructE: In August 2020, the Institution of Structural Engineers released a document 'How to Calculate Embodied Carbon,' which provides principles to guide structural engineers on how to complete embodied carbon calculations, (Gibbons and Orr 2020). The guidance aims to produce robust consistent calculations to enable meaningful comparisons to be made across projects. The guidance focuses on specifying materials that produce an overall reduction in the carbon used in each project, as well as highlighting the benefits of low carbon design to clients. The document aligns with and supports the sustainability elements of the Structural Plan of Work 2020, the RIBA Plan of Work 2020, (Yates 2020). This is a positive development although significant choice remains in the selection of assumptions needed for the calculations.

CIOB: The CIOB has developed a Carbon Action 2050 toolkit which aims to provide simple guidance to members of the CIOB and the wider construction industry. The toolkit focuses on cutting carbon emissions by using innovative, best practice techniques on design, construction, maintenance, operation, and waste management as well as a strong focus on the refurbishment of existing buildings, (Crane, 2020). Like the RICS guidance, parts of this toolkit are open to interpretation and allow some leeway in the assumptions and application.

LETI: The London Energy Transformation Initiative (LETI) is a voluntary group of over 1,000 industry professionals established in 2017. LETI has produced guidance to industry in progressing towards net zero carbon, but focusing specifically on the London area, (LETI 2020). LETI's recommendations to the Greater London Authority have been incorporated into it policy guidance and it has pushed for embodied carbon

to become part of legislation to achieve net zero carbon. This legislation has not yet been introduced, and anyway needs to introduced UK wide not just within London.

**Databases and Tools for Calculating Embodied Carbon**

The Inventory of Carbon and Energy (ICE) was created to compile data on embodied carbon from both primary and secondary public sources, (Hammond *et al.,* 2011). Although this is widely used, Sturgis Carbon Profiling LLP has been analysing materials carbon emissions since 2007 and considers that many challenges remain in assessing embodied carbon, not least that there was still not one comprehensive database that industry can use as a data source on embodied carbon in materials, (Sturgis 2017), which can lead to inconsistencies when comparing projects.

More recently, Hawkins Brown architects in collaboration with UCL have developed the emission reduction tool H\B:ERT, (Hawkins Brown 2020). This is a Revit-based tool which measures the volume of each material within the digital model and applies data on the embodied carbon content to each. This tool addresses the production, construction, use and end of life, and therefore aligns with BS EN 15978:2011. It aligns with latest RIBA and RICS guidance and uses the data from the ICE database while also allowing the input of other data, which is key for enabling a meaningful comparison between construction projects.

The structural and civil engineering practice Heyne Tillet Steel (HTS) has also developed its own plug-in tool to use embodied carbon data from Environmental Product Declarations (EPDs) and the ICE database, (Furminger and O'Riordan 2020). HTS continues to develop embodied carbon and guidance tools within its own team and has also examined where it could alter its construction methods to reduce embodied carbon, (Furminger and O'Riordan 2020). Although the progressive tools developed by Hawkins Brown and Heyne Tillet Steel highlight how architects and engineers are reacting to the need for an embodied carbon tool, there is still the opportunity for inconsistencies without one tool that is used industry wide. This raises question if there could ever be one tool used by all.

**Conclusions from the Review of Literature**

Despite the increasing amount of guidance available, there is still currently no one comprehensive database that industry can use on the embodied carbon content in different materials, and the different approaches to a life cycle assessment make it difficult to make comparisons between projects, (De Wolf *et al.,* 2018). RIBA notes that although the methods for calculating embodied carbon are widely established and that RICS provides data for embodied carbon for the whole of life carbon content of materials, and that the number of EPDs for construction materials is increasing, (Anderson 2019), there is still not one agreed approach that professionals in the construction industry use to calculate embodied carbon, (RIBA 2019). Both Hawkins Brown (2020) and Furminger and O'Riordan (2020) also note that the lack of standardised measurement tools being used has resulted in industry professionals developing their own tools and ways to collect the data on materials.

Key to calculating embodied carbon is obtaining accurate data on the embodied carbon content of materials. This data is derived from assumptions and can be difficult to obtain and interpret. There is also an overall lack of transparency regarding the data on embodied carbon. Smith (2020) argues that only when all parties in the supply chain are transparent and accountable for the emissions at each stage in the material cycle, can a complete understanding be made of the levels of

emissions generated, and the steps identified to reduce embodied carbon in each project.

These conclusions were used to design the primary data collection stage.

## RESEARCH FINDINGS

From an analysis of the literature and the interviews, several issues have emerged relating to how embodied carbon is addressed.

*Database limitations*
Interviewees B and C highlighted significant limitations with the widely used Inventory of Carbon and Energy (ICE) database. They note that database is neither current nor clear, particularly for timber-based materials, cross-laminated timber, Glulam and other materials for which the database has no data. Interviewee A highlighted the large number of assumptions that need to be made, and interviewee C estimated that the assumptions made on material data can be wrong by as much as 20%. Interviewee B noted that while the concrete and steel industries have their own data sets, there is no one common database. Interviewee B suggested that a European classification on embodied carbon would help. Interviewee D noted that he used one data source for part of a project, and others for the remainder, highlighting again the lack of a single source of data. These comments support the concerns raised in the literature that a more comprehensive dataset is needed.

*Collaboration and transparency over sharing of data within the industry*
The literature highlighted a lack of collaboration, transparency, and willingness throughout the construction industry to share information, which must be overcome if accurate data on embodied carbon is to be created, (Smith 2020). Interviewees B, C, D and E confirmed this, and interviewee D noted that it is worse with design and build projects where the contractor may use alternative materials to what was specified, without informing the design team, leading to the assumptions made at design stage being incorrect, adding 'currently there is not one main data source, instead lots of companies are creating their own databases and not sharing information'.

The literature revealed the increasing use of EPDs and the interviewees confirmed that these are used where available. However, the suppliers often show little interest in calculating the embodied carbon content of their products. Interviewee H noted that only one cement supplier in the UK was willing to provide the required information on embodied carbon for a particular project.

Therefore, although data is available on embodied carbon for some products, it is not available for all construction materials. Suppliers need to ensure that all products have EPDs as these are key data sources for the calculation of embodied carbon.

*Multiple calculation tools and approaches*
Several tools are used to calculate embodied carbon. The literature cited that One Click LCA and eTool are used (Hawkins and Mumovic 2014), but revealed that several engineering and architecture practices have started to develop their own calculation tools (e.g. Furminger and O'Riordan 2020). One downside to the variety of tools is that each one uses different assumptions, sources of measurement, and approaches to the calculation, which results in variations in the embodied carbon figures, (Säynäjoki1 *et al.,* 2017). The experts confirmed this, with Interviewee D highlighting that this reduces the ability to compare projects and hinders the progression of the reduction of embodied carbon. InterviweeE said 'there still appears

to be a lot of assumptions made on data and little consistency when comparing projects'. This is a major implication for practice and the UK construction industry.

*Reducing embodied carbon at the design stage*

Both the literature and the interviewees confirm that the design stage provides the greatest opportunity to influence embodied carbon, and that this is the focus of the guidance developed by the professional institutions, (Sturgis 2017). There is evidence that designers are beginning to use EPDs, (Anderson 2019), and interviewee A confirmed that engaging sustainability consultants to address embodied carbon is becoming more common. However only interviewees B, C and D noted they are actively designing to reduce embodied carbon on any projects. This is yet to become widespread and is not common on smaller projects. None of the design consultants interviewed considered that industry is meeting its obligations to reduce whole life carbon. Interviewees A, B and D pointed to the fact that embodied carbon has only become a focus since around 2019 and emphasised that until addressing embodied carbon is backed up by regulatory requirements, there is no real obligation on designers to either calculate or reduce it on most projects.

*Prioritising building refurbishment*

Significant embodied carbon savings can be achieved if existing buildings retain the primary building structure, (Sturgis 2017 and Hawkins Brown 2020). The design consultants interviewed all agreed that refurbishment should be the first approach considered, rather than demolition and new build. Interviewee A highlighted how RIBA encourages architects to prioritise refurbishment, and interviewee B said 'Embodied carbon is easier to minimise in existing buildings'. Interviewee G agreed and said that re-using existing materials and refurbishment should be prioritised, as new buildings only introduce more carbon. The literature highlighted that as 70% of current residential houses will still be in existence in 2050, that these buildings will need refurbished rather than replaced, (Carbon Action 2050, 2020). This suggests that designers need to consider not only the building's operational use, but also its end of life, not designing how buildings can be demolished in a way that ensures the materials can be reused.

*The need for policy guidance from Government*

Although LETI and UKGBC have published general guidance on how the industry can achieve net zero carbon, this does not go as far as to include a calculation tool, data source or methodology. Even the 10-point plan issued by the UK Government in November 2020 contains no specified data source, tool or approach, (Goodwin, 2020). Although interviewees A, B and C have all followed specific guidance on how to address embodied carbon, the guidance produced by the various professional bodies is focused on the different professions. These interviewees consider that clear guidance is needed from policy makers and legislators, in terms of embodied carbon targets and reduction requirements, and in terms of acceptable data and assumptions that can be made, and on approaches to the calculations. Interviewees B and C referred to the past success of the Building Regulations in reducing operational carbon and were optimistic that a similar change in approach to embodied carbon could be achieved if the UK Building Regulations were revised. Interview H concluded that 'If the industry will not embrace embodied carbon voluntarily, it needs to be enforced through legislation and policy'.

## CONCLUSION

This study has shown that the industry needs to improve its efforts to calculate and reduce embodied carbon. Despite the publication of BS EN 15978, there remains widespread lack of understanding throughout the UK industry on the importance of addressing embodied carbon. Despite a growing volume of guidance published by UK professional institutions for reducing embodied carbon, there is no comprehensive material database or one calculation tool used throughout the UK industry.

The research also suggests that the professional bodies need to collaborate to create a robust national database as a central, respected source for all industry disciplines. A clear agreed approach for calculating embodied carbon is also needed to reduce the variations and discrepancies in the calculations which hamper an honest appraisal of projects' carbon performance and enable comparison between projects.

It is clear that policy guidance is also needed. Government should set targets for embodied carbon, and policies encouraging circular economy principles at a building level should be incorporated into legislation. Changes are needed to the Building Regulations to include stipulations to reduce embodied carbon and to require a whole life approach to carbon, with the priority on using materials with low embodied carbon. This can be done by establishing a consistent methodology for calculating embodied carbon which allows comparison between projects.

The study also concludes that awareness and skills within the industry need raised and upgraded. Designers must learn to prioritise reuse and refurbishment in all projects before considering new build. EPDs should become standard for all construction materials. Designers must become experienced with whole life carbon reduction approaches and learn to account for embodied carbon as well as operational carbon, in order to understand where the largest savings can be achieved. Designers and contractors need to favour materials like low carbon concrete over more carbon intense products. Sustainable timber should be considered in far more applications as an alternative to other materials.

Clients must be encouraged to design and construct low embodied carbon projects, and to take low carbon capability into account when selecting the designer. Targets should be set and reviewed frequently between the client, design team, and main contractors. The contract documents should allocate responsibility for monitoring and reporting on all construction works demonstrating compliance with the original embodied carbon targets determined and set at design stage by the consultant team.

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# IS THE DANISH CONSTRUCTION SECTOR READY FOR SUSTAINABLE AND CIRCULAR CONSTRUCTION SITES?

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Sustainable construction has gained increased attention, demanding sustainable solutions in the local building regulations. A significant part of Danish building regulations' requirements is currently regulated by having a new sustainability building class to boost the green transformation of construction. One of the new sustainability requirements is to save resources by promoting circularity at construction sites. Thus, this study investigates Danish construction organizations' readiness and willingness to use the new sustainability building class to establish sustainable construction sites, focusing on circular solutions. It considers actors' understanding and current level of implementing sustainability principles and circular strategies and highlights the perceived challenges and actors' practical experiences. A qualitative and quantitative survey was collected from 146 actors, including contractors, engineers, architects, and professional building owners. Results reveal the awareness of sustainability in construction sites, as 32 % of organizations use sustainable onsite principles with various levels of experience, and 85 % are willing to use circular solutions. Lack of expertise and economy are perceived as significant challenges when establishing sustainable construction sites. Many actors are still unaware of the relevant rules and do not have a specific strategy to manage waste and perceive this topic with high risk and uncertain benefits.

Keywords: construction site; sustainability; circular economy; waste; readiness

## INTRODUCTION

According to the European Commission (EC), the building sector is a massive industry that accounts for one-third of all waste and 40 % of the world's CO2 emissions. The Danish governmental climate action has set ambitious goals to reduce its total CO2 emissions to 70% in 2030 compared to 1990 and being climate neutral by 2050 (Agency, 2020). This requires significant efforts and a change that can be felt and seen across the building sector, responsible for achieving this. A study by EC identified inefficient use of resources in the built environment and emphasized the importance of optimized resource consumption (Ministry of the Environment, 2016). An action for Circular Economy (CE) proposed by the EC in 2015 focuses on sustainable resource use aiming for increased growth, job creation, the security of

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supply, and environmental benefits through reduced waste generation, increased recycling, and resource efficiency (Von Der Leyen, 2015). The greatest resource-saving will be achieved by reducing waste from construction, recycling construction waste, and demolition materials (Pomponi and Moncaster, 2017). According to Ellen MacArthur Foundation (2015), there is a significant potential for gaining benefits through the CE to make construction less waste-generating. In 2015, the Danish government launched a waste prevention strategy to reduce waste and avoid turning valuable resources into waste. It underpins the efforts on demolition waste, ensures that hazardous substances are handled responsibly from a health and environmental perspective, and secures improved knowledge sharing (Ministry of the Environment, 2015).

The Danish building regulations (BR) have currently regulated sustainability by launching a new sustainability building class to promote sustainable construction by introducing new sustainability requirements. It aims to embrace sustainable construction's three dimensions, including environmental, social, and economic qualities. One of these requirements is reducing resources on construction sites, including transport, energy, and water consumption, and the amount of construction waste must be measured, registered, and documented (Danish transport, 2020). Resource use on construction sites is in a narrow focus but can significantly impact a building's environmental and climate impact during the construction phase. The intention is to create increased awareness of this among actors, thereby achieving less resource consumption, reducing the environmental impact with economic savings (The Danish Housing and Planning Agency, 2020). Thus, this study investigates the Danish building sector readiness for sustainable construction sites in terms of circularity, focusing on reducing resources and waste, optimizing reuse, and recycling.

## LITERATURE REVIEW

*Promoting sustainability in construction sites*

The construction stage accounts for an essential part of a project's total energy use and can result in several nuisances and inconveniences for the surroundings. Efforts should consequently limit the use of resources and energy, decrease the amount of building waste, and minimize the nuisance from sound, vibration, and dust on and from the construction site, leading to significant environmental gains (City of Copenhagen, 2016). The urgency of reducing, reusing, and recycling construction and demolition wastes (CDW) releases the pressure off landfills and enhances the waste diversion practice, which has driven the sustainability movement from both governmental and industry perspectives (Jin, Yuan, and Chen, 2019). Research reveals that CE can be promoted through government legislation and improving stakeholders' attitudes towards CDW reduction (Ghisellini, Ripa and Ulgiati, 2018). A systematic literature review by Mhatre *et al.,* on the CE initiatives in the European Union remarks that CE can be facilitated by government policies, infrastructure, technological availability, awareness, stakeholder collaboration supply-chain integration (2021). A Danish study proved a periodical shift from the traditional linear economy to a circular one with significant policy implications (Magazzino *et al.,* 2021). In Denmark, initiatives are taken by policy and decision-makers such as landfill and incineration tax to promote recycling, separate collection schemes, targets for waste recycling, changes in waste regulation, and landfill ban of incinerable waste (Iyamu, Anda and Ho, 2020). The Danish Building Industry Innovation Network for Sustainable Buildings proposed requirements for sustainable building sites in buildings tender material regarding waste and material management, transport,

logistics, energy and water supply, materials, social sustainability and total economy (InnoBYG, 2019).

Resource optimization and circular economy in the construction process
Resource use on construction sites can highly impact a project's environmental impact during execution. It includes transport of building materials and soil to and from the construction site, transport at the construction site, and energy consumption, i.e., construction and drying building materials, water consumption, and construction waste (VCØB, 2021). To reduce the CDW, the circular economy breaks the linear value chain, which starts with the extraction of resources and ends up as waste. CE keeps materials and products in the economic cycle with the highest possible value and a long lifecycle. This is achieved by designing for disassembly, reuse, recycling construction materials, and selective demolition (Ellen MacArthur Foundation, 2015). It is a prerequisite in circular construction sites to ensure proper collection and sorting of construction waste to handle the resources at a high level and to increase the possibility of reuse and recycling. Another essentiality is investigating the possibility of cooperation on return schemes for off-cuts, spills, and debris. Some manufacturers have implemented solutions for this, also referring to the building materials manufacturer about reducing the amount of packaging (Environment, 2016). A study pointed that integrated supply chain, extended responsibilities of different actors, and the entire building supply chain, new business and ownership models are required when applying circular strategies (Ghisellini, Ripa, and Ulgiati, 2018). Generally, enhancing recycling and avoiding incineration is recommendable as the environmental performance is improved in several impact categories (Larsen *et al.,* 2010).

*Waste management in construction*
CDW refers to a mixture of surplus materials, including inert, non-inert non-hazardous waste, and hazardous waste (Menegaki and Damigos, 2018), generated from the construction, renovation, and demolition activities, e.g., site clearance and roadwork (Jin, Yuan, and Chen, 2019). CDW constitutes a significant share of the total amount of waste and approx. 87% of construction waste is recycled (Ministry of the Environment, 2015). Waste management focuses on waste characterization, quantification, and management practices. Factors like improved legislation, enhancing public awareness, novel treatment technologies, and experienced personnel can enhance waste management (Esmaeilian *et al.,* 2018). The quantity and composition of CDW vary between regions depending on population growth, legislation, regional planning, and the country's construction industry. In general, the quantity and quality of CDW are influenced by several internal factors (e.g., age, type, construction materials, and technologies) and external factors (e.g., demolition technologies and constructors), CDW management capabilities, population growth (Menegaki and Damigos, 2018). Esmaeilian *et al.,* (2018) highlight the value of product lifecycle data in reducing waste, enhancing waste recovery, and the need for connecting waste management practices to the whole product life cycle. An example of tracking and data sharing technologies for investigating waste management was proposed. Waste is the shared responsibility of both public and private actors. Danish waste competencies are characterized by the special relationship between public and private actors in the waste sector over the last four decades (Cluster, 2017).

*Selective demolition*
A large part of the demolitions today follows the voluntary NMK96 agreement (Environmental Control order 1996) of the demolition industry on buildings' selective demolition, aiming to ensure that recyclable materials are sorted out at the time of the

demolition itself. Selective demolition is performed by sorting contaminated and hazardous waste and source sorting (Environment, 2016). Demolition companies do not consider that there is a sufficient financial incentive to recycle roofs and bricks. There are insufficient rules for selective demolition, and adequate control of waste streams is not performed during demolition. Today, it is not possible to reuse roofs and bricks from after 1960 as they are bricked up with cement mortar. They are not suitable for recycling, as the cement mortar is stronger than the brick itself, and the stone will then crack upon cleaning. Recycling of bricks requires that the stones are whole, which is why it is not allowed to drive in the rubble at the demolition site (Byggestyrelsen, 2015). Waste management strategies should be implemented during the use and end-of-life stages. After onsite sorting and screening, materials should be recycled and reused in secondary materials or product production. However, some materials like wood can only be recycled for wooden composite production or energy recovery, depending on their quality and market readiness (Hossain *et al.,* 2020). Part of the CDW contains hazardous substances, which must be removed, so they do not spread and add risk to the environment and inhabitants' health (Ministry of the Environment, 2015). Thus, buildings must be screened before any demolition and renovation and possibly mapped for environmentally harmful substances. The materials used on site must not contain substances that appear on the REACH candidate list (list of particularly problematic substances) or LOUS, which is a Danish list of undesirable substances (InnoBYG, 2019). Screening and source sorting of environmentally hazardous substances is a demanding and costly process (Ministry of the Environment, 2015).

*Circular construction site challenges*

Although barriers vary across regions, commonly they are related to factors like regulatory environment, lack of waste-processing facilities, poor communication and coordination among parties involved, low awareness and behaviour from project stakeholders, lack of awareness of environmental implications of waste disposal, cultural resistance to implement CDW diversion, and low project processes and activities. The most recurring barriers tend to be cost and time associated with sorting and recycling CDW alongside the availability and low cost of virgin raw materials. Law enforcement and financial incentives are considered the most critical drivers for proper CDW management (Menegaki and Damigos, 2018). CLEAN uncovers insufficient financial incentives for recycling on the demolition companies, and the lack of rules for selective demolition and control of waste streams is a barrier to the spread of a market (Cluster, 2017). Screening and source sorting environmentally hazardous substances is a demanding and costly process. Danish municipalities do not perform sufficient inspections to ensure that demolition occurs in an environmentally and waste-correct manner (Byggestyrelsen, 2015). There is uncertainty whether the CE-labelling requirement for construction products applies to recycled materials. Some recycled materials do not comply with the current legislation. Today, focusing on recycling in demolition is not part of the demolition planning. There is also insufficient knowledge about recycled bricks' general use and quality (Byggestyrelsen, 2015). Small contractors and crafters have limited knowledge of materials' environmental conditions (Ministry for Food, 2016). According to Hossain *et al.,* (2020), understanding CE is missing in diverse stakeholders' social and institutional dimensions. It is crucial to increase the awareness and understanding of CE and unveil implications through education, training, and visionary thinking to change actors' attitudes and behaviours toward using recycled products. A study in the UK identified CDW challenges of ineffective

CDW regulations, incoherent data quality, undeveloped reverse logistics, and low market readiness for secondary materials (Villoria Sáez and Osmani, 2019). Waste from construction has relatively high quality than waste from demolition, typically cut off and the like from new products (Research Centre for Energy Savings in Buildings, 2020). One of the main difficulties for proper management and logistics of CDW is the distributed nature, which substantially differs from the more conventional generation of waste at industrial production facilities (Gálvez-Martos and Istrate, 2020).

## METHODOLOGY

A mixed research method was applied, including a literature review, as presented in the previous chapter, followed by a quantitative and qualitative online survey according to Dillman (2007). Data was collected from 146 respondents targeting mainly contractors and engineers, architects, and professional building owners. The study investigates the current national situation regarding organizations' readiness and willingness to apply the building regulations' new sustainability building class (SBC), focusing on sustainable construction sites (SCS), mainly reducing construction sites' resources, and using circular strategies. The survey consisted of open-ended questions and closed questions with multiple-choice options, yes/no questions, and rating questions based on the Likert scale (Likert, 1932) to investigate the strength of the actor's attitudes. The survey was conducted using Microsoft forms and distributed by e-mail to organizations collected from the Danish Central Business Register (CVR virk, 2021). According to similar studies, the response rate of 17% is considered adequate, considering an expected response rate between 15-35% and a sampling error of 10% (Dillman, 2007). Limitations involve some undelivered mails, also building contractors' tasks can vary, e.g., road and sewage works, so some contractors were not relevant for this study. However, results indicate the general state of organizations' readiness to apply sustainable construction site principles (SCSP). Both survey design and data analysis are based on two theories: The three domains of technology presented by Orlikowski and Gash (1994), which include what the technology is, why it was introduced and how it was used are: Nature of Technology refers to people's images of the generic technology and their understanding of its capabilities and functionality, benefits and demands. Technology Strategy refers to people's understanding of the motivation behind the adoption and its likely adding value to the organization, concerning actual plans assisting its implementation. Technology in use refers to people's understanding of how the technology will be used on a day-to-day basis and the possible or actual condition and consequences linked with such use. Thus, the results' analysis investigates organizations' current circular strategies, experiences, benefits, and perceived challenges. Besides, the Readiness theory by Holt *et al.* (2007) was used to assist in gauging readiness for organizational change. Readiness for change refers to organizational members' shared resolve and motivation to implement a change (change commitment) and shared belief in their collective capability to do so (change efficacy) which is best suited for examining organizational changes where collective behaviour change is essential to implement the change effectively (Holt *et al.,* 2007), (Weiner, 2009). Here, implementing a change is linked to actors' motivations and expected benefits (Heavey, Gilbert and Murphy, 2011).

## ANALYSIS AND DISCUSSION

The survey results were collected from 146 respondents, including 43% contractors, 15% engineers, 14% architects, 28% professional builder owners. The survey starts

with introduction questions including organization size (measured in the number of employees), geographic location, and actors' roles, followed by the survey's main questionnaire, involving four topics: 1. The building sector's readiness to use building regulations SBC, focusing on SCSs and CE. 2. Actors' existing experiences in SCSs. 3. Organizations' motivation to establish SCSs. 4. The perceived challenges in SCSs.

Implementing sustainability in Danish building regulations and construction sites
The study examines the building sector's readiness to implement the building regulations SBC, providing an insight into the Danish building sector's readiness and current status in implementing sustainability in construction sites. Results show that 10% of respondents evaluate themselves as very well prepared for the new requirements, 20% are well prepared, and 45% prepared to some extent, including small organizations (10-50 employees), followed by medium-sized organizations (50-249 employees). In contrast, 25% of respondents do not think that their organizations are prepared at all or only to a very low degree. Thus, results indicate that a majority of the building sector is not ready to implement the new SBC, and only a few actors are already implementing sustainability in their projects. It is found that organizations' readiness to implement the SBC is connected to their size and location, whereas medium and big-sized organizations located in bigger Danish municipalities are more ready than others. Also, 75% of respondents are aware of the new SBC, which requests requirements for SCSs, indicating that many actors are aware of the new governmental sustainability requirements but not yet ready to implement them. Data indicates that contractors are mainly ready to implement SCSPs among other actors, confirming that they have the overall responsibility to manage construction sites.

*Experiences in sustainable construction sites*
Respondents were asked whether they have worked with SCSPs or not, revealing that 32 % of them have already implemented SCSPs to some extent, and 63% of respondents do not have any relevant experience but intending to implement SCSPs, indicating their positive mindset towards green transition. Respondents were asked how often they have implemented SCSPs in the last five years, showing that only 17 % of respondents work with SCSPs in most projects and 43% sometimes, while 39% rarely, indicating that actors are improving in implementing more SCSPs with increased focus. But still many have not worked with it yet. Results show that 45% of respondents mainly choose to work with SCSPs due to building owners' requirements, and 27% of them generally focus on sustainability, especially in buildings certified according to the Danish (voluntary) sustainable assessment method DGNB-DK, and only 6% follow consultants' recommendations. This reveals that building consultants, including architects and engineers, have a minor influence on building owners' decisions. Here, consultants are obliged to promote SCSPs, indicating that deciding and planning to have SCSs is not specified and elaborated early in the building design and tender phases. However, it is mainly related to contractors' own strategies and benefits due to the fact; if waste is sorted correctly, it can add economic benefits to contractors. Research reveals insufficient financial incentives for recycling on the demolition companies (Cluster, 2017).

Actors were asked to evaluate their experiences in SCSPs according to eight principles, including resources and waste reduction, management of CDW, handling of hazardous substances from building materials, waste sorting, cleaning building materials, building's location, and the construction site logistics, energy consumption on construction site and vibration and noise. Results show that most organizations

who already work with SCSPs have high experience in waste sorting and handling hazardous substances from building materials but lack experience managing vibration from construction sites, reducing energy consumption, cleaning, and preparing building materials for second life use. Thus, organizations are more prone to work with specific strategies with bigger experiences but postponed to other strategies where they had fewer experiences. Many respondents include SCSs via DGNB certification and when focusing on the UN's 17 sustainable development goals. It is found that building owners do not focus on a specific SCSP, but they have in general a significant request to focus on sustainability as much as possible. Respondents who use SCSPs were asked whether their organizations have a specific strategy to establish SCSs, revealing that 61% follow their own strategies for waste sorting on construction sites, above the municipality's instructions, and 30% do not have any strategies, as most construction sites have waste management plans to sort the various fractions for further possible treatment.

Organization's motivation to work with sustainable construction sites
Respondents were asked about their motivation to establish SCSs. Results reveal that 41% of respondents are highly motivated to establish SBSs and 44% only to some extent, while 17% have almost no interest. Here, the actor's motivation is linked to the benefits gained as 59% of respondents strongly confirmed the environmental benefits, contributing to reduce the carbon footprint of buildings by reducing construction waste and resources. Resource use on construction sites can highly impact a project's environmental impact during execution (Byggestyrelsen, 2015). Additionally, 37% of responses confirmed the economic benefits of reducing resources, recycling, and reusing building materials. A study shows that demolition companies do not consider a sufficient financial incentive to recycle roofs and bricks (Byggestyrelsen, 2015). Generally, 39% of respondents are not sure of the benefits added when using SCSPs. Other motives collected from respondents' comments are related to organizations' social responsibility and eagerness to promote sustainability, reduce waste and raw resources consumption, following the national political strategies to reduce the environmental impact of construction. Research reveals that circular strategies can be promoted by improving stakeholders' attitudes towards construction and demolition waste reduction (Ghisellini, Ripa and Ulgiati, 2018). As stated by several respondents, SCSs supports their organization's vision in sustainable development and adds value to them by developing their competencies in SCSs, obtaining a green profile. Furthermore, working with SCSs improves their position in the competitive building sector, which requires more extensive efforts, as there is an increased market and demand for sustainable construction sites, reduced emissions, and fossil-free construction sites. One of the respondents' comments: *"We can see an advantage in promoting ourselves as someone who can offer green construction sites."*

*Challenges in sustainable construction sites*
To investigate organizations' readiness and potential to apply SCSPs, they were asked if they had experienced any challenges when working with SCSPs. Results show that 72% of respondents face challenges in SCSs, while 28% do not experience any challenges, reflecting the variating level of experience among actors. The respondents were asked about the perceived challenges when working with SCSs. Results confirm the presence of several barriers that hinder implementing SCSs, as shown in Fig 1.

It is revealed that the biggest challenges are related to the economy due to expensive solutions with uncertain financial profits, as 66% agree on the fact that the cost of

implementing and operating an SCS is too high. For example, screening and waste sorting concerning environmentally hazardous substances is a demanding and costly process (Byggestyrelsen, 2015).

Also, 34% of responses strongly agree that SCSs require more resources than a traditional construction site without using sustainable principles, and 57% of responses agree to some extent and 9% of responses to a minor extent. Here, resources can refer to cost, competencies, and time.

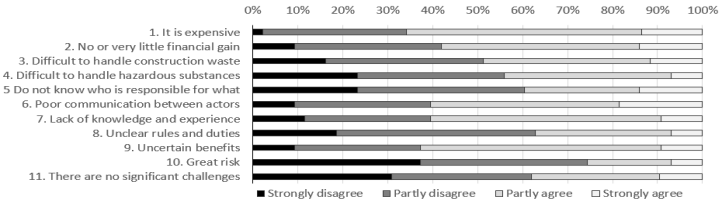


*Fig 1: Organizations perceived challenges in sustainable building sites*

Moreover, poor communication between involved actors is perceived by respondents as a significant barrier. Parameters such as lack of experience and know-how are highly challenging, especially in handling construction waste and hazardous substances. Other challenges collected from respondents refer to inflexible municipalities, actors' unconcerned attitude in sustainability, poor planning, lack of general overview of project strategies, and cultural factors. As expressed by several respondents, organizations only make a change when great incentives are gained and when it is a governmental requirement. According to Menegaki and Damigos (2018), law enforcement and financial incentives are considered the most critical drivers for proper waste management. Results confirm that the economy is a risk factor; it is not evident whether profits can be gained, or extra expenses will be added. Comparably, research reveals insufficient financial incentives for recycling on the demolition companies (Cluster, 2017). Respondents stated that measurements and documentation at construction sites according to the new SBC requirements are also difficult to provide. Measurements and documentation can relate to energy consumption, hazardous substances, and waste quantities. Also, space conditions on construction sites are sometimes challenging, creating difficulties. A comment from a building owner involves difficulties in using recycled materials when their characteristics are unknown. Responses show that the primary reason for not thinking sustainably about construction sites is 46% related to lack of experience and knowledge in this area and 36% according to the economy. Thus, actors must focus on improving their knowledge and collaborate with experienced professionals. However, responses show a willingness to gain knowledge in SCSs as 85% are willing to learn more, indicating their positive mindset to make a change. Menegaki and Damigos (2018) reveal that poor communication and coordination among parties involved, low awareness and behaviour from project stakeholders, cost and time related to sorting and recycling construction waste are the most recurring barriers. Respondents who work with SCSPs were asked whether their organizations follow specific rules for waste sorting on construction sites above the municipality's instructions; 61% answered yes, and 39% do not follow any specific rules. Similarly, Cluster (2017) confirmed the lack of rules for selective demolition, a barrier to the spread of a market.

## CONCLUSION

This study investigated the Danish building sector's readiness to use the building regulation's requirements for sustainable construction sites, focusing on circular

solutions such as reducing resources and waste, highlighting their practical experiences, expected benefits, and perceived challenges. Results indicate actors' willingness to implement sustainability in construction sites. However, deciding and planning to establish SCSs is not clearly specified and elaborated early in the building design and tender phases. It is revealed that many actors are still unaware of the relevant rules when establishing circular construction sites and do not have a specific strategy to manage waste, but it is mainly related to contractors' own strategies. Furthermore, actors perceive this topic with high risk and uncertain economic benefits. It is concluded that actors are still not quite ready to implement SCSs but are progressing towards the proper direction with great interest and a request to learn more. Although some existing barriers can influence how fast and prepared the building sector is, barriers such as the economy and effective communication between actors should be considered when planning new projects as both factors are essential to fulfil environmental, economic, and social sustainability.

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# A FRAMEWORK FOR IDENTIFICATION OF CRITICAL MATERIAL WASTE CAUSES DURING CONSTRUCTION USING DEMATEL AND SOCIAL NETWORK ANALYSIS

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The construction sector is the second major contributor to India's gross domestic product with the consumption of natural resources such as sand, aggregate, and lime. Along with the consumption of these resources, material waste also occurs during a construction project with its knock-on effect on cost and other detrimental effects on the environment. Understanding various factors causing material waste and the inter relationships would help the construction industry to alleviate the detrimental effects of such causes on sustainable construction. While the literature review has provided the reasons for the material waste, limited research is available on investigating the interrelations between the contributing factors. Therefore, an integrated framework consisting of construction site specific questionnaire survey, decision-making trial and evaluation laboratory (DEMATEL) and social network analysis (SNA) is proposed to identify the critical causes of material waste and its inter relationships. The results have indicated that 55 out of 110 interrelations are important. Further, tendering errors and design errors are the critical causes of material waste, and human errors are central within the network of critical interrelations.

Keywords: material management; material waste; network analysis; sustainability

## INTRODUCTION

Responsible Consumption and Production (RCP) is one of the 17 Sustainable Development Goals (SDG) towards achieving sustainable development, as per agenda 2030 of United Nations (UN). In an increasingly resource-constrained world, India, a signatory to the UN, is therefore focused to balance the economic aspirations as a developing economy and environmental responsibilities towards SDG. Construction sector being the second-largest contributor to the nation's economy has a bigger role to play in this movement by contributing to the RCP targets by producing more with fewer resources. However, waste generation during new construction in India is at 8% - 10%, and with increased construction activity due to the government's infrastructure and housing schemes, waste generation is poised to increase in the years to come (CPCB 2017). Since construction material component form 40-50% of the

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project cost (Oko and Emmanuel 2013), significant efforts are therefore required to reduce the material wastage while executing projects to positively contribute towards SDGs.

One of the obstacles in material waste management is identifying the critical causes of waste generation at construction sites. Existing literature has explored the ranking of such causes using qualitative research with mainly a list of causes as the research outcome (Al-Hajj and Hamani 2011; Adewuyi and Odesola 2015). Owing to the uncertain environment in construction project sites such as unpredictable environment, resource unavailability, interdependent activities, and inefficiency of operations (Dubois and Gadde 2002), identifying the right causes and finding the remedies are suggested as the key to better waste management (Liu *et al.,* 2020). In material management, the causes of material waste typically occur in isolation, and as an outcome of each other (Ofori and Ekanayake 2000). For instance, Polat and Ballard (2004) reported material wastes due to procurement errors, which has occurred due to both the wrong choice of material while planning (planning error) and providing incorrect purchase order information (procurement error). Construction sites have several such instances of material waste generation instances, and there is a need for understanding the interrelation of each factor with other causes for better material management and avoiding unnecessary wastages (Formoso *et al.,* 2002; Nagapan *et al.,* 2013). This study proposes an integrated approach of questionnaire survey-based data collection and analysing the data through decision-making trial and evaluation laboratory (DEMATEL) and social network analysis (SNA) to quantify the inter relationships and the weightages existing between material wastage causes.

## RESEARCH BACKGROUND

### Material Waste Causes

Conceptually, sources of material waste are organized into six categories such as design, procurement, handling of materials, operation, residual related, and others (Gavilan and Bernold 1994). As was previously mentioned, the existing literature (Kaliannan (2018)) has identified several such causes, and a comprehensive list of material waste causes is presented in Table 1. The associated literature is referred in Table 2.

### Network Analysis Methods

The graph theory forms the basis of network analysis methods (NAM), and the major NAM includes structural equation modelling (SEM), SNA, analytical hierarchical process (AHP), interpretive structural modelling (ISM), and DEMATEL. SEM is typically used where the sample size is more than 100 (Xiong *et al.,* 2015). AHP does not help analyse relationship influence, whereas ISM can only be used to analyse direct relations (Ristono *et al.,* 2018). DEMATEL and SNA are more suitable methods quantitatively analysing inter relationships and the weightage of those relations between the nodes (Bastian *et al.,* 2009; Ristono *et al.,* 2018; Liu *et al.,* 2020).

Decision Making Trial and Evaluation Laboratory (DEMATEL)
In order to identify the core causes in a complex network of relationships and establish the cause-and-effect relationship, DEMATEL is adopted in management research (Chang *et al.,* 2011; Zhou *et al.,* 2011). Input for DEMATEL analysis is a direct relation matrix (DRM). It is prepared based on the opinions obtained, usually through questionnaire surveys or interviews.

*Table 1: Compilation of material waste causes*

| Cause | Explanation |
|---|---|
| Tendering Errors (TE) | Errors in contract specifications and documents; misinterpretation of contractual terms |
| Design Errors (DE) | Constant design changes; design errors, bad design quality, inexperienced designer, poor coordination during design |
| Material Requirement Planning Errors (MRPE) | Errors in quantity take off; over allowances; inappropriate site layout planning, lack of waste management plan; construction method selection; delayed information flow between teams; last minute changes |
| Material Procurement Errors (MPE) | Ordering errors, supplier errors, poor supply chain management |
| Material Receipt and Storage Errors (MRSE) | Storage mistakes; damages during transportation; |
| Material Use Errors (MUE) | Poor supervision, inefficient material usage, wastage due to equipment/resource problems; excess offcuts; interference by other trades, rework |
| Project Site Specific Errors (PSSE) | Congested site, difficult to access site, untidy construction site, unforeseen ground conditions |
| Human Related Errors (HRE) | Poor workmanship, lack of skill, damage, negligence, no interest, overtime, poor coordination and communication |
| Lack of Supporting Culture Within Organization (LSCO) | Lack of support from senior management; lack of training about the work and material management; lack of awareness about environmental protection by waste reduction |
| Lack of Contractual Incentives (LCI) | No contractual provisions to prevent material wastage; No incentive for reducing waste |
| Lack of Regulation/ Policy Implementation (LRPI) | No policy by government to prevent waste; lack of policy enforcement; no government action for waste generation |

*Table 2: Material waste causes- literature meta-analysis*

| Years Range | Sources | Factors identified |
|---|---|---|
| <2000 | Skoyles (1974) ; Gavilan and Bernold (1994); Bossink and Brouwers (1996); Faniran and Caban (1998); | TE,DE,MPE,MRSE,MUE |
| 2000-2010 | Ofori and Ekanayake (2000); Lingard et al., (2000); Poon and Jaillon (2002); Alwi et al., (2002); Poon et al., (2004); Polat and Ballard (2004); | TE,DE,MPE,MRSE,MUE,PSSE,LRPI,LSCO,LCI |
| >2010 | Al-Hajji and Hamani (2011); Mokhtar et al., (2011); Nagapan et al., (2013); Adewuyi and Odesola (2015); Llatas and Osmani (2016); Ikau et al., (2016); Kaliannan et al., (2018) | TE,DE,MRPE, MPE,MRSE,MUE,PSSE,LRPI ,HRE,LSCO |

DRM indicates factors in rows and columns, indicating the relationships and the associated weightages. After DRM is developed, a normalized relation matrix (NRM) is prepared by dividing each cell with a maximum of the sum of each row's value in DRM. Further NRM and identity matrix are used to derive the total relation matrix (TRM). The summation of each row value and column values of the TRM is computed to determine the causes and effects between the factors. From the TRM, the relations which are above the threshold value (above the average of the total elements in TRM) are considered as critical relations. Overall, the output of DEMATEL provides a network of important relations from the total relation matrix as a network graph. More details regarding the procedure and formulae for conducting DEMATEL analysis can be referred from Tsai *et al. (*2015) and Chang *et al. (*2011).

Social Network Analysis (SNA)

SNA is defined by Wasserman and Faust (1994) as "a finite set of actors and the relation or relations [between them]." The application of SNA in construction management is growing prominence, as construction projects are predominantly visualized in the form of networks (Zheng *et al.,* 2016). SNA is generally used for

studying people aspects, i.e., teams, performance, and interactions (Lin 2015; Pryke 2004; Chinowsky *et al.,* 2008), and process aspects of construction management, i.e., logistics, accidents, and defects (Li *et al.,* 2016; Eteifa and El-Adaway 2018; Lee *et al.,* 2019). SNA provides network visualization, and the network characteristics are computed with software tools such as UCINET, Gephi, NodeXL, Pajek, and NetMiner.

The vital structural characteristics computed for a network are nodal degree, closeness centrality, betweenness centrality, and eigenvector centrality. A nodal degree is a weighted sum of relations that are leading-in and leading-out of a given node. Meanwhile, closeness centrality indicates how far each node is from other nodes. If the value of closeness centrality is high, then the time taken to reach the node by other nodes would be less, implying that the node can create an immediate effect on other connected nodes. Likewise, betweenness centrality measures how a node is situated between other pairs of nodes. A higher value of betweenness centrality indicates the power to control the interrelations. Further, eigenvector centrality considers the leading-in and leading-out relations of the given node as well as its neighbour node. If the eigenvector centrality for a given node is high, then it means that the node is central in the network of relations (Wasserman and Faust 1994).

### Research Motivation

As was previously mentioned, several studies have explored in detail about the causes of material waste causes during construction through questionnaire surveys, interviews, and case studies (Kaliannan *et al.,* 2018; Wu *et al.,* 2019). However, research on identifying the interrelations between the material waste causes during construction and quantifying the criticality of such interrelations is limited. A network-based approach is necessary to identify such relationships and understand the most critical factors that have the maximum knock-on effects on other factors. Such a result would be appropriate for a project manager to control the waste generation in construction projects, considering the triple constraints of cost, time, and scope in construction projects (Silvius *et al.,* 2017; Liu *et al.,* 2020). As the DEMATEL method provides criticality of each factor and SNA provides the centrality of each factor, DEMATEL and SNA are selected in this study as combined quantitative and network approaches, for analysing the data collected from construction professionals.

## RESEARCH METHODOLOGY

Fig 1 summarizes the proposed framework of the study. The research work involves four main steps. The first step involves identifying the causes of material waste from literature. A survey approach is adopted for identifying the interrelationships. The second step involves conducting a survey to obtain responses from the construction professionals. The respondents chosen are site engineers, site managers, and project managers from the construction industry in India. Purposive sampling is used to select respondents whose work experience and primary location is mainly at construction sites (Amoatey *et al.,* 2015). As a third step, the inputs from the respondents are analysed to create the matrix of relations. The fourth step identifies the most critical cause and effect relation matrix using the DEMATEL method. The final step is creating a network map, using UCINET version 6.716 of the matrix derived from DEMATEL and performing SNA to identify the vital metrics of the network (Borgatti *et al.,* 2002).

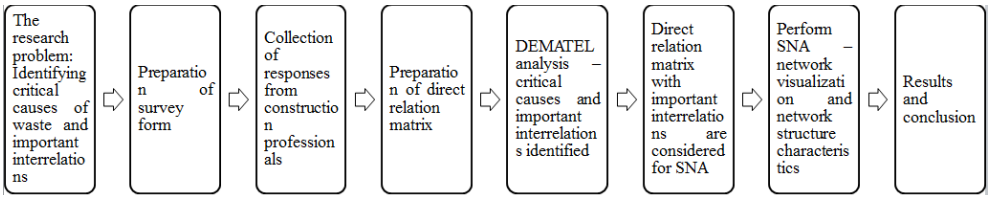


Fig 1: Framework for identifying critical causes and interrelations of material waste

The data required for the research is the connection(s) between the 11 factors identified in Table 1. The number of connections possible in an 11 x 11 matrix is 11 * (11-1) = 110, excluding the self-relation. Survey form with an entire network is prepared both in Microsoft excel and, in a web,-based platform and floated through e-mail to the construction professionals so that the respondents use the form of their convenience. The survey form comprised of collecting following inputs:

- General information (experience and role) ……. (A)
- Rating each factor towards its potential to cause material waste …… (B)
- Rating each link /interrelation as the frequency of occurrence ..…… (C)

A five-point Likert scale is used for both questions (B) and (C) with textual and numerical score values as: never (0) / rarely (1) / sometimes (2) / usually (3) / always (4)) (Chang *et al.,* 2011). The responses are collected as text inputs, and the same is converted to corresponding numbers while performing quantitative analysis.

## DATA COLLECTION

A total of 114 construction professionals were approached through e-mail during 17-31 March 2021, of which a total of 35 responses were received. Thirty-one (31) fully completed survey responses were considered for analysis, indicating a response rate of 27%. Respondent's characteristics such as role, experience, and representing organization are provided in Table 3 below. The responses were collected using the full-network method and yielded maximum information as each respondent provided answers for a total of 110 questions. Moreover, the response rate is in the range of 25 - 40%, as commonly observed in web-based surveys in construction management research (David and Carol 2002; Carter and Fortune 2004). Further analysis is carried out using DEMATEL and SNA, as explained in the next section below.

*Table 3: Respondent's profile*

| Organization | Years of experience | | | | | Role | No. of respondents | % |
|---|---|---|---|---|---|---|---|---|
| | <=5 | 6-10 | 11-15 | 16-20 | Total | | | |
| Contractor | 7 | 9 | 8 | 4 | **28** | Site engineers | 8 | 26% |
| Client | | | | 1 | **1** | Site Managers | 10 | 32% |
| Consultant | 1 | | | 1 | **2** | Project managers | 13 | 42% |
| **Total** | **8** | **9** | **8** | **6** | **31** | **Total** | **31** | **100%** |

## RESULTS AND DISCUSSION

Referring to the question seeking the degree of importance of each factor in material waste generation (MWG), the mean of response scores is calculated. Ranking based on the mean of response scores, the top three factors are material usage errors, human-related errors, and material requirement and planning errors, indicating the degree of importance of execution, people, and planning in a construction site. Regarding the network of interrelations, one significant contribution here is the responses sought by using the Likert scale (as explained in research methodology) provided the weights that indicate the strength of each relation. The average scores were computed from the responses received, and a direct relation matrix is prepared as presented in Table 4

below. As can be inferred from Table 4, every factor is leading to other factors, indicating that material waste generation is a complex issue (Adewuyi and Odesola 2015). A total of 110 weighed connections were determined, taken as an input to the DEMATEL method for identifying the cause-and-effect pattern within the factors.

*Table 4: Direct relation matrix of all the 11 causes ad their weighed interrelations*

| Adjacency Matrix | TE | DE | MRPE | MPE | MRSE | MUE | PSSE | HRE | LSCWO | LCI | LRPI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TE | | 2.10 | 1.48 | 1.42 | 0.74 | 0.87 | 1.19 | 1.39 | 1.10 | 1.32 | 1.16 |
| DE | 1.39 | | 2.19 | 1.71 | 1.06 | 1.52 | 1.61 | 1.71 | 1.10 | 1.10 | 1.23 |
| MRPE | 1.00 | 1.16 | | 2.03 | 1.97 | 1.81 | 1.61 | 2.03 | 1.26 | 1.13 | 1.03 |
| MPE | 0.87 | 1.06 | 1.39 | | 1.68 | 1.81 | 1.65 | 1.81 | 1.45 | 1.42 | 1.06 |
| MRSE | 0.84 | 0.90 | 1.52 | 1.68 | | 1.84 | 1.45 | 1.90 | 1.29 | 1.26 | 0.94 |
| MUE | 0.74 | 0.97 | 1.61 | 1.84 | 1.42 | | 1.68 | 1.87 | 1.48 | 1.29 | 0.97 |
| PSSE | 0.90 | 1.29 | 1.87 | 1.87 | 1.45 | 1.68 | | 1.77 | 1.29 | 1.39 | 0.97 |
| HRE | 1.58 | 1.71 | 2.32 | 2.26 | 2.19 | 2.29 | 1.77 | | 1.68 | 1.48 | 1.06 |
| LSCWO | 0.87 | 0.94 | 1.39 | 1.52 | 1.32 | 1.42 | 1.42 | 1.90 | | 1.23 | 1.06 |
| LCI | 1.23 | 1.26 | 1.39 | 1.52 | 1.19 | 1.29 | 1.39 | 1.87 | 1.35 | | 1.26 |
| LRPI | 1.42 | 1.39 | 1.06 | 1.23 | 1.06 | 1.10 | 1.16 | 1.29 | 1.19 | 1.13 | |

The threshold value is calculated as a mean of each weighed relation in the total relation matrix, and the relations having the value below the threshold are eliminated. Fig 2 indicates from the DEMATEL analysis that critical causes of material waste in construction sites are DE, TE, LRPI, LCI, HRE, and remaining factors (LSCWO, PSSE, MRSE, MRPE, MUE, and MPE) are corresponding effects.

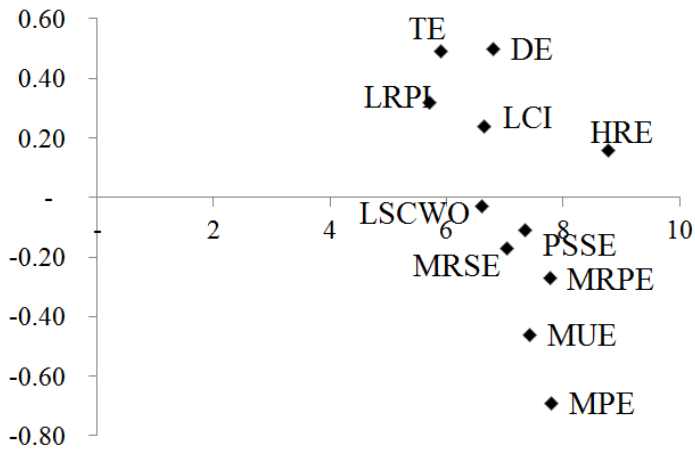


*Fig 2: output of DEMATEL method – cause-and-effect graph*

The total relation matrix with only the relations above the threshold value of 0.32 has eliminated 55 interrelations as unimportant, leaving the balance interrelations as input for SNA. The network of 55 interrelations is imported to Gephi software, and essential network characteristics are calculated (Bastian *et al.,* 2009). Table 5 indicates the summary of the SNA structural characteristics. The node-level parameters studied are weighed degree and closeness centrality. HRE has the maximum weighed degree with 34.82, followed by MPE and MRPE. HRE has maximum closeness centrality.

The network-level characteristics computed were betweenness centrality and eigenvector centrality. In terms of betweenness centrality, HRE remains at the top, indicating that construction project's material management is dependent on the interests, attitudes, and behaviours of the people involved in the process. This result agrees with Wu *et al. (*2019), indicating that exploring human factors involved in material waste management as a research direction is growing prominence. The

network visualisation of the 55 important interrelations is represented in Fig 3. The material waste causes are represented as nodes, and the relations are depicted as arrows. The arrow width is in proportion to the weightage as provided by the construction professionals. The node size reflects the betweenness centrality of each cause.

*Table 5: Output of SNA using Gephi- Key structure characteristics*

| Id | Indegree | Outdegree | Degree | Weighted indegree | Weighted outdegree | Weighted Degree | Closness centrality | Betweeness centrality | Eigen centrality |
|---|---|---|---|---|---|---|---|---|---|
| HRE | 10.00 | 9.00 | 19.00 | 17.54 | 17.28 | 34.82 | 1.00 | 39.40 | 1.00 |
| MPE | 10.00 | 5.00 | 15.00 | 17.08 | 8.34 | 25.42 | 0.69 | 3.40 | 1.00 |
| MRPE | 9.00 | 5.00 | 14.00 | 15.16 | 9.45 | 24.61 | 0.69 | 1.40 | 1.00 |
| MUE | 8.00 | 5.00 | 13.00 | 13.66 | 8.42 | 22.08 | 0.69 | 0.40 | 0.97 |
| PSSE | 8.00 | 5.00 | 13.00 | 12.58 | 8.64 | 21.22 | 0.69 | 0.40 | 0.97 |
| MRSE | 6.00 | 5.00 | 11.00 | 9.77 | 8.39 | 18.16 | 0.69 | - | 0.92 |
| DE | 1.00 | 6.00 | 7.00 | 1.71 | 9.80 | 11.51 | 0.75 | - | 0.18 |
| LSCWO | 1.00 | 5.00 | 6.00 | 1.68 | 7.65 | 9.33 | 0.69 | - | 0.18 |
| LCI | 1.00 | 5.00 | 6.00 | 1.48 | 7.46 | 8.94 | 0.69 | - | 0.18 |
| TE | 1.00 | 3.00 | 4.00 | 1.58 | 4.29 | 5.87 | 0.60 | - | 0.18 |
| LRPI | - | 2.00 | 2.00 | - | 2.52 | 2.52 | 0.56 | - | - |

In terms of eigenvector centrality, HRE, MPE, MRPE are having the highest score indicating that human factors, material procurement, and material planning are major root causes than the other eight causes. Therefore, for reducing the waste generation, the construction project managers in India should focus on these three factors for reducing their knock-on effect on other causes.

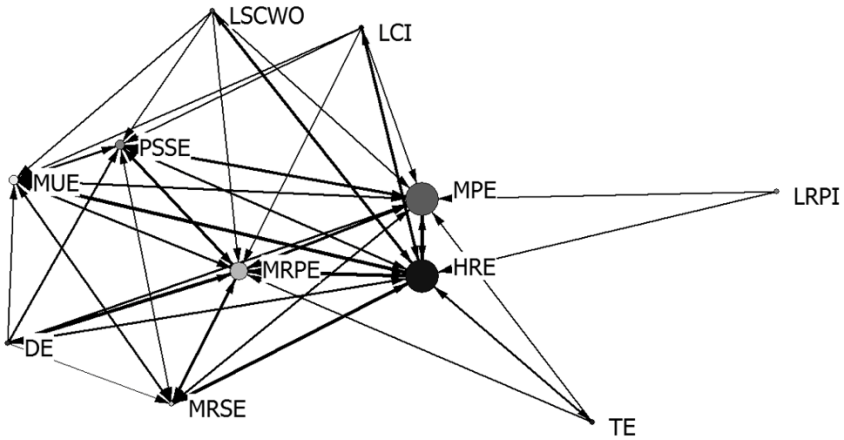


*Fig 3: Output of SNA- Node size is representative of betweenness*

## CONCLUSIONS AND A WAY FORWARD

The study is aimed to identify the most critical causes and the causes more central in the network of interrelations between causes of material waste. The study proposes a novel approach to use DEMATEL and SNA as combined network methods to assess the interrelations between the material waste causes and quantify the weightage of those relations. The results from the DEMATEL method indicate that TE, DE, LRPI, LCI, and HRE are critical causes to be addressed for material waste reduction. Further, SNA results identified that HRE, MPE, MRPE are to be managed efficiently as these causes are central to the network of important interrelations. As the human-

related errors were critical and central, the study can be a theoretical basis for further studies on human factors in construction waste reduction.

From a practical perspective, for efficient and effective results in material waste reduction, human resources are to be managed and trained by the project managers apart from process improvements.

The study focuses on the interrelations between material waste causes rather than material waste in general, specifically to the construction industry in India. However, similar studies can be carried out in other developing countries based on the framework proposed. Further, the study analysed the total relations from a macro perspective, whereas further studies can focus on specific relationships. Overall, the study and the novel framework proposed can be considered a significant step to imbibe sustainability in materials management of construction projects in developing countries.

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# ENERGY EFFICIENT BEHAVIOURAL TRENDS IN RESIDENTIAL SECTORS FOR LOW-INCOME CULTURAL BACKGROUND: A CASE-STUDY OF SLUMS IN CHITTAGONG, BANGLADESH

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Slums may be a by-product of the urbanization process in a developing country like Bangladesh. The slum dwellers' lack of energy awareness is the primary impediment to domestic energy savings. In countries such as Bangladesh, where wages are extremely low, energy awareness is primarily focused on behavioural issues. This study presents the results of an energy awareness feedback program on the energy-efficient behaviours of various groups of slum occupants in Chittagong, Bangladesh. All slum occupants are classified here according to their housing structure and economic circumstances. Initially, occupants are informed about the various solutions and opportunities for energy conservation through low- or no-cost measures. Following that, a survey was conducted (between May and June 2020) in 54 individual houses (similar in size but with varying housing structures and economic conditions) in slum areas to ascertain the impact of efficient energy behaviour on lighting and appliances. A statistical analysis (two-way ANOVA) was conducted to determine the efficient energy behaviour trends associated with the selected housing groups' structure and economic conditions. The study will aid in the implementation of several actions aimed at addressing various energy-efficiency issues affecting low-income communities in Bangladesh.

Keywords: energy efficiency; residential; slums; statistical analysis

## INTRODUCTION

Since the onset of the economic crisis in the majority of industrialized and developing countries, the rate of energy efficiency improvement has slowed (Yang and Zhao 2015, Karim *et al.,* 2017). Buildings are often the largest end-user sector, followed by transportation (32%), industry (26%), and agriculture (2%) (Bosseboeuf 2015; Yang and Zhao 2015). In certain countries, such as Hungary, Latvia, and Estonia, the building industry consumes more than 45 percent of overall energy consumption (Bosseboeuf 2015). Regrettably, this industry has received little attention in developed and developing countries alike, despite the fact that it urgently requires

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energy conservation measures. In developing countries such as Bangladesh, India, and Pakistan, newly constructed or refurbished buildings consume an enormous amount of energy; therefore, effective energy refurbishment is critically needed in these regions (Bardhan *et al.,* 2018; Debnath *et al.,* 2019). At the moment, it is widely acknowledged that the building/construction industries are incapable of sustaining energy efficiency projects in the absence of appropriate government rules and regulations (Elsharkawy and Rutherford 2015). Nonetheless, many government institutions at the national or local level lack information and expertise about possible policies, techniques, and tools within their particular context (Bardhan *et al.,* 2018, Debnath *et al.,* 2019; Uddin *et al.,* 2021). Without well-designed policies, techniques, or instruments that typically affect both the energy demand and supply sides of the equation, improvements in building energy proficiency will continue to progress at a slower rate (Elsharkawy and Rutherford 2015; Yang and Zhao 2015). Typically, in the majority of fast-growing developing countries, the housing/residential sector represents the most cost-effective and feasible opportunities for energy efficiency programs, as well as the largest co-benefits. However, several hurdles must be controlled/removed in order to turn these opportunities into reality (Elsharkawy and Rutherford 2015). The United Nations Development Programme (UNDP) and the International Energy Agency (IEA) are proposing several cross-cutting programs to disseminate their most recent study, findings, and recommendations to encourage policymakers to implement various energy efficiency programs in the housing sector methodically, thereby reinforcing excellent cooperation for energy efficiency schemes in both developed and developing countries (Uddin *et al.,* 2019; Debnath *et al.,* 2020). Despite rapid advancements in the housing sector's impact on energy consumption, resource depletion, and waste generation, the built environment (e.g., housing, infrastructure, and cities) continues to be critical to a country's economic development, particularly in newly industrialized and developing countries such as Bangladesh. This has a significant impact not just on the residential sector in Bangladesh, but also on the entire construction industry, which is a major candidate for sustainable growth (Yang and Zhao 2015; Uddin 2018; Uddin *et al.,* 2019; Uddin *et al.,* 2021; Uddin *et al.,* 2021). However, as a developing and overpopulated country, sufficient modern energy is critical for the country's economic and health sectors (Kabir *et al.,* 2017; Uddin 2018).

Bangladesh is a low-energy-consumption country with an area of approximately 147570 square kilometres and a population of approximately 164 million people. Although only 30% of the population lives in urban areas, the country's per capita primary energy consumption is extremely low (Kabir *et al.,* 2017; Karim *et al.,* 2017). In general, approximately 60% of Bangladesh's population lacks access to adequate electricity, while only 1.5 million households rely on natural gas to meet their energy needs. Additionally, nearly 90% of households in Bangladesh cook with biomass, while the remainder use LPG, natural gas, or biogas (Kabir *et al.,* 2017; Uddin 2018). Domestic energy consumption is inextricably linked to the country's standard of living and economy in this country. Typically, a large number of poor people migrate from rural areas, and the very poor in urban areas live in slums. Improving the energy efficiency of this largest segment of the poor or low-income population (e.g., slum dwellers) is critical for a long-term solution to Bangladesh's energy scarcity (Rashid 2009; Uddin 2018). They are typically integrated into larger energy policy initiatives. However, governments may choose to implement specific measures to increase energy efficiency adoption among slum dwellers (Uddin 2018). Generally, energy efficiency has never been a national priority in extremely low-income housing (e.g.,

slums). National funding or initiatives to improve the living conditions of slum dwellers and energy efficiency have been woefully inadequate. Additionally, there is a significant disparity between energy consumption and efficiency among slum dwellers in Bangladesh, and unmet energy requirements impede the country's development toward Vision 2021. (Kabir *et al.,* 2017). Although very few people living in slum areas have access to electricity, the scenario of energy conservation awareness is at an acute level for this particular low-income population, as slum dwellers are unaware of the sustainable development goal. Thus, energy literacy, awareness, and conservation behaviour among slum dwellers are critical, as energy consumption in this sector represents a significant opportunity for resource conservation. In this regard, energy audits, peer feedback, and awareness are all extremely effective methods for determining individual needs, particularly for slum dwellers (Steg 2008; Zvingilaite and Jacobsen 2015). Additionally, it is a pioneering and evolving effort to bring attention to and increase the urgency of addressing a persistent problem that is all too frequently overlooked in discussions of environmental, energy, and economic issues. Recognizing the significance, a study on the energy consumption habits of slum dwellers in Chittagong, Bangladesh, was conducted. A preliminary energy awareness feedback program was conducted with selected slum dwellers (N = 54), followed by a questionnaire and survey data analysis using two-way ANOVA (e.g., energy bill, income level, etc.).

In this case, a combined approach is preferable to others. The study's distinguishing feature is that households are classified according to their income level and housing structure. The primary goal of this study is to accurately reflect the effects of energy consumption patterns on various slum dwellers following the implementation of a peer feedback program through the use of factual statistical analysis.

This article is structured as follows, section 2 describes the literature review of the study; section 3 explains the research method; section 4 describes the results and discussions, and section 5 concludes the study.

## LITERATURE REVIEW

*Low-income residents*

Numerous studies have revealed that nearly 90% of households in the capital city of Dhaka's municipal poor areas have access to electricity. However, the electricity infrastructure in slum areas is woefully inadequate in terms of affordability, accessibility, and reliability (Rashid 2009; Kabir *et al.,* 2017; Karim *et al.,* 2017). While low-income households in slum areas are covered by insufficient energy access, it is frequently used illegally at a very high cost. Additionally, the studies revealed that residents of slums are unaware of energy conservation or savings programs, and there is no energy review or active inspection by any agency or group (Rashid 2009; Karim *et al.,* 2017). Additionally, several empirical studies (Bhide and Monroy 2011; Kowsari and Zerriffi 2011; Bisu *et al.,* 2016) have demonstrated the impact of energy education on stacking methods, which contribute to an understanding of low-income residents' sociocultural energy demand practices. All these findings have emphasized the importance of energy conservation as a socio-technical method for promoting energy savings in areas such as cooling, heating, lighting, and cooking. Debnath and Bardhan's research revealed that low-quality slum treatment may have a detrimental effect on energy sustainability, dwellers' health, and inhabitants' well-being (Bardhan *et al.,* 2018; Debnath *et al.,* 2019). A similar study on the rehabilitation of slum housing in India indicates that a substandard built environment forces resident into

energy poverty by increasing their home energy bills (Debnath *et al.,* 2019). Tulsyan *et al.,* (2013) examined the effect of the Energy Conservation Building Code (ECBC) on the energy-saving options available to a large number of low-income households, demonstrating that the building envelope can save up to 15% of total energy consumption. Devi and Palaniappan (2014) proposed an existing energy assessment influence sequence for a case study dwelling in South India, in which they counted the dwelling's embodied, operational, demolition, and entire lifecycle energy consumption. According to Gillingham and Newell (Gillingham *et al.,* 2006), low-income residents are more likely than high-income residents to be harmed by economic difficulties when choosing energy-efficient deals, implying that subsidization approaches benefit low-income residents.

*Intervention policies*

It is demonstrated that resident behaviour plays a significant role in energy consumption, consistent with previous research on various intervention strategies for changing behavioural practices. As an effective behaviour measure, a few studies (Pisello and Asdrubali 2014; Azar and Al Ansari 2017) have presented a target direction for residential dwellers' intervention planning, which is associated with the design process of persuasive systems (Oinas-Kukkonen and Harjumaa 2009), which may contribute to the advancement of effective actions to change occupants' behaviour and improve sustainability. Additionally, other studies (Wyon *et al.,* 2006; Höök and Tang, 2013) observed specific social interventions that reduced energy consumption by up to 20% while implementing several energy behaviour transitions and action plans. In this context, deliberate social interventions are used to alter occupants' energy consumption behaviours. The method used in social interventions is largely determined by the users in question and the issues/problems that need to be addressed (Elsharkawy and Rutherford 2015). Energy-related social interventions are particularly beneficial when they are tailored to the occupants' interests and are cost-effective in terms of time, effort, money, or social dissatisfaction, and when occupants do not face severe behavioural limitations (Steg 2008). Additionally, interventions can reveal environmentally unfriendly behaviours/attitudes and explain why homeowners/inhabitants are resistant to implementing sustainable behaviour profiles. These findings all assist researchers in determining the most effective intervention method to use. Zvingilaite and Jacobsen (2015), for example, emphasized the benefits of consistent intervention, prolonged, disaggregated, and continuous feedback. Another study (Faruqui *et al.,* 2010) discovered that providing direct feedback via an In-Home Display (IHD) encourages residents to adopt more energy-efficient behaviours. However, a growing body of research has begun to examine several contextual factors (e.g., social, economic, and housing structure), particularly for low-income residents, which contributes to global studies on the advancement of energy-efficient behaviour and products and provides insight for policymakers in Bangladesh and other developing economies (Yang and Zhao 2015; Uddin 2018; Debnath *et al.,* 2019; Debnath *et al.,* 2020; Uddin *et al.,* 2021).

All studies (including a variety of factors and intervention approaches) have demonstrated that a variety of factors can have a significant impact on low-income residents' comfort and energy conservation behaviours. This complicates the evaluation of the effect of specific contextual factors (e.g., income, household structure) on slum dwellers who are reliant on existing research. This exhaustive study aims to dissect the unresolved effect of slum dwellers' contextual factors on their energy conservation behaviour.

# METHODOLOGY

This study is based on a mixed-method approach such as face-to-face interviews as well as paper-based survey data. The cluster method is implemented for the categorization of slum dwellers.

*Study location, housing types, and economic condition*

Chittagong, which covers an area of 2510 km2 and is 29 meters above mean sea level, has a population of 2.59 million and is a large port city on Bangladesh's south-eastern coast. May to October is the summer and rainy season, which is cloudy, warm, and wet. A slew of social and environmental issues have harmed Chittagong's port city as a result of the growth of slums, which are frequently criticized for their unplanned urbanization. The employment landscape in a slum is quite different and complex in this case.

The empirical data for this case study were gathered through a scheduled interview in three slum areas of Chittagong, Bangladesh. The study was conducted between May and June 2020, during the summer months. Occupants from 54 slums with varying income levels were surveyed (BDT 5000 - BDT 13000). Throughout the respondent's housing arrangements, Jhupri, Tong, Chai, Tin-Shed, and Semi-Pucca structures are used.

*Data sample and measurement*

Fifty-four (Total 70) valid slum dwellers from three different categories (e.g., housing type/monthly income) were enlisted for a two-way ANOVA test using the semi-structured interview-based survey approach. Additionally, three categories of housing type and income level were considered: housing type I (Juphri), housing type II (wooden/bamboo), and housing type III (brick wall/tin); and income groups 1 (BDT 5000-7000), income group 2 (BDT 7000-9000), and income group 3 (> BDT 9000). The authors do not wish to disclose the exact location of the slum for data security reasons. Typically, dwellers were given an information sheet outlining the study's purpose and objective. Meanwhile, consent was obtained from slum dwellers using a standard consent form. All residents were between the ages of 15 and 70. The data collection period has been extended from 1st May to 30th June 2020 to make it more convenient for residents.

The entire research process has been divided into several stages (Fig 1). To begin, slum dwellers were questioned about their current energy consumption practices (lighting and fan control) and any known energy-efficient behaviours. This data would be used to assist in determining which behaviours and actions to emphasize throughout the program. Second, an energy-saving awareness campaign (e.g., oral communication/leaflet) has been launched, followed by a survey to determine whether people are already conserving energy. Additionally, target residents are informed about actions and suggestions that are superior to or more important than the current approach. Typical actions and suggestions include the following: use natural light rather than electric light; turn off lights and ceiling fans when leaving the house; ensure that window or floor vents are not blocked by furniture or other obstructions that prevent natural air circulation; and so on.

Thirdly, collecting a monthly energy bill that serves as a baseline for subsequent evaluation and comparison. Typically, authors compare responses to questions about energy consumption behaviours before and after the campaign to determine the effectiveness of the campaign/intervention in modifying slum dwellers' values and

habits. In this case, data were analysed primarily using a two-way variance. Statistically significant findings were defined as those with a p0.05.

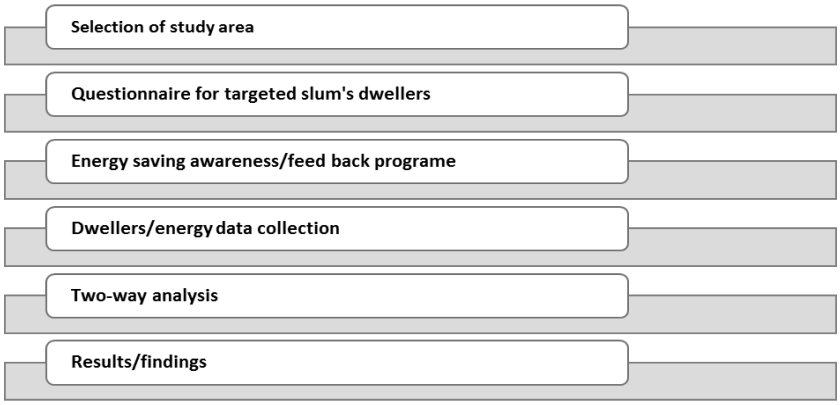


*Fig 1: Schematic representation of research approach*

## RESULTS AND DISCUSSION

*Descriptive statistics*

The detailed descriptive statistics are presented in Table 1. According to these statistics, energy consumption was slightly higher in Type II (Wooden/Bamboo) houses prior to the intervention/campaign, but significantly higher in Type III (Brick wall/Tin) houses following the intervention campaign. Additionally, Type I (Juphri) houses consumed the least energy both before and after the intervention. Following the intervention, energy consumption was significantly reduced (p = 0.014). (Table 2). However, there were no significant interactions between housing type or monthly income and energy consumption for these selected slum dwellers before and after the interventions (Table 2). Similarly, no significant differences in energy consumption were observed between three types of housing or three income groups (p>0.05) (Table 3).

*Table 1: Descriptive data*

| Housing | Income Group | Energy Consumption (Pre) Mean (SD) | Energy Consumption (Post) Mean (SD) |
|---|---|---|---|
| Type I | BDT 5000 – 7000 | 67.34 (12.28) | 63.08 (11.24) |
| Type II | BDT 7000 – 9000 | 67.34 (12.28) | 65.71 (14.04) |
| Type III | > BDT 9000 | 67.34 (12.28) | 65.92 (11.49) |
| All | | 67.34 (12.28) | 64.68 (12.29) |

*Table 2: Comparison of energy consumption before and after intervention*

| Variables | Type III Sum of Squares | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Energy consumption (Pre vs Post) | 79.249 | 1 | 79.249 | 6.513 | 0.014* |
| Energy consumption * Housing (Type I vs II vs III) | 42.903 | 2 | 21.451 | 1.763 | 0.183 |
| Energy consumption * Income (Low vs Moderate vs High) | 35.711 | 2 | 17.856 | 1.467 | 0.241 |
| Energy consumption * Housing * Income | 8.015 | 4 | 2.004 | 0.165 | 0.955 |

*Statistically significant at p<0.05

*Table 3: Comparison of energy consumption between three housing type or three income group*

| Variables | Type III Sum of Squares | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Housing (Type I vs II vs III) | 304.859 | 2 | 152.429 | 0.514 | 0.601 |
| Income (Low vs Moderate vs High) | 1193.309 | 2 | 596.655 | 2.012 | 0.146 |
| Housing * Income | 823.275 | 4 | 205.819 | 0.694 | 0.600 |

*Effect of intervention/campaign*

It is established that human behaviour plays a significant role in energy consumption, and previous research on various intervention strategies to change individuals' behaviours demonstrates beneficial approaches to sustainable development. To maximize the benefits of progress, an intervention should be conducted with a thorough understanding of the human behaviour that is to be changed or transformed, as well as the factors that influence this behaviour. Although this study demonstrated significant energy savings across all classes of dwellers (as illustrated in Fig 2) because of the campaign/intervention system implemented for slum dwellers in Chittagong, Bangladesh, much more needs to be understood about the success of intervention strategies for energy conservation behaviour.

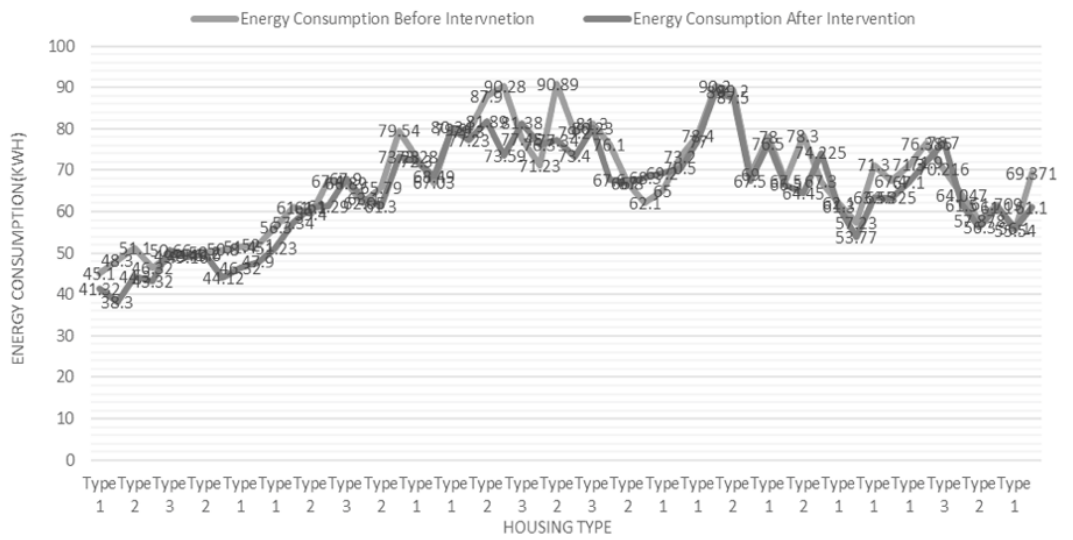


*Fig 2: Effect of overall energy consumption before and after the intervention/campaign (All types)*

*Drive innovation and boost research to deepen energy conservation behaviour*

This study approaches energy conservation from a unique perspective by emphasizing low-income residents' perspectives, in response to criticism of conservation factors that ignore residents' actual energy use (Patterson 1996). This is because it appears as though maintaining the quality of energy input to end users is critical to the overall energy efficiency of slums. For example, a low-quality energy input, such as insufficient cooling in an indoor space, will exacerbate the slum dweller's discomfort, resulting in increased control over his or her thermal environment. An example of this type of control is operating a personal fan, which not only assists in regaining occupant comfort but also results in additional energy consumption. This behaviour, induced by user manipulation of the built environment, is a classic example of a rebound effect that works against slum energy conservation, regardless of the

mechanical systems' high efficiency (Lee 2013). Additionally, technology alone will not achieve slum dwellers' energy conservation goals.

Occupants and their energy-related behaviour in houses should be commended for their efforts to improve energy performance. Despite numerous studies on the relationship between occupant behaviour and housing energy performance, our understanding of occupant behaviour and its role in overall energy performance remains complex, unclear, and contradictory. Along these lines, greater emphasis should be placed on incorporating residents' fundamental characteristics into the development of energy strategies. For example, to improve existing energy consumption, certain intervention systems, such as building layout and information programs for tenants or residents, must be considered. Additionally, the interventions examined include the dissemination of information, feedback, and incentives, all of which aim to alter individuals' knowledge and perceptions about energy conservation activities.

## CONCLUSIONS

By examining a variety of contextual factors, this study fills a research gap in the literature on housing types, economic conditions, and slum dweller behaviour by recognizing their unmatched influence on energy-efficient behavioural trends. The study used a semi-structured interview-based survey and a two-way ANOVA test to elicit the most efficient energy consumption profiles following the implementation of an energy awareness program. The data were analysed and classified according to housing structure and economic status using a standard descriptive statistical analysis. Although the study found no significant effect ($p>0.05$) on the housing types and economic conditions of slum dwellers, it did discover a significant reduction in energy consumption following the intervention ($p = 0.014$). Additionally, the study discovered that slum dwellers' attitudes and social norms are significant drivers of changes in or reductions in energy consumption patterns following the intervention. In this context, attitude refers to a dweller's belief about a behaviour they are aware of and believe will benefit them in the long run, whereas social norm refers to the social desirability or acceptability of slum dwellers' behaviours.

However, because typical dweller behaviour and comfort are more complex factors than other available factors affecting the energy performance of low-income housing, they require more comprehensive data and technical expertise. If this complication and other complex issues relating to the configuration of indoor systems, structures, social, and economic issues are not adequately addressed, the performance of total energy consumption may suffer. Thus, this study contributes significantly to the global body of knowledge about the contextual factors affecting slum dwellers' energy consumption by elucidating the relationships between housing types and economic conditions. It may be more useful for quickly identifying barriers that require serious intervention to facilitate the adoption of sustainable housing technologies in developing countries.

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# MATERIAL SELECTION FOR SUSTAINABLE BUILDINGS

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The study provides an insightful view on the institutional infrastructure for regulating and guiding sustainable material selection practice, and different approaches for configuring them. It is noted that this should follow the accelerating demands of the real estate market, providing guidelines, measurement criteria, verification methods as well as investigating market potentials and third-party certification requirements. The study investigates two well-known green building rating systems (GBRSs) according to these defined scopes for the efficiency of materials and resources (MR); BREEAM and LEED. These provide a set of guidelines and measurement criteria. A mixed qualitative and quantitative approach was used to investigate and compare the percentage fulfilment for each scope in their latest version developments. In addition, interviews and designed questionnaires were carried to investigate practitioners' opinion about the use of both rating systems for MR in their sustainable projects. This contributes to a broader discussion about the comprehensiveness of available guidelines, reliability of measurement criteria, quality of verification tools as well as availability and price of certified materials and products. The result showed that new versions put more emphasis on verification of the environmental impact of sustainable materials but less is paid for certification and market potentials. This makes it challenging to comply with these criteria and require further consideration and balance from developers as well as more effort for practitioners to acquire related knowledge and practice about life cycle approach. This points out the importance of striking a balance between prescriptive and performance requirements for material selection and procurement in practice, noting that it is still research in process for a standard acceptable method that is both relevant to construction best practices and supported by scientific knowledge.

Keywords: BREEAM; green materials; LEED; sustainable material selection

## INTRODUCTION

Sustainable material selection and procurement are considered important pillars in the green building process. This study aims at investigating available guidelines, tools and methods in practices. This is conducted through a qualitative and quantitative approach using content analysis of sustainable criteria recommended by two well-known green building rating systems (GBRSs); BREEAM and LEED, as well as surveying local practitioners. The result showed that practitioners used guidelines obtained from GBRSs to provide a set of prescriptive requirements for material selection. Yet, this operates in quite a simplistic and abstract manner if not considered early in design decisions and complemented with a more robust approach for

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environmental assessment. This explains the evolution of these systems to raise the bar for minimum requirements of building codes and standards and follow the accelerating demands of the real estate market. Challenges may be associated with determining proper guidelines for sustainable material selection and procurement, setting proper benchmarks and measurement criteria, means of verifying performance as well as investigating the market readiness and potentials for green certification requirements (Ismaeel, 2019b). This constitutes the four scopes as shown in Fig 1, which were investigated by a previous study by (Ismaeel, 2019b) as shown in Fig 2.

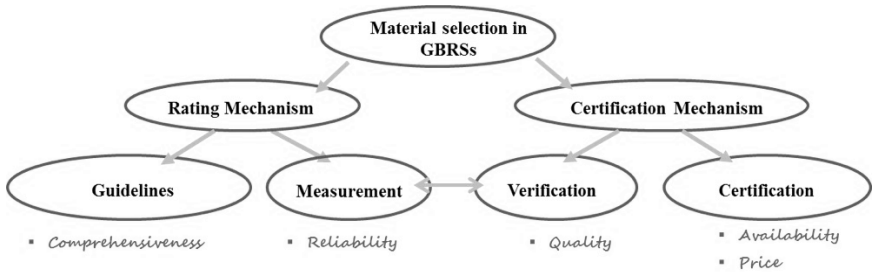



*Fig 1: Sustainable material selection using GBRSs, author's elaboration after (Ismaeel, 2019b)*

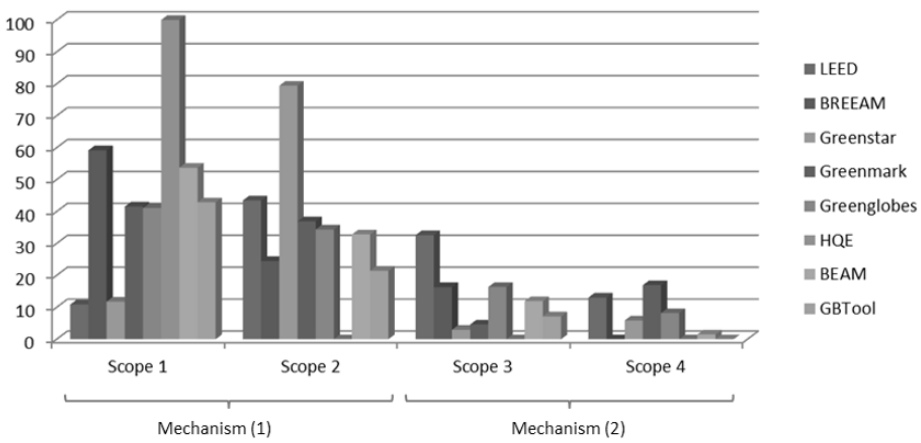



*Fig 2: The status of 8 GBRSs according to the four defined scopes (Ismaeel, 2019b)*

## GBRS And Material Selection

GBRSs assess the projects' environmental performance according to defined parameters and present certified third-party statements (Ismaeel, 2019a). Some GBRSs include prescriptive guidelines while others provide a performance-based approach using Life Cycle Assessment (LCA) for the sustainability of materials and resources (MR)- this includes all inputs and outputs for a material/product. The former is easier for practitioners to use, based on physical material properties (area, weight and volume) while the latter provides accountable results for their environmental impacts along the project's life cycle (Ismaeel and Ali, 2020).

On one hand, Building Research Establishment Environmental Assessment Method BREEAM (BREEAM) is a leading GBRS, developed in the United Kingdom and applied worldwide. Its two latest version developments cover MR under two categories; Materials and Waste (Breeam.com). It was the first to require LCA and Environmental Product Declarations (EPDs) to compare materials' profiles (Ismaeel, 2018). On the other hand, the Leadership in Energy and Environmental Design-Materials and Resources category (LEED MR) is another international GBRS. It

discusses several issues that support material selection and minimizing waste during building construction and operation. In earlier versions, it presented a set of prescriptive guidelines for material selection but the latest development incorporated LCA with more emphasis on disclosure and optimization (USGBC.org).

**Sustainable Materials**

*Guidelines*

Several attempts were carried to support sustainable material selection e.g., index-based methods, multi-objective optimization, cost-benefit analysis and ranking methods (Sirisalee *et al.,* 2004; Giudice, La Rosa and Risitano, 2005; Castro-Lacouture *et al.,* 2009). Also, some guidelines are found in different GBRSs which can create synergies with other sustainable criteria, these include:

- Designing for robustness, disassembly and adaptability as well as paying due consideration for material durability and resilience. It also includes designing for speculative floor and ceiling finishes and material efficiency.
- Promoting onsite and offsite recycling activities. It is noted that the former is more sustainable. Dedicating a recycling area in the building should be planned in advance to reduce landfill, primary materials cost, energy use and maintenance saving. The latter should associate the source and recycling location. It should also consider the mass of the recycled object- the energy used for recycling- distance for recycling location, in addition to transportation (energy used for transportation and waste emitted). Nevertheless, both types count on the proximity to recycler hauliers and working with local jurisdictions as incentives.
- Promoting the use of local/ regional materials reduces the impact of transportation and promotes local products. This includes proximity to extraction, harvesting and manufacturing locations e.g., LEED specifies 500 miles of the project site.
- Promoting the use of rapidly renewable materials (e.g. cork, bamboo, natural rubber, wheat, and cotton) look at raw materials favouring plants with a short harvesting cycle. LEED specifies 10-year or shorter.
- Promoting the use of reused materials (include salvaged, refurbished, or reused materials) reduces the demand for virgin materials and reduces waste. This minimizes the impact resulting from extraction and processing stages. Examples include reusing structural beams, flooring, doors, cabinetry, brick…etc.
- Promoting the use of recycled content materials reduces the demand for raw materials and resources e.g., masonry, concrete, metals, gypsum wallboard, tile, carpet and insulation. This includes pre consumer content (manufacturing waste) and post consumer content (consumer waste)- considering greater environmental benefit for the latter. It is noted that the National Institute of Standards and Technology argues LEED guidelines which account for the cost of materials (Scheuer and Keoleian, 2002).
- Promoting the use of low emitting materials minimizes health associated problems arising from indoor building materials and products. LEED specifies limits of volatile organic compounds and urea-formaldehyde for composite wood and agrifiber products. Nevertheless, these should be benchmarked against third party certification for a broader list of manufacturing standards' emission requirements e.g., American National Standards Institute.

- For construction waste, mixed waste is separated and recycled in waste management facilities. Then, reports and declarations for the list and percentage of recycled content are generated. Special concern is also paid for dealing with hazardous materials onsite according to local regulations.

Many practitioners were able to comply with these direct guidelines in terms of material selection and calculations. Also, manufacturers and contractors were able to provide declarations stating that materials comply with the requirements, reporting quantities, cost, harvesting and manufacturing distances, recycled contents as well as recycling hauliers. This witnesses market change for more availability with competitive rates. Nevertheless, this depends on project location and feasibility. It also lacks scientific proof about their environmental impacts.

*Measurement*

Previous literature investigated the following measurement criteria for sustainable materials (Castro-Lacouture *et al.,* 2009; Ismaeel, 2018, 2019b):

- Area accounts for the space dedicated for recycling activities compared to the total building area. It is also used to account for building reuse areas, floor, facades and internal divisions.
- Weight (or mass) is used to measure diverted construction waste from landfill.
- Volume is also used to measure diverted construction waste from landfill.
- Material cost is used to measure the percentage of reused, recycled content, renewable and local materials in the project.
- Emission level is used to determine the maximum emission limits of materials according to international standards.
- Environmental impact is used to determine and compare low impact materials for material selection. Also, for solid waste planners, the Waste Reduction Model developed by the Environmental Protection Agency may assist in tracking and reporting the effect of using different waste management practices to reduce greenhouse gas emissions.

*Verification*

Verification tools and methods vary according to the aim and scope of sustainable criteria. These may be used for external communication, decision-making and internal development (Ismaeel, 2019c; Morsi, Ismaeel and El-Hamed, 2020). The list may include the following:

- Applying LCA to support decisions related to material selection, building reuse as well as construction and demolition waste management plans. This accounts not only for the physical properties of materials (e.g., weight, area or volume) but above all their environmental impact (Ismaeel and Ali, 2020). Nevertheless, material inventory databases should be checked for information consistency.
- Investigating synergies and trade-off relations with energy efficiency when choosing materials.
- Investigating the direct effect of building materials on Indoor Air Quality (IAQ) and buildings' environmental impact. There are several health-associated problems including short term and long-term effects. This can be investigated through a post occupancy evaluation and continuous monitoring and follow-up measures.

- Verification and management procedures include setting management plans by including inventories to reduce harmful environmental impact as well as follow up process to confirm regular maintenance and inspection practices.

*Certification*

Material quantity and quality require further investigation for market availability and prices of green-certified materials (Ismaeel, 2019b). Certification schemes may address the following.

- Investigating market potentials for the availability and prices of reused, recycled, renewable and local materials as well as their functional requirements.
- Accordance with third party certification for sustainable management of resources e.g., Forest Stewardship Council's, Sustainable Forestry Initiative and the American Tree Farm System.
- Providing meaningful and consistent information about the environmental impact of a product using ISO 14020 (2000) e.g., EPD. This is required by BRE 'Environmental Profile' and LEED V4.0.

# METHOD

The study adopted a mixed qualitative/quantitative approach to discuss the problem in previous literature and track its implication in practice. Guidelines for material selection were obtained from two well-known GBRSs; BREEAM and LEED. The two systems were compared in terms of structure and measurement criteria as well as the weighting assigned for MR category in each (Ismaeel, 2018, 2019b). The two recent versions for both LEED 'Materials and resources' and BREEAM 'Materials' and 'Waste categories' were analysed. This includes one category from LEED and two from BREEAM, but the results were normalized as a percentage of the overall score rate for each rating system. The research method followed the following steps:

1- Tracing MR in BREEAM and LEED: content analysis and deducting information about the fulfilment of each scope as shown in Table 1.

2- Comparing the percentage fulfilment for each scope in the latest version developments of BREEAM and LEED: quantitative comparative analysis

3- Conducting structured interviews and designed questionnaires for practitioners in selected projects of BREEAM and LEED certification in The United Arab Emirates (UAE). This includes Al Zahia Residential Development and Lulu -Regional Office in Dubai, Kempinski Mall of Emirates and INSEAD Middle East Campus. This step investigates practitioners' opinions about the benefits and challenges of using both rating systems for material selection in their sustainable projects.

*Table 1: Tracing MR in BREEAM and LEED*

| Guidelines | Measurement | Verification | Certification |
|---|---|---|---|
| Prescriptive recommendations for material selection along the project life cycle<br>During design: promoting the use of recycled, reused and natural materials.<br>During construction: performing construction waste management plan<br>During building operation: promoting onsite recycling activities. | Following quantitative measurement criteria using calculations based on building's area, weight or volume of waste and salvaged building materials as well as material cost. | Using LCA and setting emission reduction levels. | Recommending the second and third level certified building materials and products, as well as discussing the availability and price of green materials and products. |

The study used guidelines from BREEAM and LEED rating systems referring to a previous study by (Ismaeel, 2019b). This provides a breakdown analysis for their role in the building process, providing; guidelines, measurement methods, verification criteria as well as certification and market-related value- as shown in Table 2.

*Table 2: Comparing the four scopes for the recent versions of BREEAM and LEED*

| BREEAM 2016 | Total | Guide lines | Measur ement | Verification | Certification |
|---|---|---|---|---|---|
| Materials | | | | | |
| Life cycle impacts | 7 | | | 7 | |
| Responsible sourcing of materials | 3 | | | 3 | |
| Designing for robustness | 1 | 1 | | | |
| Waste | | | | | |
| Construction waste management | 4 | | 4 | | |
| Recycled aggregates | 1 | 1 | | | |
| Operational waste | 1 | 1 | | | |
| Speculative floor and ceiling finishes | 1 | 1 | | | |
| Total | 18 | 4 | 4 | 10 | 0 |
| | | 22 | 22 | 56 | 0 |
| BREEAM 2018 | | | | | |
| Materials | | | | | |
| Environmental impacts from construction products - Building life cycle assessment (LCA) | 7 | | | 7 | |
| Environmental impacts from construction products - EPD | 1 | | | | 1 |
| Responsible sourcing of construction products | 4 | | | 4 | |
| Designing for durability and resilience | 1 | 1 | | | |
| Material efficiency | 1 | 1 | | | |
| Waste | | | | | |
| Construction waste management | 5 | | 5 | | |
| Use of recycled and sustainably sourced aggregates | 1 | 1 | | | |
| Operational waste | 1 | 1 | | | |
| Speculative finishes (Offices only) | 1 | 1 | | | |
| Adaptation to climate change | 1 | | | 1 | |
| Design for disassembly and adaptability | 2 | 2 | | | |
| Total | 25 | 7 | 5 | 12 | 1 |
| | | 28 | 20 | 48 | 4 |
| LEED V3.0 | | | | | |
| Materials and Resources | | | | | |
| Storage and Collection of Recyclables | - | * | | | |
| Building Reuse—Maintain Existing Walls, Floors and Roof | 3 | 3 | | | |
| Building Reuse—Maintain Existing Interior Non-structural Elements | 1 | 1 | | | |
| Construction Waste Management | 2 | | 2 | | |
| Materials Reuse | 2 | 2 | | | |
| Recycled Content | 2 | 2 | | | |
| Regional Materials | 2 | 2 | | | |
| Rapidly Renewable Materials | 1 | 1 | | | |
| Certified Wood | 1 | | | | 1 |
| Total | 14 | 11 | 2 | 0 | 1 |
| | | 79 | 14 | 0 | 7 |

| | | | | | |
|---|---|---|---|---|---|
| LEED V4.0 | | | | | |
| Materials and Resources | | | | | |
| Storage and Collection of Recyclables | - | * | | | |
| Construction and Demolition Waste Management Planning | - | * | | | |
| Building Life-Cycle Impact Reduction | 5 | | | 5 | |
| Building Product Disclosure and Optimization - Environmental Product Declarations | 2 | | | | 2 |
| Building Product Disclosure and Optimization - Sourcing of Raw Materials | 2 | | | 2 | |
| Building Product Disclosure and Optimization - Material Ingredients | 2 | | | 2 | |
| Construction and Demolition Waste Management | 2 | | 2 | | |
| Total | 13 | 0 | 2 | 9 | 2 |
| | | 0 | 15 | 69 | 15 |

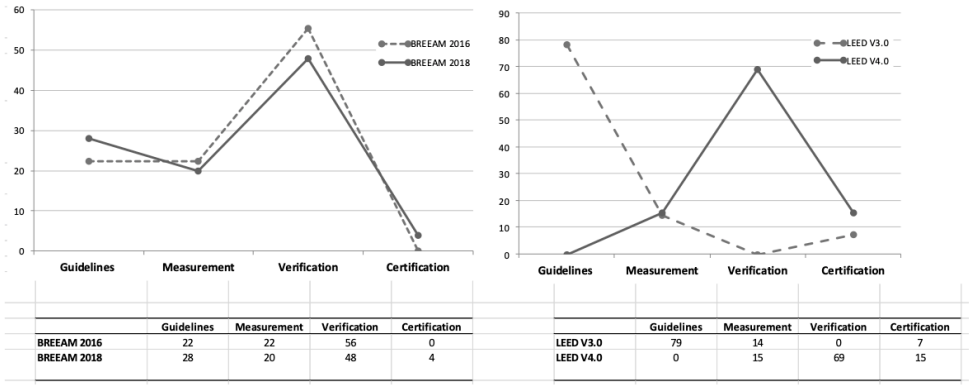
The development of BREEAM and LEED shows different approaches for sustainable MR; more consistent for the former and witnessing a huge change in the latter. This includes prescriptive guidelines; a) design guideline e.g., dedicating onsite area for storage and collection of recyclables and building reuse, b) construction practices e.g., waste management plan and c) specifications for materials e.g., reused, recycled, regional and renewable. Measurement criteria for MR credits are continuously changing according to guidelines. Nevertheless, these are always related to practitioners' best practices and require time and money. Verification methods are paid more concern-particularly for materials' environmental impact. It is also noted that credits' requirements are associated with materials' availability and price for BREEAM 2016, 2018 and LEED V3.0 as well as materials' data disclosure for BREEAM 2018 and LEED V4.0. Also, the two version developments mandated conducting a CWM plan and a whole building LCA.

Then an online web-based questionnaire for a sample of 54 participants in UAE and structured interviews with other 32, investigated practical experience for applying MR criteria according to the predefined scopes. These were carried from Jan-March 2021 through the following link http://www.esurveyspro.com/Survey.aspx?id=bdab1d67-cbc2-40ac-817e-0f39672266bc. The survey received 32% responses from different participants' specialisations: engineering and construction, management and consultancy, research and development as well as designing and planning. It included 26 questions (3 open ended as well as single and multiple choices). This started with general questions for the benefit of using the two rating systems for material selection in the international and local context. Each participant indicated which system he/she had applied in their project and their opinion about their latest version developments to address sustainable issues. Then they answered specific questions concerning the requirements of each MR related credit in light of the four defined scopes.

## RESULT

The result shown in Fig 3 indicates that with the development of new versions of BREEAM and LEED, more emphasis is put on verification of the environmental impact of sustainable materials but less is paid for certification and market potentials. This makes it challenging to comply with these criteria and require further consideration and balance from developers of these GBRSs as well as more effort for practitioners to acquire related knowledge and practice. This was expressed during the survey to be the result of insufficient knowledge about applying LCA and the timely and complex procedure it requires. Also, practitioners indicated specific challenges for each defined

scope. This includes the risk of misinterpretation of the system's guidelines and following a point chasing approach, inaccurate measurements and unreliable information. They also indicated that risk factor should be considered for every verification method. This is in addition to incomplete documentation relating to the green features of a product. Furthermore, failure to meet sustainable standards or expectations may compromise other sustainable aspects e.g., IAQ. Last but not least, they highlighted the uncertainty due to the use of new and untested materials or from traditional products being used in new and untested ways.




| | Guidelines | Measurement | Verification | Certification |
|---|---|---|---|---|
| BREEAM 2016 | 22 | 22 | 56 | 0 |
| BREEAM 2018 | 28 | 20 | 48 | 4 |

| | Guidelines | Measurement | Verification | Certification |
|---|---|---|---|---|
| LEED V3.0 | 79 | 14 | 0 | 7 |
| LEED V4.0 | 0 | 15 | 69 | 15 |

*Fig 3: Comparing the four scopes for the two latest developments of BREEAM and LEED*

## DISCUSSION

This study provides know-how for practitioners for proper material selection. This 4-tier framework can be used by practitioners at early stages to categorize and classify MR related criteria and understand their contribution to the sustainable project. Also, it enables comparing different GBRSs based on common ground and accordingly, resolves most of the associated conflict in the academic area. Similarly, it enables comparing buildings based on the four scopes which provide a better understanding of their environmental performance. Point gaining can be planned and managed according to the proposed framework as well. This shall facilitate the proper management of certified projects. It can also be associated with other project management research to facilitate allocation of time, money and resources and investigate which aspects require more investment, be it; guidelines for using green materials, carrying field measurements, verification using standard methods, or obtaining materials with the required green material specifications.

For the purpose of this study, only BREEAM and LEED were discussed, being the most widely used GBRSs but this study can be replicated for other rating systems as well. The study was limited to materials and resources for new construction excluding residential buildings. Hence, some credits were excluded which do not fall under this scope. Furthermore, a similar context (UAE) was selected to be able to compare the effect of using the latest versions of the two rating systems and how this affected practitioners' experience. This normalized all variations associated with material availability and cost in the local market.

## CONCLUSION

The study presents an insightful study on the institutional infrastructure for regulating and guiding sustainable material selection practice, and different approaches for configuring them in light of using two well-known GBRSs e.g., BREEAM and LEED. This compares them in terms of how they address the sustainability of materials and

resources using qualitative and quantitative approaches. The research notes that MR should follow the accelerating demands of the real estate market-defined in four scopes. This includes 1) providing guidelines, 2) measurement criteria, 3) verification methods as well as 4) investigating market potentials and third-party certification requirements. Hence, the research investigates and compares the percentage fulfilment for each scope in their latest version developments therein. These may vary according to the type of guidelines and the significant importance they put for sustainable criteria, nevertheless, they all put MR as a major concern for any sustainable project. Some criteria may provide prescriptive requirements in the form of guidelines along the project life cycle. Other criteria describe measurement methods which are important to define why, what, when and how to measure along the building process. Using standard agreed-upon verification methods such as LCA indicates the environmental impact of materials and products. It also discusses third party certification systems, and how international initiatives for green material certification can play a major role in streamlining the green building certification process in sum. It is also important to mention the need for a continuous update about market potentials and best practices.

The survey indicated associated problems in practice, e.g., the comprehensiveness of available guidelines, reliability of measurement criteria, quality of verification tools as well as availability and price of certified materials and products. Furthermore, tracing point-weighting allocation showed that new versions put more emphasis on verification of the environmental impact of sustainable materials but less is paid for certification and market potentials. This makes it challenging to comply with these criteria and require further consideration and balance from developers of these GBRSs as well as more effort for practitioners to acquire related knowledge and practice about the life cycle approach. Hence, the study points out the importance of striking a balance between prescriptive and performance requirements for material selection and procurement in practice. It is still research in process for a standard acceptable method that is both relevant to construction best practices and supported by scientific knowledge. This also contributes to a broader discussion about the comparability of GBRSs and green-certified projects.

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# A DILEMMA BETWEEN BUILDING INDOOR ENVIRONMENT PREFERENCES AND OCCUPANT ENERGY BEHAVIOURS

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Often, building occupants compromise the energy savings of the building when they modulate their comfort through occupant behaviours. Therefore, this study identifies the relationships among indoor environmental conditions, comfort preferences, and occupant behaviours to improve future energy modelling works on occupant behaviour in buildings. A self-administered online questionnaire survey was conducted using a purposive sample of 46 occupants selected from five educational office buildings. Results show that the occupants' satisfaction with indoor environmental quality (IEQ), user-centred building controls, and furniture arrangements across the three office types: private, shared, and open-plan office has a similar value except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. The results also show the relationships of 17 occupant behaviours with 15 comfort preferences, where that highlights that the occupants were highly concerned about satisfying individual indoor air quality (IAQ) and thermal comforts through their behaviours rather than to save energy and follow management guidelines. Furthermore, IAQ and control over thermal and IAQ related parameters such as heating, cooling, and ventilation are highly correlated with the occupant behaviours, and these could be considered as primary predictors of occupant energy behaviours. These relationships of IEQ and user-centred building controls with occupant behaviours could be utilized to enhance future occupant energy behaviour modelling approaches and pinpoint the energy wasteful behaviours.

Keywords: controls; comfort; energy; indoor environment; occupant behaviours

## INTRODUCTION

With the rapid urbanisation and industrialisation, most people spend 90% or more of their time indoors and in confined spaces including time spending on living, learning, working, and travelling (Abdulaali *et al.,* 2020). Therefore, indoor environments have widespread effects on building occupants' health, well-being, satisfaction, and performance (Wong, Mui and Tsang 2018). In recent years, many studies have investigated the Indoor Environmental Quality (IEQ) of buildings in terms of occupant satisfaction in comfort and productivity (Rasheed Rasheed, Khoshbakht and Baird 2019). Key factors of IEQ are derived through those studies and include

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thermal comfort, indoor air quality (IAQ), visual comfort, acoustic quality, and spatial comfort (Bluyssen 2019).

Usually, unconscious and conscious actions of humans to control the physical parameters of the surrounding built environment to their preferences are possible when they are in discomfort and trying to create a comfortable indoor environment (Nicol and Humphreys 2002). As Schweiker (2010) defined, these unconscious and conscious actions refer to occupant energy behaviour, where the occupants are trying to achieve the desired personal comfort level using various strategies. Building occupants influence the indoor environment through their presence and by modifying the building's systems and elements (Bluyssen 2019) such as opening and closing windows, adjusting blinds, adjusting thermostat temperature, and turning the air conditioning on or off (Hong *et al.,* 2017). The research by Fabi *et al.,* (2012) and Hong *et al.,* (2017) showed that occupant behaviours (OB) highly influence the increase of building energy demand. The contribution of OB is extremely significant as the difference between predicted and actual energy use is mainly due to the way that occupants behave, their presence, and occupancy levels in buildings (Gaetani, Hoes and Hensen 2016). The reliability of simulation results depends on the quality of assessment of occupants' influence on buildings (Royapoor and Roskilly 2015). Therefore, the occupants should not compromise the energy savings of the building when they modulate their comfort.

Driven by these it is believed that the design and control of indoor environmental conditions, occupant comfort preferences, and occupant energy behaviours are inter-connected to each other. A proper balance between those aspects is significant to reduce the energy wastage due to occupants while realising energy saving potentials of occupants. However, the focus on empirical studies is still limiting to IEQ parameters such as thermal, IAQ, visual, and acoustics and their influence on occupant energy behaviours. For example, a study by Amasyali and El-Gohary (2016) in their study highlighted the association between OB and the level of satisfaction of the building occupants. Another study by Bavaresco *et al.,* (2021) has connected the main sources of discomforts into windows, blinds/shades, thermostats, and lighting in office settings. Their study only addressed triggers such as temperature, air, light, view, noise, and access to the thermostat as driving factors of OB.

However, review studies often suggest other indoor environmental factors such as furnishings, the spatial layout of workspaces, and the access for controlling heating, cooling, lighting, etc. as important (Fabi *et al.,* 2012; Weerasinghe, Rasheed and Rotimi 2020). For example, shared work areas and open-plan workstations also show a greater impact on occupants due to the unwanted noise, disturbances, lack of storage space, privacy, and no control over the indoor environmental conditions (McElroy and Morrow 2010; Mesthrige and Chiang 2019). Onyeizu (2014) identified that occupants who have control over the temperature were highly satisfied with the thermal comfort of the space. To this end, OB and comfort preferences in different types of offices may further be expanded integrating indoor environmental conditions: thermal, IAQ, visual, acoustics, spatial comforts, and user-centred designs such as access to control indoor environmental parameters.

In the context of New Zealand, the studies conducted on office environments pointed out that the occupants prefer air-conditioned spaces over naturally ventilated spaces to fulfil their thermal comfort preferences (Rasheed *et al.,* 2017) and acoustic

improvements in office design to reach their perceived comfort level. However, the relationship among indoor environmental conditions, comfort preferences, and OB are merely addressed in the context of New Zealand. Driven by this motive, this study explores the existing indoor environmental conditions including IEQ, user-centred designs and furniture arrangements, and the occupants' satisfaction with these conditions. The paper also explores the prominent occupant energy behaviours and the occupant comfort preferences of office buildings in New Zealand. More importantly, the study compares the occupant's satisfaction with the indoor environment across different types of workplace arrangements such as private room, shared room, open-plan office, and the relationship of OB with indoor environmental conditions.

## METHODS

Oftentimes, quantitative methods such as surveys and questionnaires have been used to understand occupants and their energy-related behaviours and construct building energy models (Day and O'brien 2017). Moreover, Hong *et al.,* (2017) showed survey method can provide more insights into OB compared to experiments and field observations in terms of various factors that drive behaviours. In the current study, a survey method was used to explore the occupant's satisfaction with indoor environmental conditions, prominent occupant energy behaviours, and occupant preferences across different working arrangements. An online questionnaire was designed and administered through Qualtrics Survey software. This is a popular data collection platform used in contemporary research studies. The questionnaire has consisted of four sections. Sections 1 included occupants' background information such as the job role, gender, occupancy period of the current workspace, and the characteristics of the workspace. In section 2, participants were asked to mention the office type that workstations are arranged in the building. Section 3 has consisted of questions related to occupants' satisfaction and they were asked to rate the satisfaction in terms of thermal comfort and ventilation in summer and winter, visual comfort and acoustic comfort, user-centred designs, and furniture arrangement. Section 4 focused on OB and comfort preferences. All measures related to satisfaction were estimated by a Likert-type item of 1-7 (completely dissatisfied, mostly dissatisfied, somewhat dissatisfied, neither satisfied nor dissatisfied, somewhat satisfied, mostly satisfied, completely satisfied). The participants for the survey were conveniently recruited from the university staff and PhD students regularly occupying office spaces from five buildings in a University in New Zealand. Emails were sent to potential respondents of 257 inviting them to complete the survey. A total of 46 valid responses from building occupants in office spaces were collected. Likert-type items have a clear rank order without an even distribution, therefore, the data generated from these types of questions are considered ordinal data which has a non-normal distribution of data (Guerra, Gidel and Vezzetti 2016). Therefore, frequency analysis and Spearman rank correlation were used to analyse the data. The Statistical Package for Social Sciences (SPSS) version 27 was used to conduct these analyses.

Cronbach's alpha reliability analysis was conducted to test the internal consistency of the instrument that shows how well the survey measures what the study wants to measure. In the current study, it was applied to questions relating to satisfaction on indoor environment conditions such as IEQ, user-centred designs, and furniture arrangements. Reviewing empirical studies, Taber (2018) explained that alpha reaching 0.70 value is a sufficient measure of internal consistency. The overall

Cronbach's alpha value for the current occupant survey is 0.716 which shows an acceptable level of reliability for 13 constructs of this study.

## RESULTS AND DISCUSSION

Five buildings in a university were selected for the current study that available office spaces for the staff and PhD students who are regularly occupying the buildings. The number of occupants in the buildings ranged between 12 to 96 were mostly occupied by staff. Demographic information of participants is presented in Table 1. There were more males than females in the selected sample. Most participants had worked in their present work area for a year or more than a year. Furthermore, most participants were in shared offices that accommodated two to five people, and both staff and students occupy the three types of office spaces; private room, shared, and open plan. The current study compares the difference of occupant's satisfaction level and practice of OB across diverse types of workplace arrangements such as private room, shared room, open-plan office.

*Table 1: Demographic Information of Participants*

| Demographic Info | | Staff | Students | Total |
|---|---|---|---|---|
| Gender | Male | 12 | 13 | 25 |
| | Female | 16 | 5 | 21 |
| Years in Present Work Area | Less than a year | 11 | 10 | 21 |
| | A year or more | 17 | 8 | 25 |
| Office Type | Private Room | 13 | 5 | 18 |
| | Shared Space | 12 | 8 | 20 |
| | Open-plan Office | 3 | 5 | 8 |
| Location of Workstation | Close to a window within 5 feet | 23 | 11 | 34 |
| | Centre of the office | 2 | 2 | 4 |
| | Close to an exterior wall within 5 feet | 3 | 5 | 8 |

### Occupants' Satisfaction with IEQ across Private, Shared, and Open-plan Offices

Discomforts in indoor environmental quality and access to user control can be considered as drivers of OB. Therefore, building occupants were asked to rate their satisfaction on thermal comfort and ventilation in summer and winter, visual comfort and acoustic comfort, user control availability on heating, cooling, ventilation, lighting, and noise, and arrangement of workstation furniture and equipment (i.e. desk, chair, footrest, telephone, document holder and printer, etc.). The percentage of frequency values of the occupant satisfaction with IEQ, user-centred building controls, and furniture arrangement is shown in Fig 1.

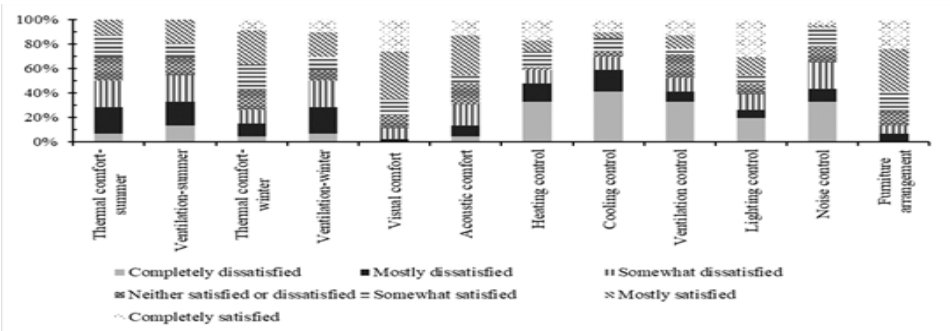


*Fig 1: Occupants' Satisfaction with Indoor Environment*

Overall, 50% or more than 50% of the building occupants rated their satisfaction on thermal comfort in winter, visual comfort, acoustic comfort, user control in lighting,

and furniture arrangement as "somewhat satisfied" or higher. Going further, it is also important to discuss the satisfaction with IEQ comfort, user control, and workstation furniture and equipment across different office types.

Occupants' satisfaction must be comprehensively understood to improve IEQ, user-centred designs, and arrangement of workstation furniture and equipment across all types of office spaces. Literature identified that occupants' satisfaction can be vary due to the concerns over sharing of building systems and controls. The median values of the satisfaction rating given by the building occupants across different office types: private, shared, and open-plan office are presented in Table 2.

*Table 2: Occupants' Satisfaction Across Different Office Types*

| Indoor Environmental Condition | Median Value of Satisfaction | | | Indoor Environmental Condition | Median Value of Satisfaction | | |
|---|---|---|---|---|---|---|---|
| | Private | Shared | Open plan | | Private | Shared | Open plan |
| Visual comfort | 6 | 6 | 6 | Ventilation-winter | 5 | 3 | 3 |
| Furniture arrangement | 6 | 6 | 6 | Ventilation-summer | 4 | 3.5 | 3 |
| Thermal comfort-winter | 5 | 4.5 | 6 | Heating control | 4 | 2.5 | 2 |
| Acoustic comfort | 5 | 4 | 6 | Ventilation control | 4 | 3.5 | 1 |
| Lighting control | 4 | 6 | 4 | Noise control | 3 | 2.5 | 3 |
| Thermal comfort-summer | 3 | 3.5 | 5 | Cooling control | 2 | 1.5 | 2 |

As seen from Table 2, visual comfort and furniture arrangement were rated as the highest satisfaction across three office types. There was a similarity in the satisfaction rating by the occupant across private, shared, and open-plan offices in terms of visual comfort and furniture arrangement. Additionally, the building occupants in open-plan offices were highly satisfied with thermal comfort in winter and acoustic comfort, while the occupants in shared offices have rated higher satisfaction in access to lighting control. Furthermore, the same parameters in the other office types were received a somewhat satisfactory or neutral opinion from the occupants. However, this is contrary to the previous studies that support the occupants in shared work areas and open-plan offices are less satisfied due to unwanted noises and no control over the indoor environmental conditions (McElroy and Morrow 2010; Mesthrige and Chiang 2019). Thermal comfort in summer and ventilation in winter were rated as somewhat satisfactory in open-plan offices and private rooms, respectively, but the same received somewhat dissatisfactions across other office types. However, other parameters: ventilation in summer and user control in heating, ventilation noise, and cooling were rated as dissatisfied or neutral across all three types of offices.

Overall, these results indicate that occupants across the three office types: private, shared, and open-plan office have a similar value of satisfaction except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. Since occupants' satisfaction across different office types is mostly similar, overall occupants' satisfaction with IEQ, user-centred controls, and workstation furniture and equipment can be considered as triggers or drivers of OB and comfort preferences, irrespective of office type. The next section analysed these OB and comfort preferences in the office environment.

## Occupant Behaviours and Comfort Preferences

Referring to previous studies Bavaresco *et al.,* (2021), Hong *et al.,* (2017) and Weerasinghe, *et al.,* (2020), 15 OB and 15 comfort preferences were given as a multiple-choice question in the questionnaire. The building occupants were asked to select the OB they practice while working and the expected changes from these behaviours. These OB and comfort preferences are summarised in Table 3 with the frequency (%) distribution and the ranks were assigned in descending order.

*Table 3: Occupant Behaviours and Comfort Preferences*

| Occupant behaviour | Frequency (%) | Rank | Comfort Preferences | Frequency (%) | Rank |
|---|---|---|---|---|---|
| Open/close windows | 78.3 | 1 | To let in fresh air | 76.1 | 1 |
| Drink hot/cold beverages | 73.9 | 2 | To feel cooler | 71.7 | 2 |
| Adjust clothing | 65.2 | 3 | To feel warmer | 71.7 | 3 |
| Open/close internal doors | 63.0 | 4 | To increase air movement | 67.4 | 4 |
| Turn lights on/off | 58.7 | 5 | To air freshness | 60.9 | 5 |
| Adjust shades and blinds | 56.5 | 6 | To avoid outdoor sounds | 43.5 | 6 |
| Adjust computer screen brightness | 54.3 | 7 | To feel healthier | 30.4 | 7 |
| Adjust personal heaters | 50.0 | 8 | To avoid glare | 28.3 | 8 |
| Turn off the computer monitor | 47.8 | 9 | To have access to outside view | 26.1 | 9 |
| Open/close external doors | 43.5 | 10 | To save energy | 23.9 | 10 |
| Moving through spaces | 34.8 | 11 | To increase artificial lighting | 17.4 | 11 |
| Report discomfort | 32.6 | 12 | To increase daylighting | 17.4 | 12 |
| Adjust portable/ceiling fans | 28.3 | 13 | To experience the variety of the outdoor climate | 10.9 | 13 |
| Adjust room air conditioning unit | 17.4 | 14 | To hear outdoor sounds | 6.5 | 14 |
| Adjust thermostats | 10.9 | 15 | To follow management guidelines | 4.3 | 15 |

As seen from Table 3, opening/closing windows and drinking hot/cold beverages were ranked the highest (more than 70%) among the other OB. Further, adjusting clothing, opening/closing internal doors, turning lights on/off, adjusting shades and blinds, adjusting computer screen brightness, and adjusting personal heaters were practiced by 50% or more occupants and ranked, respectively. Additionally, adjusting the computer desk was newly added by one of the occupants. Considering the comfort preferences, most of the building occupants (76%) were expected to let in the fresh air through open windows, while a considerably less percentage of occupants were also expected to feel healthier, access to outside view, and experience the variety of the outdoor climate by opening windows. Another considerable percentage of occupants (71%) were expected to feel cooler or warmer depending on the temperature they experience, which was achieved through drinking hot/cold beverages, adjusting

clothing levels, and adjusting personal heaters. Other expectations were to increase air movement and air freshness and to hear outdoor sounds through opening internal/external doors and to avoid outdoor sounds by closing internal/external doors. Although most of the building occupants are visually satisfied, they are expecting to avoid the glare by adjusting shades/blinds and computer screen brightness, But, the considerable percentage of the occupants highlighted turning lights on/off, although the concern on increasing artificial and daylighting is reduced. Most of the occupants were expected to improve comfort conditions through their occupant behaviours, while 32% of the occupants report the discomforts to the building management. However, adjust portable/ceiling fans, room air conditioning units, and thermostats have received a considerably less percentage (10%-30%) due to the limited availability and accessibility to control these systems. Only very few occupants were expected to save energy and follow management guidelines through their OB, while most of the occupants were concerned about individual comfortability.

This reinforces the OB association with indoor environmental conditions as presented in previous studies irrespective of office type. For example, Amasyali and El-Gohary (2016) explained that OB such as adjusting thermostat, portable/permanent heaters, room air conditioner, portable/ceiling fans, and open/close doors are associated with thermal comfort. Furthermore, open/close windows and doors, and use/adjust the humidifier are linked to indoor air quality. Similarly, Bavaresco *et al.,* (2021) found that open/close windows and HVAC are related to thermal, acoustic, and IAQ; adjust blinds and shades to visual and thermal comfort; while turn lighting on/off is affected by visual comfort. Additionally, the current study provides insights into drivers of drink hot/cold beverages, adjusting clothing, adjusting computers, moving through spaces, and report discomfort. Majority of occupants trying to reach their IAQ and thermal comfort preferences via most of OB due to the lack of self-reported satisfaction with these parameters and their user control. The findings highlight the buildings' inability to perform up to the expectations of the occupants. However, further studies are required to analyse the other social, physiological, and psychological drivers influencing OB in office buildings and compare those with IEQ and user-centred design and control triggers. Further, occupants were asked to rate the frequency of OB practice and how influential are these behaviours towards the comfort preferences. Fig 2 shows the frequencies of the rating by occupants.

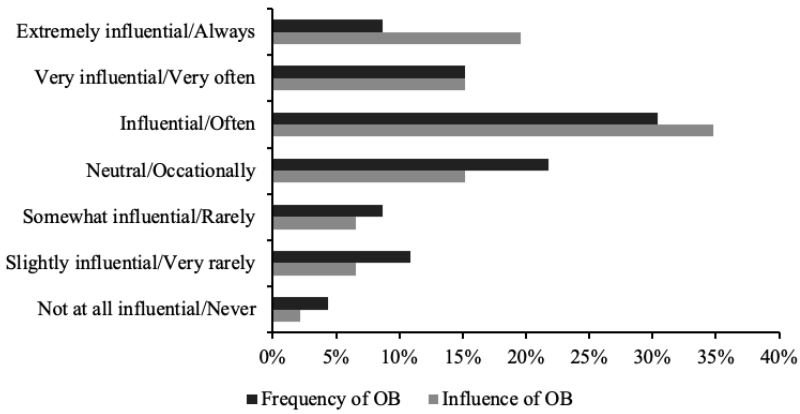


*Fig 2: Occupant Rating on Influence and Frequency of OB practice*

As shown in Fig 2, in terms of frequency of the practice of OB, most of the building occupants rated "often" or more. Similarly, the influence of OB on the desired effect was rated as "influential" or more. Overall, the influence of OB and frequency of OB

were rated by 60% and 54% of the building occupants as influential or often, respectively.

Finally, the Spearman rank correlation was run for the dependent variables: influence of OB and frequency of OB, and independent variables: IEQ, user-centred control, furniture arrangement, and office type. The Spearman correlation coefficient (r) measures the strength of a relationship, that can take values from -1 to +1. According to, Weerasinghe, Ramachandra and Rotimi (2020) there is no fixed definition of correlation strength. This study used the thresholds given by Ricciardy and Buratti (2015) such as $0 < r < 0.3$ (Weak), $0.3 < r < 0.7$ (Moderate), and $r > 0.7$ (Strong). A significance level $< 0.05$ was considered to determine whether the relationships are significant. However, significant correlations have appeared only for the influence of OB, these results are summarised in Table 4.

*Table 4: Relationship between Influence of OB and Indoor Environmental Conditions*

| | Influence of OB | Significance (p-value) |
|---|---|---|
| Thermal Comfort in winter | 0.448* | 0.002 |
| Ventilation in Winter | 0.540* | 0.000 |
| Thermal Comfort in Summer | 0.390* | 0.007 |
| Ventilation in Summer | 0.561* | 0.000 |
| Visual Comfort | 0.347* | 0.018 |
| Acoustic Comfort | 0.357* | 0.015 |
| Heating control | 0.645* | 0.000 |
| Cooling control | 0.576* | 0.000 |
| Ventilation control | 0.531* | 0.000 |
| Lighting control | 0.385* | 0.008 |
| Noise control | 0.378* | 0.010 |
| Furniture Arrangement | 0.261 | 0.080 |
| Frequency of OB | -0.149 | 0.323 |
| Office Type | -0.142 | 0.348 |

As shown in Table 4, most of the independent variables show a moderately significant relationship with the influence of OB, except furniture arrangement, office type, and frequency of OB. Furthermore, heating control has the strongest relationship (0.645) with the influence of OB, which was closely followed by cooling control, ventilation in summer, ventilation in winter, and ventilation control. Overall, IAQ and control over thermal and IAQ related parameters have the strongest bond with the OB. This further cement the major influence of thermal and IAQ related drivers on OB in office buildings. This finding agrees with that of Bavaresco *et al.,* (2021) and extends the findings relating to the influence of user-centred designs and control over building systems to OB in offices. Onyeizu (2014) suggested that occupants should be given more control over the IEQ in their local environment to achieve greater comfort.

## CONCLUSIONS

The purpose of this study was to uncover the relationships among indoor environmental conditions such as IEQ, user-centred design and furniture arrangements, comfort preferences, and occupant behaviours for integrating these relationships in future energy modelling of buildings. Results show that more than 70% of occupants were satisfied with visual comfort and furniture arrangement in

office buildings. Further, indoor environmental quality (IEQ), user-centred building controls, and furniture arrangements across the three office types: private, shared, open-plan office had a similar value of satisfaction except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. Additionally, dominant behaviours and comfort preferences were identified based on the frequency distribution, which showed that dominant behaviours: open/close windows, drink hot/cold beverage, adjust clothing, open/close internal doors were to satisfy individual IAQ and thermal comfort preferences. Furthermore, IAQ and control over thermal and IAQ related parameters such as heating, cooling, and ventilation are highly correlated with the occupant behaviours, and these could be considered as primary predictors of occupant energy behaviours. These relationships of IEQ and user-centred building controls with occupant behaviours could be utilized to enhance future occupant energy behaviour modelling approaches to reduce the gap between predicted and actual energy use, while pinpointing the occupants' energy wasteful behaviours. A better understanding of OB and comfort preference driven by subjective aspects of occupants would support policy makers, designers, and building managers to optimise the building energy performance from a building's design and construction stage. This study based on surveying 46 occupants in office buildings serves as the pilot study of research that aims to develop an interdisciplinary framework for occupant energy behaviours. Therefore, the limitations of the study (i.e., purposive sampling, sample size) will be addressed in the extended research.

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# CONSTRAINTS TO DELIVERING LOW CARBON BUILDINGS IN HIGH-RISE HIGH-DENSITY CITIES

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Expected practical improvements in delivering low carbon buildings in high-rise high-density cities are still lagging behind those needed to meet global carbon reduction targets. This indicates that there could be a number of commonly prevalent constraints that hinder the delivery of low carbon buildings. Therefore, this paper aims to systematically identify and explore these constraints. The presented outcomes are based on a systematic literature review of published journal papers from 2001 to 2020 and the findings from a questionnaire survey covering seven cities in five contexts: namely, UAE (Dubai and Abu Dhabi), Qatar (Doha), Australia (Melbourne and Sydney), Singapore and Hong Kong. The systematic review led to the identification of 71 common constraints under 8 categories: namely, 'financial', 'market structure and supplies', 'policy and regulatory', 'knowledge, awareness and information', 'workforce and skills', 'technological', 'behavioural, social and cultural', and 'geographical and environmental'. While identifying the constraints common to the contexts of surveyed cities, the paper also presents the constraints specific to each context. The findings should assist decision making at both policy and project levels to accelerate the delivery of low carbon buildings by addressing and ameliorating the common constraints impeding their development in high-rise high-density cities.

Keywords: constraint; high-rise high-density city; low carbon building

## INTRODUCTION

With increased rates of urbanisation, there is a world-wide move towards a low carbon urban environment in recent years (UNEP 2019). The more intensively urbanised and developed countries should elevate carbon reduction to a national priority because cities as a whole, account for more than 60% of the global greenhouse gas emissions and correspondingly consume a significant share (around 80%) of global material and energy supplies (Hunt and Watkiss 2011; UN-Habitat 2020). Among the various sectors, the buildings sector is a prime target for emission reduction, as buildings worldwide account for about one third of global greenhouse gas emissions and consume over one third of total produced energy (Mardiana and Riffat 2015). Moreover, research outcomes and energy/ carbon related international organisations (International Energy Agency [IEA], Regulatory Indicators for Sustainable Energy [RISE]) emphasise the rapid increase of energy demand and carbon emissions from building construction and building stock in high-rise high-density cities as a major issue. Many scholars have highlighted that delivering low carbon / zero carbon buildings is one of the most significant and 'extremely supporting' strategies towards achieving the environmental sustainability goals in the buildings sector (Isiadinso *et*

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*al.,* 2011; Shi *et al.,* 2015; Pan and Pan 2018). Currently, there is a rapid growth in the total building floor area globally (GABC 2019). Most of the developed countries with high-rise high-density cities are trying to reduce the energy usage and carbon emissions from their new constructions and existing building stock, through various micro level and macro level initiatives (Pan and Ning 2015). Yet, a notable reduction of carbon emission and energy usage of buildings is not evident in these countries (GABC 2019; IEA 2020). This establishes that there may be a number of underlying constraints which hinder the delivery of low carbon and energy efficient buildings in high-rise high-density cities even in well-developed countries with strong economies.

The relevant literature also reveals that moving towards low carbon buildings has been mostly retarded by various socio-technical constraints, rather than purely technological barriers or solely societal constraints. While a number of completed studies outline the barriers for energy saving and carbon emission reduction in buildings sector, there is a lack of research particularly focusing on the constraints to delivering low carbon buildings in high-rise high-density cities.

A systematic 'identification and analysis' of these constraints is beneficial to academics and practitioners to implement strategic efforts to effectively address these constraints and uptake the delivery of low carbon buildings in high-rise high-density cities. Hence, this study aimed to identify and assess the constraints to delivering low carbon buildings in high-rise high-density cities, with two main objectives: 1. To identify the common constraints to delivering low carbon buildings through a systematic literature review and 2. To assess the above identified constraints and specifically identify the constraints to delivering low carbon buildings in high-rise high-density cities through a questionnaire survey covering 7 cities in 5 different contexts; namely, Hong Kong, Singapore, UAE (Dubai and Abu Dhabi), Qatar (Doha) and Australia (Melbourne and Sydney). In this study, the word 'context' refers to a country or a region. The following sections convey the adopted methodology, analysis, results and conclusion.

## RESEARCH METHODS

Based on the aforementioned aim and objectives, the following methodological approach was adopted in carrying out this study (Fig 1). As one of the most popular and comprehensive databases, the "Web of Science" yielded the highest number of documents for the keywords search in this study. Keywords used to search the titles of the relevant papers for this review are “(Barriers OR Constraints OR Challenges) AND (Energy OR Carbon) AND (Buildings OR Building)”. To ensure the quality, only the published articles in journals were considered for the literature review. Subsequently, a questionnaire survey was carried out using the constraints identified through the literature review, to capture the significant constraints to delivering low carbon buildings in selected high-rise high-density cities. The respondents were requested to complete a survey to rate the level of significance of the constraints identified through the systematic review, within the context of their exposure according to a Likert scale (from 1 to 5 representing “Insignificant”, “Somewhat insignificant”, “Neutral”, “Significant” and “Highly significant”). A “judgment sampling” approach was followed to select the respondents through personal contacts in the industry and academia. Furthermore, a representative sample was obtained, considering the targeted professional groups.

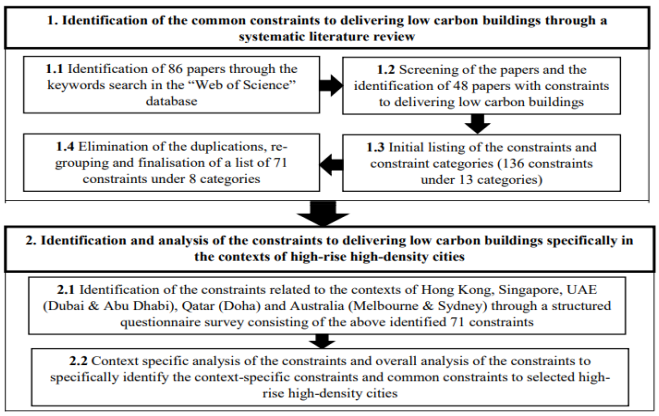


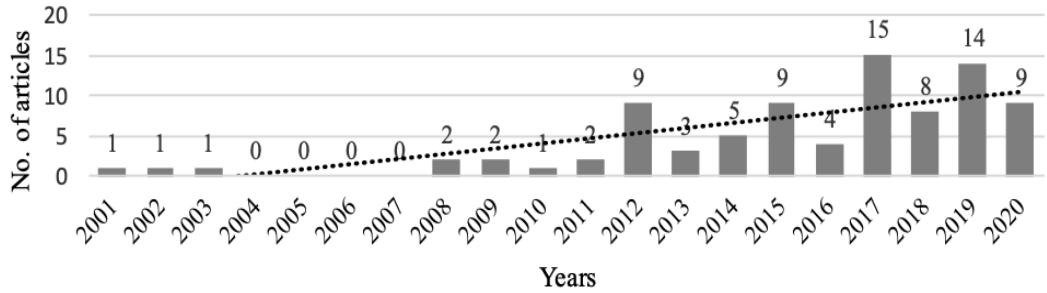

*Fig 1: Research methods*

# RESULTS AND ANALYSIS

## Systematic Literature Review

Fig 2 shows the number of publications from 2001 to 2020 relevant to the selected keywords. The graph shows an increasing trend of the number of publications on this topic which indicates that the attention of scholars was increasing over the recent years. Fig 3 shows the bibliometric network of co- authorship links among the most productive countries for the selected keywords. The node sizes are proportionate to the number of publications in the respective country. Accordingly, China and UK had 22 and 15 articles respectively. USA, Canada, Australia, Germany, Spain and Sweden were the other productive countries. This highlights an increasing attention towards identifying the constraints to delivering low carbon/energy buildings in these economically developed countries.

*Fig 2: Number of publications from 2001 to 2020*



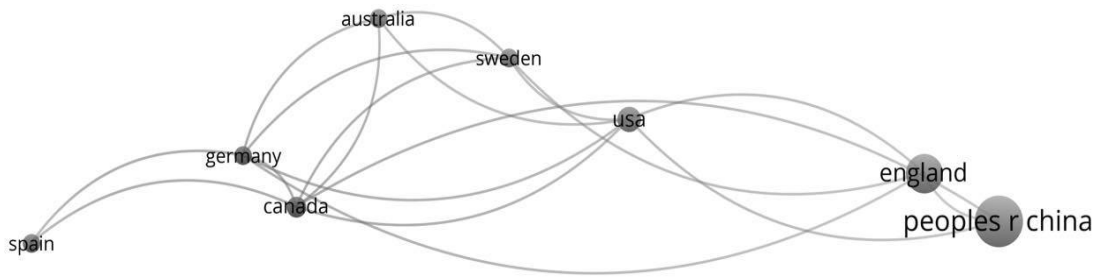




*Fig 3: Co-authorship network of countries*

Constraints to delivering low carbon/energy buildings were extracted after examining the content of the screened 48 papers from the literature search. The final list of 71 constraints under 8 categories are indicated in Table 1.

*Table 1: List of constraints identified through the systematic literature review*

| Constraints | Publications* |
|---|---|
| Financial constraints- F1) Less interest of investors due to high initial cost and less financial gains, F2) Uncertainty of financial gains, F3) Lack of investment capital, F4) Expenses, additional responsibilities and time consumption related to energy and carbon compliance, F5) Split incentives, F6) Non-liquidity of low carbon and energy saving investments, F7) High labour costs, F8) Increased operational and maintenance costs and risks, F9) Complex procurement models and inappropriate approval procedures, F10) Difficulties in getting approvals and financial contribution when there are multiple owners | 2,3,4,5,6,7,8, 10, 11, 12, 13, 14,15,16,17, 18, 24, 26, 27, 28, 29, 30, 32, 33, 34, 36, 38, 39, 40, 41, 43, 45, 46 |
| Market structure and supply constraints- M1) Lack of low carbon materials, equipment and technology availability due to lack of suppliers, M2) Energy efficient and low carbon features of buildings are considered as not contributing to increase the market value of the property, M3) More concern on aesthetic appearance, M4) Lack of energy service companies (ESCO's), M5) Less availability of long-term warranties and insurances for low carbon/ energy efficient materials and equipment | 3,6, 11, 26, 28, 29, 32, 41, 43 |
| Policy and regulatory constraints- P1) Lack of national mandatory standards and regulations, P2) Lack of incentives from government and financial institutions, P3) Non availability of a carbon tax scheme, P4) Non availability of proper building carbon emission trading mechanisms, P5) Unclear incentives for the building material/equipment market, P6) Contradiction between energy/ carbon compliance and other compliance requirements, P7) Lack of promotion, P8) Unavailability of efficient energy/ carbon labelling schemes, P9) Lack of legal penalties due to non-compliance, P10) Less willingness of government to increase low carbon and energy efficiency investment, P11) Less priority for building energy and carbon reduction and management in national policies, P12) Tenant and staff priorities are considered over low energy and carbon initiatives, P13) No top management commitment and no priority in organisational vision and mission, P14) Organisational business models are not considering the integration of low carbon and energy efficient initiatives, P15) Low quality equipment and poor post sale services due to improper legalisation, P16) Penetration of low quality materials to the market due to improper legalisation, P17) Lack of collaboration between government departments, P18) Policy initiatives related to energy and carbon do not cover the whole life of a building, P19) Unavailability of a proper energy quota mechanism | 1,2,3,4,5,6, 7,8,10,13,14, 15, 16, 18, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30, 33, 36, 38, 39, 41, 46 |
| Knowledge, awareness and information related constraints- K1) Lack of customised research and development, K2) Research outcomes are not effectively translated in to technology innovations, policy initiatives and industry practices, K3) Lack of usable energy and carbon data in buildings, K4) Weak energy feedback systems, K5) Less coordination between Management Company and tenants, K6) Not following collaborative design practices, K7) The integration between energy/ carbon in buildings and indoor environmental quality is not well established through research and customised studies, K8) Lack of motivation, awareness and knowledge of client, K9) Little knowledge of end-users about the consequences of their actions on carbon emissions and energy consumption, K10) Lack of proper education, experience sharing and training on energy efficient/ low carbon technologies and initiatives, K11) Stickiness to old technologies and methods in building construction and management, K12) Less experience and environmental awareness of professionals engaged throughout the building lifecycle | 1, 2, 3,5,6, 7, 8, 9, 10, 11, 16, 17, 18, 20, 21, 26, 27, 28, 29, 32, 33, 37, 38, 39, 41, 42, 43, 44, 45, 46 |
| Workforce and skills related constraints- W1) Workforce with less knowledge and technical expertise on new technological advancements, W2) Lack of professional staff resources and enterprise for implementing and assessing / auditing/ calculating carbon reductions and energy efficiency | 1, 2, 4, 7, 8, 19, 26, 30, 36, 39, 43, 45 |

| | |
|---|---|
| Technological constraints- T1) Lack of innovation and technology advancements, T2) Maintainability and operability issues, T3) Safety issues T4) Shortcomings of energy and carbon modelling tools for high-rise buildings, T5) Currently available modelling and simulation technologies are not perfectly feasible to take behaviour patterns, climate, cost effectiveness, etc... in to consideration simultaneously, T6) Construction companies are not up to the standards in terms of quality and strict construction practices, T7) Design strategies are focusing on a single building and neglects the interactions with the surrounding and the environment, T8) No proper user energy behaviour and demand analysis before designing, T9) Lack of production capability to produce cost effective energy efficient and low carbon products, T10) Inconsistencies and uncertainties in energy/ carbon calculation methods, T11) Lack of pilot projects, T12) Incompatibilities with new technologies due to existing building conditions, T13) Building façade materials contribute to increase the urban heat island effect, T14) Complexity of technology | 2, 3, 4, 7, 12, 14, 15, 17, 18, 20, 22, 28, 29, 34, 35, 37, 38, 41, 43, 44, 45, 46, 48 |
| Behavioural, social and cultural constraints- B1) Staff/ visitor/ customer satisfaction and acceptance related issues, B2) High energy lifestyle, B3) Conventional and negative attitudes of clients and owners towards low carbon investment, B4) Poor corporate culture which separates environmental performances and business improvement decisions, B5) Differences and uncertainties in energy behaviour patterns of occupants | 2, 3, 4, 12, 16, 17, 18, 29, 31, 32, 36, 38, 39, 45 |
| Geographical and environmental constraints- G1) Urban environment and the proximity of surrounding buildings, G2) Difficulties to model /investigate the microclimate due to different atmospheric conditions with the altitude of building, G3) Logistical challenges due to geographic locations, G4) Lack of space to install onsite renewable energy technologies | 12, 18, 24, 31, 34, 38, 39, 43, 44, 47, 48 |

*List of citations for the respective numbers of publications: 2- (Afshari *et al.,* 2016), 3-(Zhang and Wang 2013), 4-(Du *et al.,* 2014), 6-(Baek and Park 2012), 7-(Wang *et al.,* 2016), 8-(Tuominen *et al.,* 2012), 12-(Bertone *et al.,* 2018), 16-(Cherrafi *et al.,* 2017), 17-(Iwaro and Mwasha 2010), 18-(Rock *et al.,* 2019), 26-(Shen *et al.,* 2018), 28- (Li *et al.,* 2019), 29- (Zhang *et al.,* 2017), 32-(Ng *et al.,* 2013), 38-(Yeatts *et al.,* 2017), 39-(Alam *et al.,* 2019), 41-(Gupta *et al.,* 2017), 43-(Masrom *et al.,* 2017), 45-(Cagno *et al.,* 2014), 46-(Vogel *et al.,* 2015)

The relevant papers (mentioned by the respective numbers) of the following lead authors were also referenced in compiling above list of constraints, but space constrained their full citation in this paper: 1- Cattano, C., 5- Sudhakara Reddy, 9- Gerrish, T., 10-Persson J., 11-Olazabal, M., 13-Andrić, I., 14-Zhang, X., 15- Abdellah, R., 19- Biekša, D., 20-Ucci, M., 21-Jiang, M., 22-Attia, S., 23- Thollander, P., 24-Williams, K., 25- Pitts, A., 27-Häkkinen, T., 30- Nižetić, S., 31- Oregi, X., 33-Paiho, S., 34- Dadzie, J., 35-Geissler, S., 36-Kangas, H., 37-Pan, W., 40-Szumilo, N., 42-Yu, Z., 44-Yu, C., 47- Xing, R., 48-Zhao, Y.

## Questionnaire Survey Covering Seven Cities in Five Contexts

From the selected cities, 128 responses were gathered for the questionnaire survey. Accordingly, 31, 30, 24, 22, and 21 responses were collected from Hong Kong, UAE (Dubai and Abu Dhabi), Australia (Sydney and Melbourne), Qatar (Doha) and Singapore respectively. Among the respondents, 18% were Engineers, 15.6% were Educationalists, 14% were Government Officials, 13.2% were Project Managers, 12.5% were Consultants and 26.5% were from other related professions. 25.7% of the respondents had experiences for more than 20 years while 11.7%, 15.6%, 29.7%, and 17.2% of respondents had 16-20, 11-15, 6-10 and 0-5 years of experiences respectively. According to the adopted Likert scale, the responses 1 and 2 denote that a particular constraint is 'not significant' and a response of 3 indicates a 'neutral' view. Responses 4 and 5 indicate that the constraint is 'significant' to the context. Hence, for the context specific analysis, the constraints with over 75% of '4 or 5' responses (without considering the responses of 3 for the calculation) were identified as 'significant' to a particular context. A similar approach was used by Shen *et al. (*2016)

and Gan *et al. (*2018) in their studies. Subsequent to the context specific analysis, the overall mean ratings of the responses were also calculated for each constraint, taking all the 128 responses as the sample to further analyse the overall significance levels of the constraints (see Table 2).

*Table 2: Constraints to delivering low carbon buildings in selected 7 cities in 5 contexts*

| Constraints | *Significance in each context | | | | | Overall mean value | Significant and Common |
|---|---|---|---|---|---|---|---|
| | Qatar | UAE | Australia | Singapore | Hong Kong | | |
| F1- Less interest of investors due to high initial cost and less financial gains | ✓ | ✓ | ✓ | ✓ | ✓ | 4.06 | Yes |
| F2- Uncertainty of financial gains | ✓ | ✓ | × | ✓ | ✓ | 3.81 | Yes |
| F3- Lack of investment capital | ✓ | ✓ | ✓ | × | ✓ | 3.87 | Yes |
| F6- Non-liquidity of low carbon and energy saving investments | ✓ | × | × | ✓ | × | 2.95 | No |
| M1- Lack of low carbon materials, equipment, and technology availability due to lack of suppliers | ✓ | ✓ | × | × | × | 3.24 | No |
| M3- More concern on aesthetic appearance | ✓ | ✓ | ✓ | × | × | 3.31 | No |
| M5- Less availability of long-term warranties and insurances for low carbon/ energy efficient materials and equipment | ✓ | × | × | ✓ | × | 3.29 | No |
| P1- Lack of national mandatory standards and regulations | ✓ | ✓ | ✓ | × | ✓ | 3.98 | Yes |
| P2- Lack of incentives from government and financial institutions | ✓ | ✓ | ✓ | × | ✓ | 3.89 | Yes |
| P3- Non-availability of a carbon tax scheme | ✓ | ✓ | × | × | ✓ | 3.68 | No |
| P4- Non-availability of proper building carbon emission trading mechanisms | × | × | ✓ | ✓ | × | 3.28 | No |
| P5- Unclear incentives for the building material/equipment market | × | ✓ | ✓ | ✓ | ✓ | 4.04 | Yes |
| P7- Lack of promotion | ✓ | ✓ | × | × | × | 3.21 | No |
| P9- Lack of legal penalties due to non-compliance | ✓ | ✓ | ✓ | × | ✓ | 3.78 | Yes |
| P13- No top management commitment and no priority in organisational vision and mission | ✓ | × | × | × | ✓ | 3.04 | No |
| P14- Organisational business models are not considering the integration of low carbon and energy efficient initiatives | ✓ | ✓ | ✓ | ✓ | × | 3.71 | Yes |
| P17- Lack of collaboration between government departments | ✓ | ✓ | ✓ | × | ✓ | 3.90 | Yes |
| P18- Policy initiatives related to energy and carbon do not cover the whole life of a building | ✓ | ✓ | ✓ | × | ✓ | 3.78 | Yes |
| K2- Research outcomes are not effectively translated into technology innovations, policy initiatives and industry practices | ✓ | ✓ | ✓ | × | ✓ | 3.99 | Yes |
| K3- Lack of usable energy and carbon data in buildings | ✓ | × | ✓ | ✓ | ✓ | 3.76 | Yes |
| K4- Weak energy feedback systems | ✓ | × | ✓ | × | × | 3.15 | No |
| K5- Less coordination between Management Company and tenants | ✓ | × | ✓ | ✓ | × | 3.45 | No |
| K8- Lack of motivation, awareness and knowledge of client | ✓ | ✓ | × | × | ✓ | 3.59 | No |
| K9- Little knowledge of end-users about the consequences of their actions on carbon emissions and energy consumption | ✓ | ✓ | ✓ | × | ✓ | 3.74 | Yes |
| K10- Lack of proper education, experience sharing and training on energy efficient/ low carbon initiatives, | ✓ | ✓ | × | × | × | 3.47 | No |
| K11- Stickiness to old technologies and methods in building construction and management | × | ✓ | × | ✓ | × | 3.56 | No |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| K12- Less experience and environmental awareness of professionals engaged throughout the building lifecycle | ✓ | × | ✓ | ✓ | × | 3.58 | No |
| W1- Workforce with less knowledge and technical expertise on new technological advancements | ✓ | ✓ | ✓ | ✓ | × | 3.70 | Yes |
| W2- Lack of professional staff resources and enterprise for implementing and assessing / auditing/ calculating carbon reductions and energy efficiency | × | ✓ | ✓ | ✓ | × | 3.59 | No |
| T2- Maintainability and operability issues | ✓ | × | ✓ | ✓ | ✓ | 3.71 | Yes |
| T6- Construction companies are not up to the standards in terms of quality and strict construction practices | ✓ | ✓ | × | ✓ | × | 3.42 | No |
| T7- Design strategies are focusing on a single building and neglects the interactions with the surrounding environment | × | × | ✓ | ✓ | × | 3.45 | No |
| T10- Inconsistencies and uncertainties in energy/ carbon calculation | ✓ | × | ✓ | ✓ | × | 3.46 | No |
| T11- Lack of pilot projects | ✓ | ✓ | × | × | × | 3.10 | No |
| T12- Incompatibilities with new technologies due to existing building conditions | ✓ | ✓ | ✓ | ✓ | ✓ | 3.95 | Yes |
| T14- Complexity of technology | ✓ | ✓ | ✓ | × | × | 3.40 | No |
| B2- High energy lifestyle | ✓ | ✓ | ✓ | ✓ | ✓ | 3.82 | Yes |
| B4- Poor corporate culture which separates environmental performances and business improvement decisions | ✓ | × | ✓ | ✓ | ✓ | 3.69 | Yes |
| B5- Differences and uncertainties in energy behaviour patterns of occupants | × | × | × | ✓ | ✓ | 3.17 | No |
| G1- Urban environment and the proximity of surrounding buildings | × | × | × | ✓ | ✓ | 3.29 | No |
| G2- Difficulties to model/investigate the microclimate due to different atmospheric conditions with the altitude of building | ✓ | ✓ | × | × | × | 3.25 | No |
| G4- Lack of space to install onsite renewable energy technologies | ✓ | ✓ | ✓ | ✓ | ✓ | 3.83 | Yes |

*'✓' / '×' denotes that the respective constraint is 'significant' / 'not-significant'

Twenty-two constraints out of 71 were identified as 'not significant' to all 5 contexts. Seven constraints were identified as 'significant' to only one context. Table 2 presents the remaining 42 constraints which were identified as common to 2 or more contexts. Among the constraints represented in Table 2, there are 19 constraints which were identified as common to 4 or more contexts. Only 4 constraints were identified as common to all 5 contexts.

Overall mean ratings of these constraints are also presented in Table 2 for the comparative representation of context specific significance and the overall significance identified through the questionnaire survey. Among the 42 constraints in Table 2, there are 18 constraints with a mean rating value less than 3.5. The overall mean ratings of these constraints are closer to the value of 3 (neutral) than to the value of 4 (significant). Hence, these constraints were identified as not having an overall significant impact on hindering the delivery of low carbon buildings in the selected contexts.

After comparing the findings of both the context wise analysis and the overall mean ratings, 52 constraints out of 71 were identified as not common to 4 or more contexts and also having a less significant mean rating value. Accordingly, 19 constraints were identified as common to 4 or more contexts and also having an overall mean rating value of above 3.5. Accordingly, the constraints F1, F2, F3, P1, P2, P5, P9, P14, P17, P18, K2, K3, K9, W1, T2, T12, B2, B4 and G4 were identified as 'common' and

'significant' constraints which hinder the delivery of low carbon buildings in the selected 7 high-rise high-density cities in 5 contexts (see Table 2).

## CONCLUSIONS

High-rise high-density cities account for a significant portion of the global carbon emissions. Despite the various commitments to reduce carbon emissions in the building sector, a number of socio-technical constraints still hinder the delivery of low carbon buildings in such cities. The literature review showed that the majority of previous scholars have frequently discussed financial, policy and regulatory, knowledge, and technological constraints as the most commonly encountered constraints to delivering low carbon/energy buildings in general over the past 20 years. The recent literature further suggests that the levels of significance of these constraints are different from one context to another. Nevertheless, a majority of the referred articles were based on developed countries with high-rise high-density cities. Hence it was evident that the identified constraints were affecting the delivery of low carbon buildings even in these developed countries in the recent years.

The findings of the questionnaire survey specifically revealed that some of these constraints identified through the literature review still prevail, albeit to different degrees, in the selected contexts. Nineteen constraints were identified as common and significant constraints to the selected contexts. Confirming the findings of the literature, financial constraints (such as high initial cost, limited access to capital, less / uncertain financial gains), policy and regulatory constraints (such as lack of: mandatory standards, incentives, legal penalties, taxes, etc.), lack of knowledge and awareness, lack of skills, lack of motivation, lack of collaboration, and technological constraints were commonly identified in the selected contexts. In addition, behavioural constraints and space limitations were also identified as significant to the selected contexts. However, the mean ratings for these 'significant' constraints were close to the value of '4' and none of the constraints were rated close to the value of '5' which emphasises that these constraints are not rated as 'highly significant' when considering the selected contexts together as a one sample. This implies that as developed countries, these countries might have taken considerable efforts to overcome these constraints and uptake the delivery of low carbon buildings. Even though the constraints are not rated as critical and highly significant, the respondents have concluded that there is still a significant impact of these constraints to delivering low carbon buildings.

Since the identified constraints represent the status of only 7 cities in 5 selected contexts, validating the constraints in several other contexts will be beneficial in a future stage to further enhance the scope of the findings. A further exploration of the reasons for the context specific constraints will be beneficial to implement customised strategies to overcome the constraints. All the countries selected for the current study are economically developed countries. Testing the significance of these 71 constraints in the contexts of a sample of developing countries will provide an opportunity to comparatively analyse the relative significance of these constraints to delivering low carbon buildings between 'developed' and 'developing' countries. Meanwhile, the findings of this paper would benefit researchers, national policy makers and responsible stakeholders in this field by presenting significant common constraints, hence enabling them to seek solutions to accelerate the delivery of low carbon buildings by addressing the constraints.

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# CARBON EMISSIONS OPTIMISATION IN PREFABRICATION CONSTRUCTION: A REVIEW OF CURRENT DESIGN INTEGRATED APPROACHES

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The construction industry is the overarching energy consumer and contributes to significant carbon emissions globally. Prefabricated construction has been adopted to alleviate the industry's pressure on the environment. Thus, the number of scientific publications about the realisation of a sustainable built environment through prefabricated design has followed an exponential trend since 2015. However, it is still not a common practice to implement sustainability during the design stage. Therefore, this study critically reviewed relevant literature on current design tools to evaluate the remaining challenges. The general area of investigation in this research was embodied carbon emissions optimisation in the design phase. Its findings showed that, although assessing sustainability in the design stage had become a hotpot recently, current design assistant tools were ineffective for the designers to generate a sustainable design. Their limited reliability, creativity, and user-unfriendly process were claimed as barriers. In the end, this study proposed a framework for implementing carbon emissions' optimisation in the design phase and concludes by setting out the direction for further work in this area.

Keywords: carbon emissions; prefabrication; design integrated optimisation

## INTRODUCTION

Approximately 48% of energy is consumed by buildings during their construction and operation phases (Dixit 2019), out of which 29% can be potentially reduced (Liu *et al.,* 2019). As a response to it, prefabrication is increasingly being adopted worldwide (Hao *et al.,* 2020) as it has the potential to reduce 20% construction Carbon Emissions (CE) compared to conventional methods (Gao *et al.,* 2018). Although the design process generates nearly no CE, decisions in this stage determine key impacts on the projects' environmental performance (Li *et al.,* 2020). Generally, the earlier decisions are made, the more significant influence they may have (Basbagill *et al.,* 2013).

As a result, a number of studies (Basbagill *et al.,* 2014; Roberts *et al.,* 2020) have put considerable effort into integrating environmental analysis in the early design stage (Jusselme *et al.,* 2020). However, a contradiction has been widely found that a large amount of necessary data for the environmental assessment is typically not available in the design stage (Marsh 2016). Additionally, little attention has been paid to prefabrication, the construction type with the unique characteristic of assembling building elements. Merely adopting a material-based approach in prefabrication

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analysis can overestimate the benefit of efficient material utilisation but ignore the side-effect of lower transport and hanging efficiency. Since there is a logarithmic trade-off between the environmental impact and cost (Hester *et al.,* 2018), actions on the novel field produce more benefit than mature ones. Compared with reducing energy consumption during the production or operation procedure, optimizing CE in the construction process (e.g., transport and assembly) is an untapped topic. A critical review that considers this part helps to highlight the neglected hotpot for sustainability studies. Moreover, it offers the industry and the government a new direction to invest in sustainable construction.

This paper aims to determine the current research gaps in the CE optimisation of prefabrication through a review of academic literature. It culminates with a proposed framework for design integrated CE optimisation. As a preliminary stage of the study focusing on reducing CE of prefabricated construction through parametric design, its result works as background knowledge to support further research design. At this stage in the research, the prefabrication CE optimisation will be generally defined as reducing Embodied Carbon Emissions (ECE) in the production, transportation, and assembly procedure of prefabricated buildings.

# LITERATURE REVIEW

## Construction Carbon Emissions Analysis

Generally, there are three common approaches to evaluate CE, i.e., Life Cycle Assessment (LCA), economic integration analysis, and direct measurement. The categories of this part were, however, sometimes confused with the CE calculation method (Zhao *et al.,* 2018) or LCA method (Lim *et al.,* 2016). Therefore, terms with the minor cross citation were adopted in Table 1 for their classification.

*Table 1: Classification of construction carbon emissions analysis approach*

| Approach | | Method | Application | Input Data |
|---|---|---|---|---|
| LCA | Process-based LCA | CE factor | Specific Operation | Construction quantity |
| | Input-output LCA | Mass balance | Material Level | Material Consumption |
| | Hybrid LCA | Mass balance | Specific Operation | Material Consumption |
| Economic Analysis | | Mass balance | Economies and Industry | Material Consumption |
| Direct Measurement | | Measurement | All | None |

LCA is the approach that evaluates the environmental impacts through the project's life cycle (ISO 2006). It can be further divided into three sub-approaches: 1) process-based LCA, 2) input-output LCA, and 3) hybrid LCA (Liu *et al.,* 2019). The process based LCA is appropriate for evaluating CE of specific construction methods as it directly evaluates CE attributable to construction items (e.g., equipment, labour, and material) (Lim *et al.,* 2016). Fang *et al.,* (2018) employed an approach to calculate the CE distribution among construction operations and equipment. Liu *et al.,* (2020) established a construction CE monitoring system based on real-time process based LCA. In contrast, the input-output LCA is used on a broad scale, such as exploring the CE driving factors in the construction sector (Cui *et al.,* 2019). It is also adopted when considering the material as the primary contributor to calculate CE based on the bill of quantities (Cang *et al.,* 2020; Lu *et al.,* 2019). Specific cases compared CE of different materials (Zhang *et al.,* 2020) and CE reduction through material selection and quantity optimisation (Basbagill *et al.,* 2014; Basic *et al.,* 2019; Marsh 2016). As a combination of these two approaches, hybrid LCA can be considered transforming

the detailed CE list of process-based LCA to a bill of quantities used in input-output LCA (Liu *et al.,* 2019).

The strong relationship of a nation's energy to its Gross Domestic Product (GDP) is the basis of the economic analysis approach (Dixit *et al.,* 2013). Compared to LCA, it is employed at a macro level to evaluate the sustainability of economies (Han *et al.,* 2020) or industry (Chen *et al.,* 2019). These aimed to address suggestions for policy or regulation, which is different from this research. As for the direct measurement, Liu *et al.,* (2020) reported its application in construction CE monitoring. Technologies they mentioned (e.g., GIS, video camera) are mainly adopted for visualization rather than calculation or analysis. However, Christen *et al.,* (2011) put forward the thought to employ direct eddy-covariance measurements in urban-scale CE calculation. Their model, promising at the scale between 100m (size of the construction site) - 10km, pointed to the potential for construction applications.

**Design Integrated Optimisation**

Optimising CE in the design stage is to evaluate the sustainability of design alternatives and guide designs to less CE. Research on the open-source UK (Ekundayo *et al.,* 2019) and wider-rage (De Wolf *et al.,* 2017) tools pointed out the lack of precise, up to date, open-source, and user-friendly tools. A vital issue to this challenge is the insufficient information interaction between stages (Jusselme *et al.,* 2020), especially at two ends of the design integrated optimisation, i.e., the process of design data input and assessment result output.

At the former end, dealing with uncertain data is inevitable when estimating CE with early design files because of wide-spread uncertainties in the design stage (Marsh 2016). Generally, previous studies solved the issue through data refining or model simplification. The data refining refers to using information from the later phase to gain a relatively accurate calculation of CE post design (Hao *et al.,* 2020; Li *et al.,* 2016; Lin *et al.,* 2019), and adopting assumed or empirical values to replace the uncertain data (Dixit 2019). Obviously, it is hysteretic or inaccurate in these scenarios. Therefore, more studies selected the other choice, i.e., simplifying and adjusting the model to accommodate data quality. Kanafani *et al.,* (2019) classified model simplification methods into the horizontal approach (i.e., reducing the number of parameters in analysis) and the vertical approach (i.e., reducing data quality and allowing generic data). As an example of the horizontal approach, Victoria and Perera (2018) suggested to design following the carbon intensity and focused on the carbon hotpot (elements contribute to more than 80% of the total CE). Rodrigues *et al.,* (2018) strengthened this approach by predicting a robust environmental performance with less than ten design attributes. Although the horizontal approach claims to be effective and efficient, its application was less observed than the vertical approach as the latter evaluates more design alternatives and produces more comprehensive results (e.g., 14630112 alternatives were evaluated in the research of Shadram and Mukkavaara, (2018)). On the contrary, the vertical approach accepted the uncertainty and formed the alternative space by distributing uncertain design parameters. It generates results by exploring the optimized parameter sets. For instance, Hester *et al.,* (2018) established a design space by distributing parameters like building geometry, occupant behaviour, and material selection. Their design guidance, an optimised scale of crucial attributes, was extracted by quasi-optimum solutions (i.e., alternatives possessed 75% of the maximum potential) exploration. A similar idea

was adopted but not limited to the research of Basbagill *et al.,* (2013) and Feng, Chen and Lu (2019).

At the other end, assessment results are provided in four approaches (Roberts *et al.,* 2020): 1) cooperation of BIM and LCA software (Basbagill *et al.,* 2014); 2) BIM integrated plug-in tool (Basic *et al.,* 2019); 3) calculation based on bill of quantity (Cang *et al.,* 2020); and 4) parametric approach (Chen *et al.,* 2018). When employing approaches 1 and 2, architects can evaluate sustainability and aesthetics requirements simultaneously (Hollberg 2016). Specifically, Shadram and Mukkavaara (2018) transferred the design data from BIM to numeric parameters and re-instantiated them in Revit after the mathematic optimisation to visualize results. Basic *et al.,* (2019)'s method realized a real-time CE calculation within the design software. A novel expression was reported by Basbagill, Flager and Lepech (2014), who represented the probability distribution of remaining alternatives after each decision was made. It directs the decision to considering both design flexibility and sustainability. In contrast, although weak in visualisation, approaches 3 and 4 are software-independent and conveniently implemented. For instance, Lu *et al.,* (2019) calculated CE in Excel and no software was specifically noted in the study of Chen *et al.,* (2018).

### Adjustment for Prefabrication Construction

Prefabrication construction is an approach to assemble off-site-produced elements to form the final project (Li *et al.,* 2014). Compared with the conventional method, a prefabricated element (the physical entity with specific geometric size) is manipulated rather than the material. Obvious distinctions exist in the unit element and research boundary when applying CE analysis on prefabrication. A primary approach to consider these differences is counting the material reduction in manufacture. Abey and Anand (2019) differed material-level CE of conventional and prefabrication through adopting various CE factors. Hao *et al.,* (2020) reported a 15% material CE reduction due to less waste.

However, this approach ignored the concomitant weakness in construction efficiency. As a more realistic approach, Cang *et al.,* (2020) replaced the material with the prefabricated element as the evaluation unit. Although no significant variance was observed in material CE (91.80 % compared with the conventional approach), it provides the possibility in detailed construction analysis where potential gaps exist. Comparing the result of the element-based approach (Gao *et al.,* 2018) and material-based approach (Hao *et al.,* 2020), they have a similar percentage of the material contribution (88% and 90%), but a significant difference in transport (10% and 1 %). The variance was also observed in the comparison between life cycle accumulative CE, where a more significant increase in the construction appeared in element-based analysis (Liu *et al.,* 2020) than the material approach (Hao *et al.,* 2020). Besides providing precise details, the element approach was also recommended by Lützkendorf, (2019) as a simplified method for quantity determination and is advantageous in the parallel determination of design performance. It, therefore, has great potential in prefabrication optimisation.

## METHOD

As a preliminary stage of sustainable construction research, this study conducted a critical literature review to evaluate CE optimization application in prefabrication, especially in the design stage. Compared to systematic review (Roberts *et al.,* 2020) or comprehensive review (Evins 2013), this approach emphasises on the conceptual

contribution of previous research and provides the starting point for further evaluation (Grant and Booth 2009). Web of Science was selected as the main database since it is a comprehensive database. An exploratory approach was adopted with keywords selection. CE, design optimisation, and prefabrication were used as the original keywords. Sub-keywords for each one included "Carbon Footprint" "Green House Gas", "LCA", and "Embodied Energy" for "CE", "Design Integrated", "Early Design Stage", "Parametric Approach" for "Design Optimisation", and "Prefabricated Building", "Prefabricated Construction", and "Building Element" for "Prefabrication". They were developed after a thorough review of phased paper iteratively. Table 2 shows contents of the most relevant literature concerning design stage CE reduction.

*Table 2: Content of relevant literature*

| Author | CE Approach | Design Approach | Design parameter | Scale |
|---|---|---|---|---|
| Basic *et al.,* (2019) | Input-output LCA | BIM plug-in | Geometry, Material, HVAC | Material ECE + Operational CE (OCE) |
| Feng, Chen and Lu (2019) | Process-based LCA | Parametric Approach | Element size, Construction plan | Construction ECE |
| Hester *et al.,* (2018) | Input-output LCA | Parametric Approach | Geometry, Behaviour, Material, Thickness | Material ECE + OCE |
| Shadram and Mukkavaara (2018) | Input-output LCA | BIM software cooperation | Material, Thickness | Material ECE + OCE |
| Marsh (2016) | Input-output LCA | Parametric Approach | Mid variable | Material ECE + OCE |
| Hollberg (2016) | Input-output LCA | BIM plug-in | Geometry, Material, Thickness | Material ECE + OCE |
| Basbagill, Flager and Lepech (2014) | Input-output LCA | BIM software cooperation | Geometry, Material, Thickness | Material ECE + OCE |

# ANALYSIS AND DISCUSSION

Most research and policy initiatives are inclined to reduce OCE (Fernandez-Sanchez and Rodriguez-Lopez 2012), because 80% of energy is currently consumed during the operational phase (Lim *et al.,* 2016). Consequently, the embodied impact of buildings has been ignored for a long while (Pomponi and Moncaster 2016). This unbalanced focus leads to the result that the share of ECE is to exceed 60% in the future (Roberts *et al.,* 2020). In fact, ECE and OCE are related logarithmically in sustainable designs (Shadram and Mukkavaara 2018), therefore deserve equal consideration. But ECE itself suffers an inconsistent research interest as well. Only 20-40% stages, often production stages, were included in current LCA as shown in the Table 2. (De Wolf *et al.,* 2017). Although they are believed to contribute the most ECE by materials, their reduction potential is limited. The maximum impact reduction of the framework and exterior walls is 4.50% and 0.97%, through material selection, respectively (Basbagill *et al.,* 2013). In contrast, that of the construction phase is 22% (Feng *et al.,* 2019), which indicates a great significance to consider all stages comprehensively.

Regarding design integrated CE optimisation, despite achievements in the improvement of sustainability, the implementation of environmental assessments remains a challenge (Azzouz *et al.,* 2017). There has been a wide-spread misperception of sustainability analysis (Alsaadani and Bleil De Souza 2018), based on which estimation is understood more as design validation than a source of creativity. Therefore, results are usually in the form of a separate statistic table with final CE values, which is hard to understand and interpret by the architects (Jusselme

*et al.,* 2020). Although the BIM integrated parametric approach (Basic *et al.,* 2019) realizing a real-time analysis, their parameter selection remains at a preliminary stage, represented by terms like orientation, dimensions, window area, material, and HVAC system as shown in Table 2. Design at this stage is still far from a complement building and is possibly misled in the opposite direction during further design. The error of some results (Cavalliere *et al.,* 2019) is considered unacceptable in the end. Basbagill, Flager and Lepech (2014)'s framework is the only tool that supports sequential decision making, giving an example of guiding the designer to a sustainable preference. Nevertheless, the appropriate expression of decision support, considering the requirement of both analysis and design, deserves further exploration.

Things are even more challenging when it comes to prefabrication because it demands professional and detailed management during both the manufacture and design stage. As lacking the knowledge of sustainability (De Wolf *et al.,* 2017) and construction (Jaillon and Poon 2014), architects consider the design and optimization from an abstract perspective. As mentioned before, the concept of prefabricated element supports not only detailed prefabrication design but also process-based LCA. However, the term "element" seldom refers to the prefabricated products (Cang *et al.,* 2020) but building components defined by function (Basic *et al.,* 2019; Ham and Golparvar-Fard 2015). This definition ignores the difference in manufacture and construction. Sebaibi and Boutouil's (2020) research shows that even adopting emission data of conventional material in manufacture could cause significant variance due to unique prefabrication operations (e.g., steam curing). However, specific and reliable information is hard to obtain (De Wolf *et al.,* 2017). More specifically, the emission coefficient of either materials or components employed in approaches except for direct measurement is not accurate all the time for various index values (Zhao *et al.,* 2018). The uncertainty of this part can lead to serious inaccuracy of the final result as that of De Wolf, Pomponi and Moncaster, (2017). Apart from a standardized database, the need for a consistent methodology to obtain precise quantities is also put forward by Moncaster and Symons (2013). Liu *et al.,* (2020) provided a novel framework of real-time quantity measurement, which was distinct from relying on the bill of Construction Quantity (CQ) (Jafary Nasab *et al.,* 2020; Li *et al.,* 2016; Lu *et al.,* 2019). However, it was only tested on a single element and cannot be accessed in the design stage. Fortunately, construction simulation, especially Discrete Event Simulation (DES), proved high accuracy in pre-construction quantity analysis (Feng *et al.,* 2019; Vidalakis *et al.,* 2013). Therefore, a combination of these two approaches is considered a promising solution.

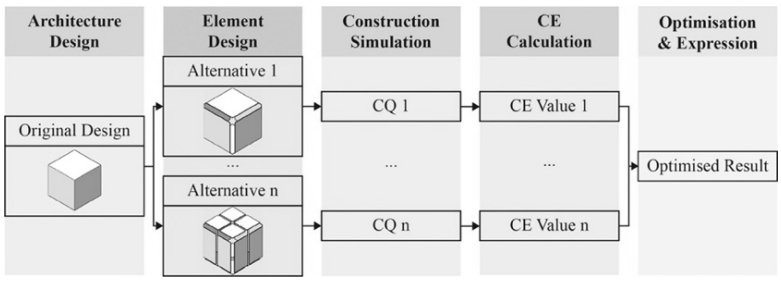


*Fig 1: Flowchart of the proposed framework*

These findings highlight the direction of the ongoing study on carbon emissions optimisation in prefabrication construction. A proposed approach is formed based on the hypothesis that schematic design rather than concept design contributes the most to the ECE of prefabrication. As shown in Fig 1, it assumes the geometric model as

the input file. Design alternatives concerning different element design are automatically generated by distributing key parameters to a given range. The model will generate CQ for every single alternative by DES. After calculating CE with process based LCA, an optimising algorithm will be employed to generate the final result. The proposed output will be a set of key parameters (i.e., size of structure elements). These parameters can be adopted in the construction design process to determine the division of elements, the selection of construction equipment, etc.

## CONCLUSIONS

This paper critically reviewed the academic literature on sustainable prefabrication construction optimisation with a design integrated approach. The reviewed articles focused on construction CE analysis, design integrated sustainability optimisation, and prefabrication application. It was found that previous research provided abundant CE analysis and calculation approaches. Although the uncertainty in the design data led to challenges of accurate evaluation, it helped to generate design alternatives for optimisation. However, research gaps exist in the research scale and prefabrication application. The sustainability analysis is biased at the operational stage and works as an extra validation process in the design phase. Limited studies reported ECE reduction approach apart from the material selection. Designers were left a narrow scale after analysis in most research and caused the ineffective implementation of the design integrated approach. Although a primary element approach realized its prefabrication application, it did not fill the demand thoroughly. Therefore, a framework aiming at reducing construction CE by design optimisation is proposed. Further research will include a larger amount of previous work to eliminate potential interpretative bias and focus on the framework development and implementation.

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# Other Topics

# PROJECT COST OVERRUNS AND RISK ALLOCATION IN PUBLIC FUNDED PROJECTS IN MALAYSIA

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Over budgeting is a recurring issue in projects. One of the main issues of over budgets is the mismanagement of risks. Risks and uncertainty should have been established, quantified and included in the cost limit of a project. Recognising the challenges of COVID posed to the current economy, it is ever more crucial for public clients to ensure the facilities are delivered with added value by eliminating the inefficient expenditure and delays, which affects the value delivery to end user. Although there are many approaches in studying cost overruns in projects, this study aims to uncover the factors driving the cost overruns and its relation towards the risks. This paper will report the first stage findings of on-going research. A total of 14 public facility projects, all delivered through traditional procurement were selected, unpacked, and analysed. The cost/m2 of each project were then compared to client's developed cost plan at the selected project stage, including further investigation for factors driving the cost changes. The study revealed that most of over budgeting were contributed to misallocation of risk. Lacked quantification and identification of risk caused over budgets and delays. Traditional procurement allow certainty but less innovative platform for contractor and client to collaborate.

Keywords: cost planning; overrun; risk allocation; traditional procurement

## INTRODUCTION

Public sector government agencies and commercial clients are tightening their purse and pulling budgets due to the current state of COVID19 and world economy. Clients, sponsors and funders for both public and private sectors have exhibited growing appetite for reduced spending and higher risk consideration in investing projects. Pressure to deliver public infrastructure and building facilities such as hospitals, motorways and schools to generate the economic activities, improving quality of life and the overall access to better public facilities; the government also shifted their trend for cleaner and socially desirable innovative projects. Now, the pandemic has diversified the spending focus, it is utmost crucial for government or any client to be agile and resilient to re-shape and modernise risk management approaches through quick risk identification with real time implementation and

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transparency in process to create public and the end users' confidence whilst enhancing the project delivery for better value (KPMG, 2021).

There are various structures and arrangement of financing public projects delivery through a degree of relationships of risk transfer among firms and consortium with the ultimate aim of managing and transferring the risks to the best party. Osei-Kyei and Chan (2017) analysed their data and indicated that an effective risk transfer is important to manage the project efficiently to avoid loss in public expenditures and the deliverance to the public needs. Wang *et al. (*2019) analysed the construction risks using a social network theory and listed twenty top risk factors, which includes legal structure, changes in market trends and errors in decision making as the top three main factors contributing to project failures.

The construction professionals are under much scrutiny to deliver better projects performance for better value for money; for construction projects to meet its expected targets and delivering maximised benefits to the public (NAO, 2004; Department of Transport, 2015). Most reasons of failing to deliver the project performance target of cost, time and quality are due to unclear expectations, bad communication between clients and team members, changing needs, restricted funding, shifts of needs of users and stakeholder's requirement. Doloi (2012) analysed those changes in design and scope, changes in output specification and issues with contracts are the main factors affecting the cost performance. Lack of cost control due to complex client requirement with high demands of needs multi-layered client organisation entities will reduce contractor's profit and project delays (Ashworth and Perera, 2015). One of factors argued by Flyvbjerg, Holm and Buhl (2002) are because of human errors in estimation and/or costing led to significant impact, and it is because of complexity and huge cost project delivery. The introduction of automated quantification using software, information modelling and data management models including visualisation may improve the accuracy of the quantification techniques. However, are human errors the main contributors in the overestimation of the cost and budgeting in projects? There is some consideration to think that identification, allocation, transfer and management of risk should have a significant bearing when it comes to managing the costs in projects. This paper seeks to examine: 1) what are the main drivers of over budgeting in projects and how these drivers impact risk allocation and how it's managed between parties. 2) How risks are allocated and at what costs it can be transferred, and whether it is worth to do so in relation to its impacts on client benefits and main contractor for its percentage of overhead and profit.

*Cost overruns and risks in projects*

Many developed countries are pushing towards zero emissions agenda; developing and underdeveloped countries are facing unprecedented struggles to rise due from health, economic and social impacts. Government should take an active stance of economic steward in by being responsive to the industries needs through innovation and initiatives (KPMG, 2021). In the UK, more emphasis to achieve the net zero target, with financial support to construction sectors to stimulate the growth and jobs opportunities as a way of creating positive start to the economic recovery.

With many targets set to achieve, the resources always remain scarce and constrained. Cutting down the waste and removal of unnecessary expenses and waste to ensure the money is invested innovatively into more socially desirable outcomes is the overarching the points in project. It is aimed to improve user's experiences, functionality and value for the long term for both clients and facility users. One main

issue affecting success project delivery is data unavailability. This will affect design and decision making, as the main issue causing the over budgets (Jackson,2002). Issues dealing with uncertainty due to the lack of information, this affects the organisation strategy and may affect the risk appetite of the client (William and Samset,2010) which may affect the whole process in managing the project. This complexity of problems may cause projects to be cost overruns, delays and loss of investment and profits in organisation. Andersen, Samset and Wilde (2016) advocated for increased transparency, estimation cost to include the uncertainty and increasing the uncertainty provision in project costing as few of the methods that can be employed to avoid cost overruns and the project failure.

Another important step in managing project to ensure meeting the budget, time and quality, is by being responsive to change. Projects, clients and their organisations are separate living entity with different set of needs. Each organisation procurement of the project is done through a complexity of risks and the uncertainties to deliver their needs and aspiration. Being agile to change while managing the uncertainty in projects seem to be a complicated process as it requires the team to have familiarity and knowledge of surrounding, the activities and processes which may differ to each client, projects and organisations within the projects (Dubois and Garde, 2002). However, it is worth pointing out that it is an understatement to exclude the fact that uncertainty needs time and having past experiences with the clients or previous similar projects should build up the organisation's knowledge. The organisation may require this reusable project knowledge to help them in decision making and managing the changes.

Having less experience in planning can be one of the main factors pushing the project cost boundary which is the case for Dlamini and Cumberlege (2021) for South African construction industry. While evidence from Nevada projects suggested that project size and duration have influence to create more complexities in pushing the increase if costs, will increase regardless of the project type and type of users (Shrestha *et al.,* 2013). Ethiopian rail and road projects have shown that technical issues, volatile economy and changes in government policy are the main elements contributing to increased costs in projects (Kassa, 2020).

In developing countries, stakeholder's competency and slow technology adoptions as the most common issues in projects in developing countries such as Thailand, Vietnam, South Africa and Afghanistan (Yap *et al.,* ,2019). Specifically, for Malaysia, Ofori (2000) discussed the element of risk included in many factors such as delay for completion, design changes, payment delays and overrun, which are the common problems and analysis discovered that culture and leadership plays vital role in managing communication, technology adoptions, risk appetite, sustainability uptake and social wealth creation.

Update research in Malaysian projects to discover the top three causes were due to changes in material prices, cash flow or delayed payment (Memon *et al.,* 2012). Other factors such as communication, increased working hours and technical plant and equipment failures were identified as the least common factors contributing to project cost overruns. It is shown that cost overrun is not a linear cause; but a plausible causal combination and it is crucial to get to the root causes of cost overruns (Ahiaga-Dagbui *et al*., 2017). However, without the identification of the recurring problems based on observation, whilst using the existing and collated data it would be a challenging process to overcome issues to project overrun. It imperative for the client and team

members to create reusable project knowledge to assist in efficient project delivery (Egbu *et al.,* 2003).

In this first stage of research, the overall main research question is how do we determine whether we are operating within the right guidelines in managing cost within projects by identifying and quantifying projects risks during project delivery to the agreed cost, time and quality? Are we using the efficient method in the project delivery and contract administration by identifying and rationalising the cost attached to the risks, what do we know from the analysis of the issues and factors contributing to overruns? What are the key metrics of costings and how can we revamp our current working processes? Are we employing the best procurement strategy or bespoke procurement need to consider? These are questions that we aimed to uncover during the investigation.

## METHODS

In this first stage research, we are conducting a desk study on the government funded projects. We are examining Terengganu, one of the rich oil states in Malaysia to evaluate the causes and issues of project overrun. The official data was provided by client includes the background of projects and its cost management. In this stage, the aim is to identify the main causes of cost overruns by auditing the project final account statement. The projects are procured through traditional procurement strategy with competitive tendering and not the lowest tendered projects were awarded the projects. The award of tenders based on the performance during pre-qualification questionnaire (PQQ) with emphasis on project cost that near to the Client's cost plan. The type of projects includes schools, administration facility, religious facility, recreation centre, and young children's centre facilities. Only four out of all projects design teams were having external consultant whereas as the rest are in-house consultant.

Originally, interviews are intended with few cost management personnel to get a clearer picture of the factors leading to cost overruns and their impact towards project. The interview would support understanding of client and project team risk appetite in managing project and its risk. The aim is to triangulate the analysis from the official data provided by the client. However due to lockdown and most personnel working from home, contacts were struggling to be interviewed for this data collection. The interviews will be included in the next stage of this research. Therefore, this has become this research limitation, the qualitative rich data from the Main Contractor and Subcontractor will triangulate and support further analysis of "why" and "how" in this study. The official data in this study (the preliminaries cost, contract sum, final account cost, tendered cost) are considered as abstract in variation of numbers and would require sense of meaning to understand relationship between the cost and their impact including identifying risk within projects to create clarity of definition, translation into specific observables to measure the indicators of the variations (Gill and Johnson, 2002). For this study, the variables were analysed to create understanding about the relationship between cost, risks and impact of management of risk to projects, which is described in introduction section.

Firstly, the analysis starts with selecting the cases for the study. At the beginning of the study, the sample size is 34 projects with the datasets contained cost limit, gross floor area, awarded tender sum or total turn-out cost at tender stage, preliminaries and final account of each project. These formed a set criterion of selection, and the projects must have records of detailed and evidenced causes of overrun for project

with its cost breakdowns, supplied with evidence of claim certificates and variation orders. This is important to identify the issues, the cost impact of the issues including other impact such as delays and social implications such as delay in school openings and delay opening access to road closure to supplement the missing context of human interaction from qualitative study can offer. The screening process selected only 14 projects.

Secondly, the process of evaluating the impact of risks started with analysing the differences between client estimated project cost and real turn out cost at the end of the project. Whether the difference would be the overrun (or underbudget), due to issues faced during project delivery which revealed the causes of the issues. The client's estimated project cost has included provision of 15% for Overhead and Profit (OHP) for main contractor. Then, the preliminaries cost was compared against the total turn-out cost to get the percentage difference. One of the main challenges to create the rigour of the analysis is to identify and link the numbers and the problems faced in the projects because of the lack of qualitative data. The final account of the projects was analysed by breaking down each of the costing into five principal headings: work estimate, project and design team fees, other development estimate, risk allowance and inflation estimate (Benge, 2014) to analyse the impact of project cost overruns.

The third stage include the analysis of the factors that caused the over budgets based on the information requested from client. The overrun or underbudget factors were analysed based on seven categories factors identified by Memon *et al. (*2012). It is because of suitability of the nature of the projects and locality of the research as Memon *et al.,* (2012) research was based on public projects in Peninsular Malaysia.

## RESULTS

Table 1 shows the analysis of the percentage difference of final account of the cost of the project, percentage of preliminaries and percentage of OHP. The formula of the calculation included in the table heading. No separate allocation of risk and inflation included in the calculation of the tender sum, project cost and final account. To reflect the effect of inflation and fluctuation material prices in the market; the monthly payment made by Client to Main Contractor will be multiplied by material index cost. The positive figure indicate that it is within client estimated cost and negative figure meant the percentage of overrun. First observation on the spreadsheet for each case before starting the analysis revealed that there is no allocation for risk allowance estimated in the cost plan. So, this would require the researcher to determine whether the cost overruns are due to misallocation of risk or increased OHP. This will be our next of research agenda as we are still in the process of critically analysing whether the differences reflected the OHP of the main contractor or the percentage of difference representing the missing risk allowances for the project.

This would require conversations with project team and the client. In Malaysia, it is an uncommon practice for main contractor to reveal their OHP in application of tender. Risk allowances such as for design development, construction, employers change, and employers' other risks are absorbed in the rate of the work. Therefore, due to the absence of risk allowances, the Client as the Government has assumed the 15% allowances in the project cost as the OHP for each project to the main contractor. Referring to the second column from the left in Table 1, there were eight projects within the client's estimated cost. Off all these projects, all have issues with design changes, technical issues on site apart from MO2. M04, M11, M12, M13, M14 had

scope reduction which reduced the total cost. Other issues include extreme weather such as flooding, facilitation works for coastal treatment and demolition works.

*Table 1: Project's information and percentage difference of Gross Floor Area (GFA), Final Account Contract Sum, Accepted Tendered Sum*

| | Gross Floor Area (GFA)in $m_2$ | % difference between Final Account and Contract Sum (Final Account- Contract Sum)/ Contract sum | % Preliminaries (Preliminaries / Final account) x 100% | % Risk allocation (Final account - total preliminaries-building cost)/Final account) |
|---|---|---|---|---|
| M01 | 2,485 | 7.2 | 9.4 | 6.7 |
| M02 | 1,598 | -1.5 | 5.2 | -1.6 |
| M03 | 1,572 | 2.8 | 5.7 | 2.7 |
| M04 | 879 | -21.3 | 6.4 | -27.1 |
| M05 | 1,572 | 8.5 | 3.1 | 7.8 |
| M06 | 1,512 | -2.9 | 3.7 | -4.0 |
| M07 | 1,752 | 11.3 | 4.0 | 10.1 |
| M08 | 883 | -5.2 | 7.0 | -5.5 |
| M09 | 1,988 | 5.6 | 5.6 | 5.3 |
| M11 | 1,972 | -1.3 | 3.2 | -1.5 |
| M12 | 1,988 | -11.95 | 2.1 | -13.6 |
| M13 | 1,000 | -6.8 | 5.3 | -7.2 |
| M14 | 883 | -10.7 | 6.7 | -11.9 |

During this analysis, the researcher thought the differences between final account and total cost of projects (building cost + preliminaries) would be the OHP for the client, which is in the last column. However, it is not really the case for the Malaysian cost management procedure, and it is not the correct terminology to name this percentage of difference as the Main Contractor OHP. This percentage contains the changes to designs, provisional sum, design scope creep, enabling work and facilitating work such as demolition of existing building on site which is included in the package and changes in material prices which is called variation of price, which are related as financial management issue. This later described as the percentage of risk allocation. The negative amount doesn't necessarily mean that the risk has been included correctly in the rates submitted to the client. But further evaluation indicated it was mainly due to reduction in work packages or value engineering approaches implemented in the projects. On the other hand, it also shows how well the contractor priced the element of risk in their project. For example, M02 provides cost savings to the client with less 1.6% of client estimated cost.

The collated factors are analysed based on the factors identified in Memon *et al. (*2012) based on the information provided by the client. The factors are contractor site management, design and documentation, financial management, information and communication, workforce and labour, non-human resource factors and project management. In this study, all these projects have sufficient supply of labour. Only nine projects (M02, M04, M06, M08, M10, M11, M12, M13and M14) were under budgets and it is due to reduction in work packages, design changes, unspent provisional sum (provisional sum was included during the award of tender) and value engineering implementation by material substitution (M14). Nearly all project faced financial management issues due to fluctuation in market prices for materials. Malaysia has no issue of labour shortages for these projects. The main factors causing the project cost overruns is changes in contract which have consequence to the design and documentation. Nearly all projects, except M03 have the changes to architectural or structural design. The changes to design either to reduce the scope or to expand the

design to meet the project's needs. Another important recurring issues with changes in design are the design error and uncertainty issue such as earthwork. Uncertainty such as the earthwork which require temporary support or extra earthworks caused delay in project programmes. Another uncertainty and risk recurring in this study is the enabling works (categorised in project management) where work to decant existing occupant or removal of existing building to another location, have big impacts to the programme and the budget. Facilitating work such as demolition work to buildings on site took extra time and increased the budget (M05).

## DISCUSSION AND ANALYSIS

*Procedure and working process in managing cost in projects.*
All these projects in this study are delivered in traditional procurements where clients have more control in projects. The tenders are selected competitively and not awarded to lowest tender. The selection criteria based on main contractor's proposed project cost and less emphasis on the overall main contractor's performance during PQQ. This indicated that the client placed high importance on best project cost (at that time) to suits the traditional procurement strategy as well as the contract administration in projects. Is cost the main driver of the project? The analysis of the spreadsheet revealed that no data was revealed to the submitted tender. This may need further analysis as it is not a linear cause effect since the element cost in projects linked with many other entities which cause the project complexities.

Experiences have impacted in managing projects. Being an experienced client and having in-house consultants, the client team must have vast experience and data of many different types of projects which would aid in project delivery and establish relationship with supply chain partners (main contractors, nominated suppliers and specialist). The client is locally based, therefore must have local information and experiences of the state. Some of the identified risks are recurring risks such as issues with technical design on site, design changes and material delays. This would lead to questions of systematic database of previous projects as a lesson learnt in avoiding recurring issues? Each project is unique, but the construction technology of building would be similar. For bespoke designs, extra time allocation must have been included earlier in the tender's stage. Fluidity of design changes either the design expansion or reduction may affect the overall quality of the project. The project will deliver the intended function set for the facility, but it may compromise the true value and vision set by client which was agreed and tendered. Intended value such as social and economy impact is something to be considered in the next stage of study. Value engineering approaches has been adopted in one of the projects(M14). Changing the type of material through whole life costing consideration shows that value added has been included in the project delivery. What are the reasons for all projects not implementing the value engineering? Could it be due to limitations in varying levels of knowledge and appreciation across the project team?

*Risk allocation is not really the percentage of Main Contractor OHP?*
The research scoured the datasheet to uncover the level of OHP from the analysis of the cost impact to quantify the percentage of risk. It is not within the Malaysian industries culture to reveal the OHP of the projects during tender which raise the next question of what is the percentage of profit for Main Contractor? The analysis in Table 1 shows that many projects (M02, M04, M06, M11, M12, M13, M14) exceeds the client's estimated cost with 15% OHP. Most of these projects faced the recurring issues such as design changes, technical issues on site and demolition work.

However, those projects meeting the client estimated cost also have similar issues. This revealed that the misallocation of risk.

The predominant issue within this study is that it lacked clarity in risk quantification, nearly all projects have design changes either to meet the structural requirements or substructure work involving piling and earthwork or roof works for superstructure work. This is one of the cost drivers for cost overruns including the main driver which are the design changes and technical issues. Earlier, we mentioned about 15% allocation for OHP for projects set by client. Is 15% tailored for each of projects sufficient? As some of the projects with negative value for risk allocation had work package reduction and time delayed. Consideration of work package capacity including main contractor capability should have been considered. Risk is tailored to the projects and main contractor should ensure all risk have been included in the rates for tender's consideration.

The fluctuation in prices for material is important. Though Malaysia has included the factor for all main material, this should have been anticipated and included in the total project cost. This would allow the smooth delivery of projects without relying for payment for the price variation, which can affect main contractor with lacked financial stability. Malaysia construction industry requires the resilience in confronting the volatile world oil prices which have direct impact towards steel and concrete due to increased demand. In this context, the Government and the Client taking the ownership of the risk by supporting the financial differences and awarding extra financial payment termed as variation of price payment to ensure the supply agencies are able to continue and complete the projects. The disparity of oil prices and material requires a monthly index adjustment, and it certainly creates uncertainty towards clients' cash flow for their programme of projects.

*Identification and quantification of risk in management of projects*

Based on the analysis on the factors of project cost overruns, most issues relating to the over or underbudgets are due to design changes. Since it is traditional procurement, the client should ensure the design would work on site. Has the client considered the early involvement of contractor? Any issues relating to design would go to client but the buildability on site should be with the contractor. The element of innovation could have been promoted during tendering to allow for an innovative approach from contractor. The traditional single stage tendering may restrict innovation in projects, other variations such as design and build may reduce client governance and control. However, selected main contractor should offer an early participation through two stage traditional procurement tendering. This may increase front end period of the project, but it may offer buildability and certainty. The early involvement also provides opportunities for the main contractor to manage its supply chain.

The missing element for design risk, construction risk and design development risk and the ownership of the risk involved in changes in policy. The absence of the risk allowances would expose client to cost overruns, delays and lower quality. Each type of risk would compel the main contractor to unpack each task to identify the risk and rationalise the cost attached to risk.

## CONCLUSIONS

The aim of this paper is identifying the main driver of cost overruns in projects and finding the link on how these drivers impact risk allocation and how they are managed

between parties. The analysis revealed that the main factors driving the cost overruns are due to design changes and technical issues. This type of controllable risk should be classified as design risk and included with the design element of the work with the distribution and work package workload. Client may need to unpack the work package of the project based on contractor capacity and capability with the availability of resources to ensure minimum disruption to the projects. Being responsive and agile in forecasting external risk such as inflation, world oil prices and sudden increase in material prices such as steel and concrete will be the crucial driving force that changes the certainty of the agreed tenders sum, which was proposed earlier by Dubois and Garde (2002). The use of factor index may offer security from the client however it is not a win-win situation for the client as clients bear the risk of price variation in order to have the project completed. The client has policies in regard to the support of the external risk however, the organisation needs to create risk culture with their supply chain partners to be clearly communicated and promoted. Reward and initiative have been one of approaches to promote organisations to work efficiently. Value engineering should have been the essence at the idea generation stage and promoted across the projects with all tenderers. The client may consider including value engineering as one of the prerequisites for tender's acceptance to promote innovation.

In this current climate, the main question is our affordability to deliver the project sustainably with socially desirable values. The client and project teams will need to be agile and transparent in appraising for better options for projects. The Pandemic had taught us about emerging risks and the clients including project teams needs to reconsider the project settings and changing strategies in project priorities. Creating risk profile to produce risk taxonomies would assist the client and team to identify risk and criteria for project delivery. In this study transparency about profits and others is one of the hardest challenges as advocated earlier in literature by Andersen, Samset and Wilde (2016). This requires a culture change where everyone would be in a win-win situation. This study will be the springboard for the next analysis and evaluation by gathering more data from projects to update the risk categories to form the taxonomies. This would create usable knowledge for the risks and the uncertainties to assist in the quantification of risks and ultimately the cost management of a project.

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# INTER-ORGANISATIONAL COLLABORATION IN MEGAPROJECTS: A DYNAMIC MODEL OF COLLABORATIVE AND OPPORTUNISTIC BEHAVIOUR

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Megaprojects are one-time endeavours costing more than one billion dollars, taking many years to complete, and involving multiple stakeholders. For the development and execution of megaprojects, an unprecedented number of organisations therefore enter into inter-organisational collaboration (IOC) with commitments to sharing common goals and working together. Although there are mechanisms governing IOC by facilitating collaborative behaviour as well as restraining opportunistic behaviour, an insight into how a specific behaviour might emerge and unfold over time remains unclear. Based on System Dynamics (SD), this study presents a conceptual model to understand how collaborative and opportunistic behaviour unfolds over time and induces the dynamics of IOC. SD has shown its feasibility and appropriateness for shedding light on complex relationships between components and feedbacks. A casual loop diagram was developed through three main steps: (1) identifying key parameters related to collaborative and opportunistic behaviour on the basis of the literature; (2) analysing the cause-effect relationships between the identified parameters; (3) identifying feedback loops. The result of this study can deepen the understanding of what happens inside the black box of IOC by showing the dynamic interplay between collaborative and opportunistic behaviour.

Keywords: megaprojects; collaboration; opportunistic behaviour; system dynamics

## INTRODUCTION

The last several decades have seen the rise of megaprojects globally, such as the Channel tunnel in Europe, the Three Gorges dam in China, the 'Big Dig' in the USA and Sydney Opera House in Australia, which have shaped our modern society. While megaprojects share several similarities with general projects, they are characterised with high complexity, expensive cost, specialised knowledge and massive resource which is impossible to be handled by a single organisation (Daniel and Daniel, 2019). An unprecedented number of organisations therefore enter inter-organisational collaboration (IOC) with commitments to sharing common goals and working together. IOC for megaproject implementation can take various forms such as coalition, project alliance and joint venture.

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Although all forms can be effective ways to facilitate IOC development and improve megaproject performance, organisations' attitude and behaviour is not easy to be changed. For example, the failure of project alliance adoption in the Environ megaproject was reported by Van Marrewijk (2005) because the involved organisations remained behaving uncooperatively. In addition, Siemiatycki (2006) observed from a megaproject that expected benefits of public-private partnership were not achieved as the government was used to being a traditional client and showed less openness to its private partners leading to cost escalation. Without a shift in attitude and behaviour, collaboration required or stated in contracts is mere lip service and non-cooperative relationships continue to be widespread (Costa *et al.,* 2019). Thus, the behavioural aspect is a key component that should be considered in IOC.

Most of the megaproject research to date have studied IOC from the perspective of governance mechanisms (Derakhshan *et al.,* 2020; Xue *et al.,* 2017). Contractual and relational governance mechanisms are two most commonly observed types (Zheng *et al.,* 2019). Contractual governance is based on transaction cost economics and emphasises the importance of formal and legal contracts to stipulate the allocation of benefits and risks and govern inter-organisational exchanges (Lumineau *et al.,* 2011). Relational governance is based on the relational exchange theory and focuses on enhancing the relationship quality by less explicit social norms such as sharing goals (Lu et a., 2015). Both contractual and relational governance mechanisms proved useful insight about conditions motivating and facilitating collaborative behaviour as well as restraining opportunistic behaviour. However, these mechanisms do not tell how a specific behaviour might emerge and unfold over time, ignoring of which might result in governance ineffectiveness.

Behavioural aspects with a dynamic view, thus, is suggested to be essential to understanding IOC and adopting appropriate governance mechanisms. With the aid of system dynamic approach (SD), this paper presents a first step in this direction by proposing a conceptual framework, based on previous literature, of how collaborative and opportunistic behaviour unfolds over time and induces IOC dynamics. There are two reasons for justifying SD as an appropriate method. First, there are a number of elements including antecedents and consequences related to both collaborative and opportunistic behaviour and their relationships are complicated that can be positive or negative, and linear or non-linear. SD is a well-developed method for identifying complex cause-effect relationships and facilitating a better understanding with visualisation. Second, highly interdependent elements can induce behavioural changes resulting in the evolution of IOC. SD is able to open such "black box" by discovering feedback loops regarding collaborative and opportunistic behaviour and illustrating the dynamics of IOC with a holistic and systematic view.

## LITERATURE REVIEW

One of the fundamental problems that IOC faces, especially in megaprojects with high levels of complexity and uncertainty, is the inherent conflict between individual interest and collective interest (Xue *et al.,* 2017). On the one hand, megaprojects as temporary endeavours gathering different organisations to work towards a common goal depend on high level of collaboration among participants whose efforts are integrated to maximise collective interests. On the other hand, organisations have inherent incentives to maximise self-interests by choosing opportunistic behaviour. Opportunistic behaviour is distinguished from other self-interest-seeking behaviour given its characteristic of 'guile' that self-interest is maximised at the expense of other

parties (Williamson, 1985). Such behaviour is observed prevailing under conditions of information asymmetry, conflicting goals between different organisations, highly uncertainty and complexity like megaprojects (Galvin *et al.,* 2021).

The extant literature has for the most part concentrated on promoting collaborative behaviour. For example, Zhang *et al.,* (2018) examined the effect of the interplay of contract functions and owners' power on contractors' collaborative behaviour. Inspired by prior research, they studied two types of collaborative behaviour: in-role and extra-role. In-role collaborative behaviour refers to mandatory responsibility explicitly described in contracts; extra-role collaborative behaviour refers to positive behaviour that has not been directly motivated by formal contracts. On the basis of Chinese construction industry, Zhang *et al.,* (2018) found that both owners' power and contractual coordination have positive effect on collaborative behaviour and contractual functions can mediate the effect of owners' power on collaboration. Similarly, Song *et al.,* (2018) also examined the effect of contractual governance on contractor's collaborative behaviour in the Chinese construction industry but focusing on contractual flexibility and risk allocation respectively, with the consideration of justice perception as a mediator. Such argument is supported in more recently by Lu *et al.,* (2020), who found that contractor's collaborative behaviour is strengthened when justice is perceived in the process of contract execution.

In addition, the opportunistic behaviour is another topic that has drawn much attention in the literature associated with its drivers and consequences. For instance, Ikuabe *et al.,* (2020) argued that project uncertainty such as unclear scope of work leads to opportunistic tendency, which has a positive effect on transactional cost. Chaudhry (2020) explained that the increase of transactional cost caused by opportunism would undermine project relationship as partners show less willingness to engage when the loss is perceived. A more comprehensive picture is shown in Lu *et al.,* (2016) and Um and Kim (2018) who suggested that high level of project uncertainty leads to opportunism, which negatively impacts project performance and project relationship. Other studies, like those focusing on collaborative behaviour, have also discussed the influence of psychological factors, such as the negative effect of justice perception on opportunistic behaviour (Feng *et al.,* 2021).

The literature on collaborative behaviour highlighted contract design and its execution process regarding the psychological aspects; while the literature on opportunistic behaviour has to a large extent discussed its drivers/inhibitors such as project uncertainty and justice perception, and consequences like transactional cost, project relationship and project performance. The extant literature shows that collaborative and opportunistic behaviour is still studied separately, indicating they are two research stream and capturing the interplay of them only implicitly. On the basis of behavioural and psychological perspectives, this paper aims to systematically tackle with the interaction between collaboration and opportunism in megaproject context.

## Model Development

### *Steps of model development*

SD, initially introduced by Forrester in 1950s (Forrester, 1961), is based on system thinking to understand internal relations between a set of parameters from a feedback view that a change in one parameter affects others which instigates modifications in the original parameter in return. In this way, an integrated pattern is provided showing how the feedback loops a system contains can lead to its dynamic behaviour over time (Bouloiz *et al.,* 2013). It has been recognised that SD modelling tools can

be classified into two main types: (1) qualitative modelling that system boundary is defined, key elements are identified, and cause-effect relationships are explained leading to a causal loop diagram (CLD); (2) quantitative modelling that elements and relationships are quantified as variables mathematic formulas leading to a stock and flow diagram (SFD) (Sales and Barbalho, 2018). As this paper presents the initial work of the three-year research achieved based on literature review, most of the information available for modelling is qualitative and descriptive. Thus, a qualitative SD modelling tool was developed and used here.

The model is constructed with four steps (Fig 1).

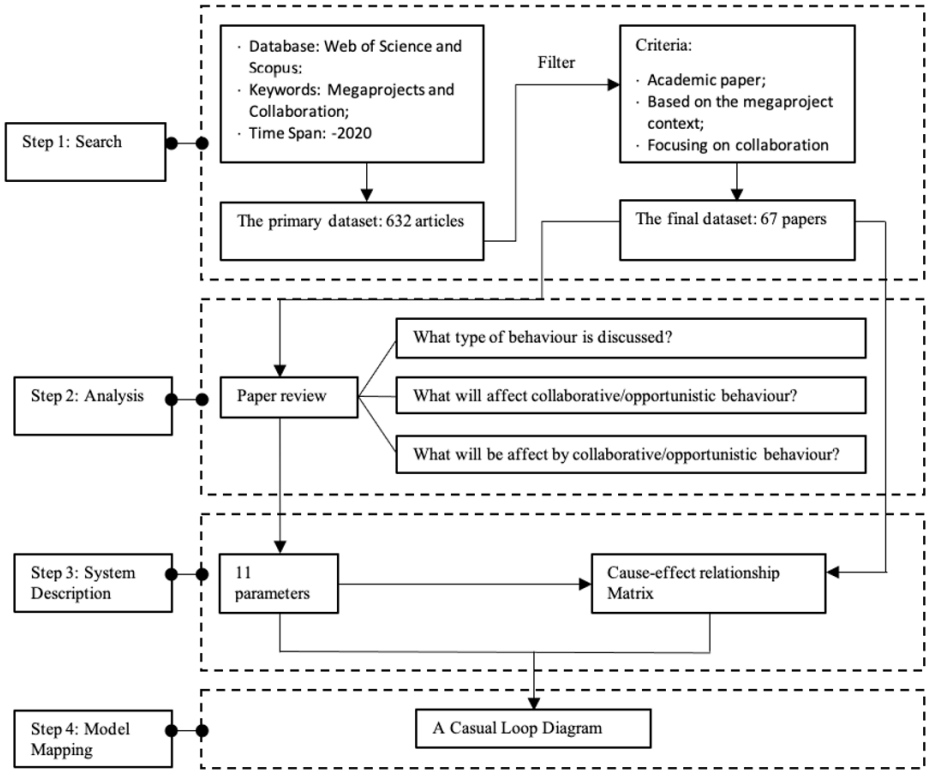


*Fig 1: Steps of model development*

First of all, the data used to define the system's boundary was collected. A total of 67 papers concerning collaboration in megaprojects was selected. Then, each paper was analysed to identify parameters drawing on three selection criteria. Third, the boundary of the system is determined by identified parameters and their relationships. The Decision-making trial and evaluation laboratory (DEMATEL) method adapted from Jalal and Shoar (2019) was used to identify cause-effect relationships between these parameters. In the DEMATEL method, there is an adjacency matrix in which mij denotes the direct impact of element i to element j. Experts are invited to complete this matrix by express where there is an influence from i to j. In this study, each selected paper serves as an expert and if the influence from i to j is mentioned/discussed in n papers (n=1 to 67), the corresponding cell would have a value of n, otherwise it would be 0. Afterwards, a casual loop diagram was developed and key feedback loops were identified and described.

**System description**

Based on the analysis of selected papers, 11 key parameters were selected defining the boundary of the system (Table 1). Following the aforementioned literature review,

collaborative and opportunistic behaviour was identified as two key parameters. Factors which can affect either collaborative or opportunistic behaviour or both involve transactional cost, profits, fairness, external pressure, dependency, non-financial capital and uncertainty. Consequences of behaviour adoption involve project performance and relationship quality. Referring to selected papers, the meaning of these parameters in this study are explained in Table 1.

*Table 1: Identified parameters*

| Code | Elements | Explanation |
|---|---|---|
| P1 | Collaborative behaviour | Refers to desired actions involved in the exchange activities contributing to shaping and promoting collaborative relationships. Open information exchange, joint problem-solving and flexibility are three key components of collaborative behaviour. |
| P2 | Opportunistic behaviour | Refers to seeking interests with fraud like stealing, cheating, misleading, distorting and disguising. Opportunism can be easily induced by high asymmetry and uncertainty. |
| P3 | Project performance | Measured with the iron triangle involving time, cost and quality. |
| P4 | Relationship quality | Refers to the strength of connection between organisations. It can be measured by the degree of closeness, the frequency of interaction, the level of input and the consistency of goals. |
| P5 | Transactional cost | Refers to cost associated with transaction activities. It is one of significant risks as additional cost occurs to develop and maintain inter-organisational collaboration according to transaction cost economics. |
| P6 | Profits | Refer to short-term and financial benefits. |
| P7 | Fairness | Refers to the equity perceived during the interaction process. |
| P8 | External pressure | The behaviour of an organisation can be influenced by external expectations. Many of megaprojects are public infrastructure and the government is one of the key sponsors. External pressure such as political appeal and public satisfaction might strength firms' willingness to conduct collaborative behaviour. |
| P9 | Dependency | An organisation is unable to control over the megaproject and conducts activities alone. Thus, to make decisions and get work done, an involved part needs external information and resources, and dependency is inevitable. |
| P10 | Non-financial capital | Involves social, cultural and intellectual capital. Organisations with social capital are more likely to acquire external resources and knowledge as well as influence partners' behaviour. Cultural capital build on the firm's reputation such as credibility and capability of successfully delivering a promise. Intellectual capital involves skills, competences and knowledges ensuring firm's sustainability and competitiveness. |
| P11 | Uncertainty | Refers to the inability to predict accurately. It consists of two types: (1) internal uncertainty, closely related to the ambiguous of partners' behaviour; (2) external uncertainty, related to the external environment with various unpredictable changes. |

The cause-effect relationship between the identified parameters is shown in Table 2. The value in a cell refers to the effect of parameter a on parameter b. For example, m13=7 indicates that the positive effect of P1 (collaborative behaviour) on P3 (project performance) is mentioned 7 times. The value also indicates the link strength showing how strongly P1 is linked to P3. In addition, the negative relationship between two elements is marked with a minus symbol. For example, m23=-1 indicates that the negative effect of P2 (opportunistic behaviour) on P3 (project performance). Consequently, a total of 26 cause-effect relationship are identified based on the adapted DEMATEL method.

*Table 2: Cause-effect relationship matrix of the identified parameters*

| | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | | | 7 | 5 | -1 | | | | 1 | 2 | -1 |
| P2 | | | -1 | -1 | 2 | 2 | | | | | |
| P3 | 1 | | | | | 1 | | | | | |
| P4 | 3 | -1 | 2 | | -2 | | | | | 3 | |
| P5 | -1 | 1 | | | | | | | | | |
| P6 | 1 | | | | | | | | | | |
| P7 | 1 | -1 | | | | | | | | | |
| P8 | 4 | | | | | | | | | | |
| P9 | 5 | | | | | | | | | | 2 |
| P10 | 5 | | | | -1 | | | | | | |
| P11 | | 3 | | | 1 | | | | | | |

## A casual loop diagram

After defining the boundary of the system, a casual loop diagram visualising the interactions among parameters was developed (Fig 2). In the diagram, curved arrows represent casual relationships between these parameters. The symbol "+" represents a positive relationship which could be linear or non-linear, while the symbol "-" represents a negative relationship between the connected parameters.

As for the collaboration, for example, the reinforcement of collaborative behaviour adoption depends on factors like project performance, relationship quality, non-financial capital, transactional cost and dependency. Collaborative behaviour can generate both short-term benefits comprising low cost, short duration, high quality and more profits and long-term benefits consisting of high-quality relationship and accumulated non-financial capital. The perceived benefits encourage an organisation with more willingness to conduct collaborative behaviour. It is essential to note that positive attitude towards collaborative behaviour can be strengthened by the perceived fairness. For example, organisations have good reasons to engage in collaboration if the benefits are allocated fairly (Lu *et al.,* 2020). Also, organisations with more dependency on external resources are more prone to conduct collaborative behaviour, which in return increasing the interconnections among organisations leading to a higher level of dependency. In addition to internal motivations, incentives for collaborative behaviour in megaprojects can be external. By exposure to political and social environment, organisations are likely to behave collaboratively so as to achieve political appeal and public satisfaction.

In case of opportunistic behaviour, project uncertainty and transactional cost are observed as two key drivers (Ikuabe *et al.,* 2020). While there are inherent incentives to choose individual rationality for short-term profits and self-interest maximisation, opportunistic behaviour is encouraged when substantial resources are invested with little certainty about the value achieved. Opportunism which means that organisations pursue profits by cheating at the expense of partners' interests will cause the damage to relationship quality (Chaudhry, 2020), hinders high project performance, as well as induce additional cost and time to develop and maintain relational transactions. Meanwhile, in a less harmonious environment, few benefits related to collaboration are perceived and organisations are more likely to adopt opportunism to increase short-term interests. Moreover, the unfairness perceived during the interaction process increases the probability of opportunistic behaviour (Feng et a., 2021).

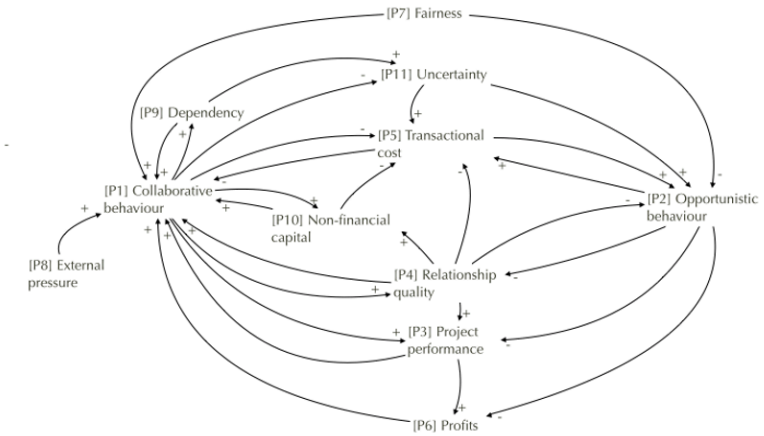


*Fig 2: The casual loop diagram*

The interplay between collaborative and opportunistic behaviour is observed as one important aspect involving several complex and overlapping feedback loops. When collaborative behaviour is adopted, transactional cost is prone to decrease resulting in low motivation for opportunistic behaviour. With depressed opportunism, negative impacts om project performance and relationship quality are mitigated, which induces more positive attitude and confidence towards collaborative behaviour. However, transactional cost is not simply related to collaborative behaviour. It also has positive relationship with project uncertainty. In other words, the effect of collaborative behaviour on transactional cost decrease might be weakened if project uncertainty is high. In addition to such reinforcing loop example, there are balancing loops involving collaborative and opportunistic behaviour. For instance, dependency strengthened by collaboration indicates that decision making and actions of an organisation rely more on partners, which increase risks of behavioural and internal uncertainties. When there are higher uncertainties perceived, an organisation is prone to choose opportunistic behaviour to assure short-term benefits while this results in higher transactional cost, which in return dis-encourages collaborative behaviour and an organisation might be more independent. This then restarts the loop leading to a balance between collaborative and opportunistic behaviour.

## CONCLUSIONS

This paper explored psychological and behavioural perspectives of IOC in megaproject context. In particular, the SD approach was adopted structuring the literature review process and offering an in-depth investigation of how collaborative and opportunistic behaviour develops over time and induces the dynamics of collaboration between participated organisations. By reviewing the extant literature, 11 key parameters and cause-effect relationships between them were identified and a casual loop diagram was proposed. The findings partly support prior research by showing that collaborative behaviour can be motivated by additional profits, fairness perceived and external requirements, project and relationship performances; while factors such as lack of fairness, uncertainty, increased transactional cost and poor relationship quality are more likely to result in opportunistic behaviour. Also, balancing feedback loops involving both collaborative and opportunistic behaviour show that there are equilibriums not only inhibiting very close collaborative relationship but also preventing high levels of opportunisms.

This paper offers two contributions. First, most of the megaproject research to date have studied IOC from the perspective of governance mechanisms regarding choosing appropriate approaches to foster collaboration and restrain opportunism. This study contributes by investigating psychological and behavioural aspects of IOC to understand why and how collaboration and opportunism can emerge and decrease. Second, the existing literature captures the interplay between collaborative and opportunistic behaviour only implicitly. This paper provides a conceptual model for a systematic understanding of the dynamic interaction.

Despite the contributions, there are some methodological limitations. First, dynamic parameters and cause-effect chains are based on existing studies. Thus, testing the validation of proposed model and its accuracy in reflecting the real world should be further explored. Second, a casual loop diagram is established to describe the interplay between collaborative and opportunistic behaviour. To facilitate a better understanding, quantifying elements and their relationships so as to run the computer-based simulation should be further explored. Third, the scope of this study only focused on the psychological and behavioural aspects. Future work should consider the interaction between behaviour and governance mechanisms so as to select appropriate mechanisms for a specific IOC state.

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# THE ROLE OF RISK ATTITUDES: DISCREPANCIES BETWEEN HUMAN AND COMPUTER-BASED RISK ANALYSIS IN THE UTILITY SECTOR

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To prevent excavation damages to utilities, as well as their negative side effects, the utility construction domain is hammering on the importance of localizing utilities in advance of excavation activities. Until now, the predominantly applied way of locating utilities is to dig trial trenches. Trial trenches expose utilities and are, therefore, considered the only method that grants absolute certainty about the utilities' locations. On the contrary, trial trenches only provide a local measure and thus require understanding about where to dig a trench. This study explores the rationale behind the trial trench method in practice to assess how effective risk on excavation damages is managed by the method. To assess the effectiveness, a computer-based risk analysis tool that calculates the level of excavation damage risk on a given construction site was used as a benchmark. After conducting a practice-based study in which the trial trench method of three Dutch construction projects was observed, the outcomes of the risk analysis tool were compared with the locations of the trenches dug in practice. Findings demonstrate differences: The number of trial trenches dug in practice is remarkably fewer than suggested by the risk analysis, whilst the locations themselves often do not align with where the risks are the greatest. The study shows that a root cause for the differences between the tool and practice is the difference in the motivation behind digging trial trenches. Illustrative examples of these differences show that the adopted risk management approaches are typically guided by both the decision-maker's risk attitude, including their intuition, judgement and expertise of the decision-maker, and time and budgetary constraints. All in all, this study demonstrates that the sense of accuracy provided by employing trial trenches cannot always be taken for granted. This study furthermore urges practice to rethink their excavation damage risk management approaches, whilst recommending the institutional setting to steer their initiatives towards establishing a mindset of careful excavation amongst the practice community.

Keywords: computer-based tools; excavation; risk management; utility sector

## INTRODUCTION

The construction industry is known for being an industry exposed to high levels of risk, due to the nature of its construction activities, processes, environment and organization (Akintoye and MacLeod 1997). Organizations in the construction industry are continuously confronted with a plethora of situations that may involve many unknown, unexpected, undesirable, or unpredictable factors (Fong 1987).

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Albeit being risk-prone, the construction industry has a poor reputation in coping with risk as many construction projects know time and cost-overruns (Shevchenko *et al.,* 2008). Also, safety in construction still underperforms (Haslam *et al.,* 2005) while more and more environmental and societal factors need to be taken into account during construction works. Due to the complexity and types of risks associated with construction projects and their activities, risk management has become a central topic of discussion in construction management literature.

Risk management is the process of identifying, analysing and assessing the risks the construction project is exposed to so that a conscious decision can be taken on how to handle these risks (Markmann *et al.,* 2013). However, as explained by Simon (1997), decision-makers are typically bounded by rationality, resulting in sub-optimal decision-making. With the rise of computer-based tools and digitization efforts in the construction industry, various authors have, therefore, suggested using computer-based tools to lessen human error during decision-making and improve the effectiveness of risk management activities (Akintoye and MacLeod 1997; Yildiz *et al.,* 2014). Surprisingly, especially given the many uncertainties in construction projects, the added benefit of computer-based risk management is often questioned in practice (Akintoye and MacLeod 1997). One sector in the construction industry dealing with high uncertainties and risks daily, while seemingly marginalizing the use of computer-based risk management tools, is the utility sector.

Utilities concern the cables and pipes that are responsible for transporting water, gas, electricity, telecommunication, sewage, heating and other services (Costello *et al.,* 2007; Jaw and Hashim 2013). Since many of the utilities are buried in the ground, the whereabouts of buried utilities are typically unseen from the surface. Therefore, new construction, maintenance, and remediation projects that work with or nearby buried utilities face a risk of damaging utilities in the process of excavation. The increasing variety and density of the networks of buried utilities due to urban growth, the development of new communication technologies (Jaw and Hashim 2013) and the energy transition (Kern and Smith 2008) further complicates excavation activities.

To prevent excavation damages, and their negative side-effects, accurate and comprehensive information about the utilities' locations and attributes are required (Chapman *et al.,* 2007; Jaw and Hashim 2013). To acquire this information, exposing utilities via trial trenches to visually inspect the buried utilities is the predominantly applied method (Lai *et al.,* 2018). However, trial trenches only provide a local measure at the point where the trench is dug. This means an understanding by the decision-maker is required about the involved risks, to make a cautious decision on where to locate the trial trenches. In combination with the uncertainty about the whereabouts of the utilities, room for human error exists, potentially leading to sub-optimal decision making.

Following this introduction, this study assesses the effectiveness of the trial trench method by comparing trial trench locations chosen by human decision-makers with those locations suggested by a previously developed excavation damage risk analysis tool. This computer-based tool calculates the level of risk to excavation damages on a given construction site, and suggest, given the calculated risk level, where to dig trial trenches. Insights from this comparison may provide valuable lessons for optimization of the utility locating practice in specific and the value of computer-based risk management tools in construction in general.

This study is outlined as follows. First, the related literature on risk management in the construction and the utility sector is described. Then, it is explained how the computer-based risk analysis tool was used to assess the effectiveness of the trial trench method, followed by elaborating on the differences and similarities found. Finally, the findings are compared with the literature before the study is concluded.

## BACKGROUND AND RELATED LITERATURE

According to the ISO 31000:2018, a risk is considered the effect of uncertainty on objectives, resulting in a deviation from the expected, leading to economic, environmental or societal consequences, to manage risks in construction, Flanagan and Norman (1997) describe risk management as being a process with four distinct phases (Fig 1). First, risk identification, in which the source and type of the risks are identified. Second, risk classification, in which the type of risks and the effect on the construction project are determined. Third, risk analysis in which the consequences and impact of the risks are evaluated. Fourth, the risk response, in which is decided how the risk should be handled. The entire process is thereby influenced by the risk attitude of the decision-maker.

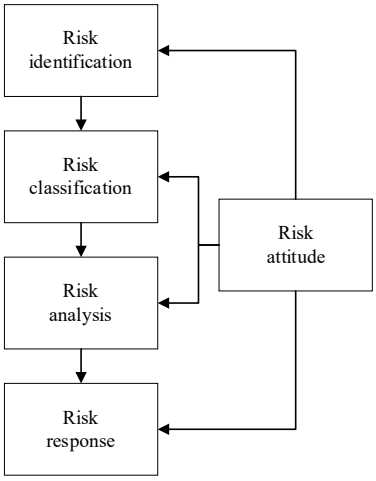


*Fig 1: Risk management framework in the construction industry*

As part of the risk attitude, decision-makers typically rely on their intuition, judgement and expertise. Due to an often lack of precise information or knowledge of the risks by the decision-maker, also known as bounded rationality (Simon 1997), inconsistencies and vagueness in the risk management process lead to sub-optimal decision-making (Yildiz *et al.,* 2014). Zooming in on the decision-making itself, Rasmussen (1983) explains three types of errors that can be devoted to the risk management process: (1) skill-based, (2) rule-based and (3) knowledge-based. Skill-based errors are the result of misapplying established expertise. This happens when a decision-maker knows how to proceed but accidentally makes an error. Rule-based errors are the result of applying incorrect rules, which are typically created in case a decision-maker lacks the expertise and relies on rules instead. Knowledge-based errors are the result of a decision-maker lacking the knowledge to adapt to new situations.

The uptake of digitization efforts in the construction industry shapes opportunities to use computer-based tools in support of the risk management process to lessen human error (Akintoye and MacLeod 1997; Yildiz *et al.,* 2014). According to Akintoye and MacLeod (1997), computer-based tools are superior to traditional methods. One major reason is that computer-based tools are more capable to deal with dynamic and

uncertain environments in comparison with human decision-makers. Despite the theoretical benefits of computer-based risk management tools, the use of these tools is seemingly marginalized in the uncertainty fed utility locating practice.

Generally speaking, four utility locating methods exist: (1) review of utility maps, (2) reconnaissance of the site, (3) use of (geophysical) detection methods, and (4) visual inspection by exposing the utilities through trial trenches. Since exposing utilities is the only method that provides absolute certainty about the utilities location's, trial trenches are still the predominantly applied locating method. However, trial trenches only provide a local measure at the point where the trench is dug and thus require understanding about where to be employed. The effectiveness of trial trenches as a risk management approach, therefore, largely depends on the decisions made by the decision-maker on where to locate the trenches. As part of the decision, the uncertainty about the whereabouts of the utilities leaves much room for human error. Arguably, in combination with the vast number of excavations and associated damage every year, the current effectiveness of the trial trench as a risk management approach seems questionable.

Utility locating is, however, considered a highly challenging task. Utility maps are often inaccurate, incomplete, out of date, or even lacking, whereas the location of utilities is typically only registered in the horizontal plane (Metje *et al.,* 2007). The predominantly applied method to improve the accuracy and comprehensiveness of the utility information is to expose utilities by digging trial trenches. However, trenches are costly, labour-intensive, disturbing, and risk excavation damages while only providing local insights (Costello *et al.,* 2007). Therefore, decisions are made on where and how many trial trenches are dug. Since a root cause of excavation damages is insufficient utility locating before excavation activities (Talmaki and Kamat 2014), the current effectiveness of the trial trench to prevent excavation damages seems questionable. To illustrate, in 2019, over 453.000 damages in the United States (CGA 2019) and over 40.000 in the Netherlands (AT 2020) were reported. These unintentional damages not only interrupt the utility services, but also contribute to project delays, road closures, environmental damages, and fatal and nonfatal accidents (Li *et al.,* 2015; Makana *et al.,* 2018). To illustrate, Li *et al.,* (2015) investigated 10.620 pipeline damages between 1993 and 2013 and found that these excavation damages accounted for 163 fatal injuries, 650 nonfatal injuries and approximately $650 million in property damage.

Following this theoretical notion, this study explores the trial trench rationale to assess how effective the method is currently applied by human decision-makers when compared to a computer-based tool. In specific, this study examines the Dutch utility sector, which primarily uses the combination of utility plans verified by trial trenches in their locating practice. Dutch legislation hammers on the requirement of having an accurate location of utilities at excavation sites, whereas a directive serves as a guideline for safe excavation nearby utilities in practice (ter Huurne *et al.,* 2020). Neither the legislation nor the directive, however, prescribes on which locations to dig trial trenches.

## RESEARCH METHOD

The effectiveness of the trial trench method has received limited attention in construction management literature. Therefore, an exploratory research approach was considered most effective. In specific, this study conducts a qualitative comparative case study to gain insights into the topic investigated (Yin 2014). The empirical

setting comprises three utility localization cases in the Dutch utility sector. In each case, the utility localization practice was carried out by a contractor, by order of the client, the utility owner. All three cases knew different contractors and utility owners. The trial trenches observed were dug as part of the investigation of the construction site before the actual start of the work. For all three cases, the main purpose of the project was to install new cables and pipes.

Data were collected by observing the trial trench method and conducting interviews with the decision-makers of the trial trench locations. During the observations, the researcher also had unstructured dialogues with the practitioners on-site. The dialogues provided additional clarification of the actions performed. The observations took, depending on the case, one or two full working days. In advance of the observations, the researcher conducted semi-structured interviews with those in charge of the decision-making process regarding the trial trench locations, respectively being project managers, engineers and foremen. Via both the observations and the interviews, insights were acquired into the risk management rationale from both the operational and managerial perspective. All participants were informed about the purpose of the research and the procedures to be undertaken before the data collection, allowing the practitioners to make an informed decision on their willingness to participate in the research. Besides, participation was entirely voluntary and all collected data was anonymized.

After data collection, the risk of excavation damage on the construction site was calculated via a computer-based risk analysis tool. The computer-based tool used in this study is a continuation of the work of Racz (2017a; 2017b). The tool incorporates expert knowledge to calculate risk scores. Multiple parameters obtained from the fieldwork were used for the calculation, including the utility type (e.g. gas or electricity), the utility material, the type of planned construction activities at the site (ranging from low risk to high risk) and the type of area the activities took place (e.g. the type of land use and type of soil). By creating a grid on the utility maps, the tool calculates the corresponding risk level for every single square of the grid. The risk is calculated by multiplying the probability of damaging the utilities with the consequences of the damage. Consequences are from economic, environmental, and health and safety-related nature. This study does not further elaborate on the development of the computer-based tool, but rather focuses on its functioning.

The analysis of the data is twofold. First, the risk management framework (Fig 1) adopted from Flanagan and Norman (1997) was used as a conceptual framework to understand and explicate the risk management rationale behind the trial trench method. Second, this study quantitively and qualitatively compared the outcomes of the computer-based tool with the locations of trial trenches as depicted by the human decision-makers. The tool was used to analyse where human decision-makers depict trial trench locations and how these correspond with the risk score of the tool to highlight differences and similarities.

## FINDINGS

The risk management process in none of the three cases was formalized or documented in organizational policies or protocols. The decision-makers decided on where to dig trial trenches based upon their intuition, judgement and expertise. Assessment of the risk management process against the risk management framework (Fig 1) shows the following results.

In terms of risk identification, it was found that the main source of risks is the often incomplete and unreliable utility maps. The observations and interviews show that the main motivation behind digging trenches was to verify the location of cables and pipes, in the x, y and z location. Interestingly, for all cases, practitioners mentioned that the main purpose of having that information is to check the preliminary design of the new cables and pipes against the in-situ situation. In specific, the consequences of concern are potential physical clashes between the design of the to be installed cables and pipes with the layout of the existing network of cables and pipes in-situ. One practitioner explained the need for trenches as following:

"We need to know whether there is enough free space to install the new (electricity) cables. Is the information as shown on the utility maps is correct or not? The only way to be sure is to dig a trial trench."

Regarding the risk classification, practitioners explain that clashes between a preliminary design with the layout of the existing buried utilities needed to be prevented. If the design clashes with the in-situ situation, it was explained that this typically leads to huge project delays and vast additional expenditures.

In terms of risk analysis, both the observations and interviews did not show any type of expressed analytic behaviour. Practitioners used their intuition, judgement and expertise to determine the risk-prone locations. No formalized or quantitative assessments were done to estimate the consequences of damaged utilities. When asked why particular locations were chosen, a practitioner answered:

"We always do it like this (e.g., digging trial trenches). We consult the utility maps and decide where we think the right locations for the trial trenches are".

Yet, a commonality between the cases showed that so-called 'bottlenecks' were typically a reason to dig a trial trench on that spot, showing a sense of rule-based behaviour. Such bottlenecks included amongst other crossings with the utilities, corners in the utility path, or locations where horizontal directional drilling had to be carried out. These were considered spots where the preliminary design faces the highest risk of not fitting in.

As a risk response, trial trenches were dug at the locations of marked bottlenecks. However, besides the bottlenecks, practitioners mentioned that other locations of trenches were typically not selected, being considered less important to the design. And if they were selected, they were based upon their gut feeling. In two of the three cases, this meant besides the trenches at the bottlenecks, no other trenches were deemed necessary to manage the (identified) risks. A remark made by one of the project managers for not digging more trial trench locations was:

"We take a bit of a gamble. We assume that the utilities go in a straight line from trench to trench, but of course you never know for sure. The construction site cannot simply be opened up entirely".

Another notion to be made is that during the observations, in several cases the cables and pipes were not found within the trench. Yet, no additional trenches were dug in those cases, because of constraints in the time and budget. As in one case, these constraints were illustrated by the project manager:

"The new cable or pipe needs to be installed in an as brief as possible time, with the least amount of costs".

When comparing the risk management process as carried out by practice with the computer-based risk analysis tool, the first thing that stands out is the type of risks taken into consideration. Where the computer-based tool is truly focused on the consequences of excavation damages, albeit it being from economic, environmental or health and safety-related nature, the process in practice is seemingly overlooking these types of consequences. The main risk as perceived by practice are physical classes between the design of the new cables and pipes and the in-situ situation.

Looking at the locations of the trial trenches, two differences are observed. First, the number of trial trenches is remarkably fewer than suggested by the computer-based tool as shown in Table 1. This means many risk-prone locations are not investigated in practice. At the same time, the location of trenches occasionally does not align with where the risks are the greatest as suggested by the computer-based tool. Interesting is the often-subtle difference in location, where the tool suggests a trial trench location just a few meters from the spot where the actual trench was dug in practice. In numbers, on average less than twenty per cent of the dug trenches by practice did correspond with those suggested by the computer-based risk analysis tool as high-risk.

*Table 1: Comparison of the number of locations of interest for investigation*

| | Locations investigated in practice | Locations suggested by the computer-based tool |
|---|---|---|
| Case 1 | 10 | 21 |
| Case 2 | 12 | 110 |
| Case 3 | 123 | 2850 |

The findings altogether show that the location of trenches in practice often do not correspond with high-risk locations. The main reason is the risk attitude of practice. Preventing physical clashes between to be installed cables and pipes and the in-situ situation seems to prevail over preventing excavation damages and their consequences. Also, way fewer trenches are dug in practice than would be recommended by the computer-based risk analysis tool. In the next section, the findings are discussed and compared with the literature.

## DISCUSSION

Preventing excavation damages is one of the main pillars in the utility sector. Worldwide various initiatives have emerged that focus on the process of careful excavation. Despite these actions, damages to utilities as a result of excavation activities are still commonplace (CGA 2019; AT 2020). This study has shown that to date, prevention of excavation damages, however, does not seem to be the main driver for practice. Instead, economical motives thrive. The risk attitude by practice thereby seems to deviate from the risk perception of the institutional setting hammering on a process of careful excavation. A shift in risk attitude by practice is likely required first before the utility sector could see a real decline in the number of excavation damages.

One possible reason for the current behaviour by practice, are the characteristics of the construction sector. The construction industry is widely regarded as a fragmented and project-based industry (Gann and Salter 2000), in which short term survival prevails over long-term durability. Localization of utilities is typically outsourced to a contractor with a fixed budget and planning in mind. The way the localization process is nowadays arranged seems to leave little room for extensive investigation of the utilities' locations. Besides, contractual arrangements may take away the feeling of

responsibility by the practitioners. They are there 'just to do their job', whereas if that same party would feel the negative consequences of improper utility localization, there would likely be a bigger incentive to give more thought to the risk management process. If held accountable, those responsible for damages are only held liable for the direct repair costs, whereas the indirect costs are, by a rule of thumb, a factor twenty-nine times as high as the direct costs (Makana *et al.,* 2016). A shared responsibility to the excavation damages and their costs may stimulate a mindset of careful excavation.

The findings also show a lack of computer-based risk management tools, despite their advantages over human decision-making (Akintoye and MacLeod 1997). This study has shown that not only computer-based tools are much more effective in assigning areas of high-risk, it was also found that practice in many cases missed the high-risk areas. A such, the overall sense of security provided by trial trenches cannot always be taken for granted. Yet, investigating more locations raises another question. Trial trenches are known to be labour intensive and costly, while the method in itself is an extra excavation activity that could potentially lead to damaging utilities. Literature has therefore researched non-destructive alternatives to trial trenches, such as the GPR and vibro-acoustics (Chapman *et al.,* 2007). Incorporating said methods into the established working practices, however, may face difficulty in breaching through established practices and above all requires training and education on their use.

Instead of using computer-based tools, the findings show that risk analysis and management is based mainly upon the intuition, judgement and expertise of practitioners. The latter can be devoted to established (organizational) routines. Organizations tend to develop their activities around their existing products and processes, reinforcing a status quo (Levitt and March 1988). As such, without an incentive to change the current behaviour, literature explains routines most likely are held stable. The process of depicting locations for utility localization is thereby mostly based upon skill-based behaviour as described by Rasmussen (1983). Where such an approach could lead to a rather random approach, findings also showed that localization often occurs at common places. This could be devoted to a set of implicit rules that practitioners incorporate in practice, describing rule-based behaviour as well.

This study also has its limitations. First, the sample size of the study is fairly small. Although the findings show many similarities between the cases, the researcher believes a bigger sample is required to be able to give generalizations about the risk management approach of the utility practice. Yet, the researcher also believes that the findings show enough preliminary evidence that the established way of localizing utilities is not contributing as much to the incentive of the utility sector to decrease the number of excavation damages as desired. Second, the researcher only spent limited time with the organizations studied. Although this study developed an understanding of the ongoing activities in terms of utility localization at these organizations, a more in-depth analysis of the risk management approach for each case could have been beneficial.

In terms of future research, a confrontation between the organizations studied and the outcomes of the computer-based risk analysis tool could enhance the understanding of the perceived usefulness of computer-based risk management tools by practice, whilst at the same time raising awareness about the pitfalls of the current localization practice. At the same time, research on the practical implementation of alternative

localization methods seems necessary, so that in the future more risk-prone locations can be investigated compared to what currently is feasible with trail trenches only.

## CONCLUSIONS

This study explored the trial trench rationale to assess how effective the method is currently applied by human decision-makers when compared to a computer-based tool. The study showed that locations of trenches are chosen based on intuition, judgement and expertise and do not follow a predefined logic. Where trial trenches are assumed to accurately verify the location of utilities, it was demonstrated that the effectiveness of the method is questionable since (1) in comparison with the computer-based tool, the method leads to a vastly lower number of locations to be investigated, and (2) trial trench locations often do not align with where the risks to excavation damage are the greatest. Arguably, computer-based risk analysis tools may help in assisting practitioners with deciding on where to dig trial trenches.

Findings also demonstrated a risk attitude that is not primarily focused on reducing excavation damages. The main motivation behind digging trial trenches turned out to be the verification of preliminary designs of to be installed utilities against the layout of the buried cables and pipes in-situ. This current risk attitude only partially does contribute to the utility sector's ambition of reducing excavation damages. Economical motives thrive, likely being fed by the construction industry's fragmented and project-based nature. Whereas computer-based tools may help in positioning trial trench locations, a shift in risk attitude by practice is required first. This study urges practice to rethink their risk management approach and recommends the institutional setting to steer their initiatives towards establishing a mindset of careful excavation amongst the practice community.

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