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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Selman, A D, Guðjónsdóttir, S and Gade, A N (2021) IS the Danish Construction Sector Ready for Sustainable and Circular Construction Sites? *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, 754-763

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.

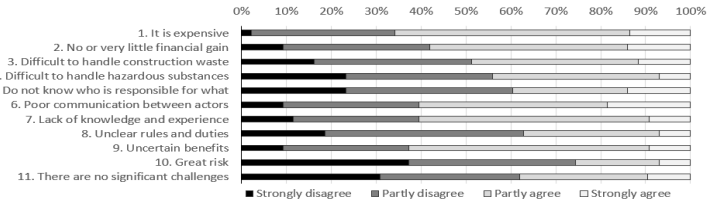

Fig 1: Organizations perceived challenges in sustainable building sites

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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