



ARCOM Doctoral Workshop on
BIM
Management and Interoperability

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Birmingham School of the Built Environment
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Workshop Chair:
Professor David Boyd



ASSOCIATION OF RESEARCHERS IN CONSTRUCTION MANAGEMENT

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ARCOM Doctoral Workshop Programme
Birmingham City University, Birmingham UK
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Time	Paper	Author
9.30-9.45	Arrivals and Registration	
9.45 – 10.00	Welcome and Introduction	Professor David Boyd
10.00 – 10.30	Keynote Address: Researching the Management of BIM	Dr Richard Davies Reading University
10.30 – 11.00	Investigation into How BIM Affects the Realisation of Offsite Construction in Civil Engineering	V.K. Vernikos, C.I. Goodier, A.G.F. Gibb, Loughborough University
11.00 - 11.30	Making BIM a Realistic Paradigm Rather Than Just Another Fad	A. Bataw The University of Manchester
11.30 – 11.45	Break (refreshments)	
11.45 – 12.15	Exploring the Problematical Nature of Building Performance in BIM Representations.	M. Mayouf and D. Boyd Birmingham City University
12.15 – 12.45	Sociotechnical Alignment and Innovation in Construction; the Case of BIM Implementation in a Heterogeneous Context	E. Sackey, M. Tuuli and A. Dainty Loughborough University
12.45 – 13.45	Buffet Lunch	
14.00 – 14.30	The BIM Information Needs for Sustainability in Conceptual Design	M. S. Cidik Birmingham City University
14.30 – 15.00	Towards Digital Information Exchange within the Construction Supply Chain	A. Mahamadu, L. Mahdjoubi and C. Booth University of the West of England
15.00 – 15.15	Break (refreshments)	
15.15 – 15.45	Using a Mobile BIM based Framework to Enhance Information Provisioning Support in Health Care Projects	N. Alaboud, J. P. Cooney and A. Zeeshan University of Salford
15.45 – 16.15	Enhancing Team Integration in Building Information Modelling (BIM) Projects	M. K. Hossain, A. Munns, and M. M. Rahman University of Dundee
16.15 – 17.00	Discussion and Conclusion	Professor David Boyd Dr Richard Davies

Introduction

This is the first workshop hosted by ARCOM in this rapidly developing field. The focus is on the way we are changing the way we work as a result of BIM. ARCOM aims to develop excellent research in the construction management field and encourages critical and alternative perspectives. Such perspectives are required as the use of BIM is in flux and as such it makes it complex to research and the results are difficult to interpret. In addition, the idealised proposals for how work should be conducted and driven by data transfer protocols obscures how work is being undertaken. The workshop will provide an opportunity to share theoretical and empirical insights in order to advance what is a fragmented field of study.

ARCOM also seeks to encourage and advance early career researchers. It does this through such workshops in order to develop the research community not just academically but socially so that it is sustainable for the future.

Professor David Boyd
Workshop Convenor
Birmingham City University

BUILDING INFORMATION MODELLING AND OFFSITE CONSTRUCTION IN CIVIL ENGINEERING

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In 2011, the UK Government mandated that all construction projects (buildings and infrastructure) that they procured would be undertaken within a 3-D BIM (Building Information Model) environment by March 2016. This has caused both construction procurers and providers to embark on a journey towards universal BIM adoption, including the integration of BIM within a revised construction process. Offsite construction has also seen significant development in the building sector in the past decade; in infrastructure however, offsite exploitation has been more limited. This paper presents research regarding how innovation initiatives such as BIM and offsite can and need to be considered together, thus allowing leaner design, a greater integration of lifetime project data and more novel technical solutions. The analysis outlines the benefits of utilising offsite within a BIM environment, the challenges currently facing the supply chain, and recommendations are made as to how best to implement the emergent benefits.

Key words: Building Information Modelling (BIM) , Civil Engineering, Infrastructure, Offsite Construction, Innovation

INTRODUCTION

Improving efficiency in construction has been on the UK government industry agenda for many years (Wolstenholme, 2009). Various initiatives have been documented, addressing different aspects of the construction industry (Simon, 1944, Emmerson, 1962, Banwell, 1964, Lathm, 1994, Egan, 1998). Recent initiatives – such as BIM, lean construction and offsite – aim to reduce costs through improved resources and enhanced data management (Vernikos et al, 2011) with BIM becoming increasingly applied within the UK construction industry in recent years. BIM implementation is occurring via a ‘push–pull’ process and BIM is slowly becoming embedded in various forms and methods in many current construction projects (National BIM Report, 2013).

The UK government wants to achieve a total of 20% savings of construction costs and aims to implement BIM in all government construction procurement contracts by 2016 (Morrell, 2011) hoping to contribute to the savings target. Many would consider this target to be a real challenge, solely through the implementation of a single innovative initiative, in such a short time. The paper presents drivers and barrier documented and discusses past research initiatives on BIM and Offsite (i.e. Avanti, PrOSPa, Manubuild). Through the analysis of 12 interviews, the research explores how the industry currently defines BIM and Offsite current BIM development their effects on Offsite construction.

BARRIER AND DRIVERS

Research literature (Goodier and Gibb, 2007, Blismas et al, 2005, Larsson and Simonsson, 2012, Nadim and Goulding, 2010, Venables et al, 2004, Bew and Underwood, 2010, Wix, 1997) and industry reports (National BIM Report, 2013, McGraw Hill Construction 2010 and 2011, Miles and Whitehouse, 2013) identify and analyse drivers (Table 1), barriers (Table 2), implementation techniques and case studies for both BIM and offsite.

Offsite has been seen to improve efficiency and productivity in construction (Blismas and Wakefield 2007). Drivers of offsite include time, quality, cost and health and safety (Blismas et al. 2006, Gibb and Isack 2003). Despite the existing literature, advantages related to offsite are poorly understood therefore there is reluctance in employing such methods (Pasquire and Gibb 2002). Barriers for offsite are process, value, conservatism and knowledge related (Blismas et al. 2005). Two major issues are the complete understanding of the process and the cooperation throughout the supply-chain (Pan and Sidwell, 2011). According to Nadim and Goulding (2009) improved communication, teamwork and problem solving is critical for increasing the usage of offsite. Many will argue that the construction industry is focused on initial construction cost rather than value, hindering offsite as it is not equitably evaluated (Blismas et al. 2006, Pasquire and Gibb 2002).

BIM	Drivers and Advantages	Offsite
McGraw-Hill, 2010 NBS BIM report, 2013	Cost	Pasquire and Gibb, 2002 Gibb and Isack, 2003
NBS BIM report, 2013	Profitability	Pasquire and Gibb, 2002
NBS BIM report, 2013	Time	Pan and Sindell, 2011 Pasquire and Gibb, 2002 Goodier and Gibb, 2007
Kriegel and Nies, 2008	Sustainability (e.g. Reduce waste)	Pasquire and Gibb, 2002
McGraw-Hill, 2010 NBS BIM report, 2013 Nisbet and Dinesenm 2010	Productivity	Pasquire and Gibb, 2002 Gibb and Isack, 2003
McGraw-Hill, 2010 NBS BIM report, 2013	Quality	Gibb and Isack, 2003 Goodier and Gibb, 2007

Table 1: Research summary of drivers and advantages for BIM and offsite

Many of the aforementioned statements can be applied to BIM and its implementation. The drivers and barriers for BIM however, are not as thoroughly documented as offsite, possibly due to the more recent nature of the innovation. Table 1 and Table 2 include some of the most critical advantages and disadvantages of BIM currently documented. Recent industry surveys in the UK and USA (McGraw-Hill, 2010, NBS BIM report, 2013) claim that productivity is one of the greatest advantages

of BIM. Nevertheless, there is very little evidence, in the literature, for these productivity improvements to have been realised (Whyte et. al., 1999, Taylor, 2007). One may argue that the surveys are more recent and the published literature is outdated. Amongst many barriers documented in the literature the most debated in its effects on cooperation and general communication. There are many (Succar, 2009, Sacks et al 2010) that believe BIM improves communication indirectly through its 3-D elements and visualisations, effectively communicating information on spatial, logistical and material requirements. However, there are others (Ashawi and Faraj, 2002, Nisbet and Dinesenm 2010) that argue that BIM does not foster collaboration.

BIM	Barriers and Disadvantages	Offsite
Bernstain and Pittman, 2005	Initial cost	Blismas et al, 2005 Goodier and Gibb, 2007
Howard and Bjork, 2008	Process and Management	Blismaz et al, 2005
Moum et al, 2009	Lead-times	Blismas et al, 2005 Gibb and Isack, 2003
Ashawi and Faraj, 2002 Verheji and Augenbore, 2006 Nisbet and Dinesenm 2010	Coordination/Cooperation	Pan and Sindell, 2011
Taylor, 2007	Lack of knowledge	Blismas et al, 2005 Blismas and Wakefield, 2007

Table 2: Research summary of barriers and disadvantages for BIM and offsite

The civil engineering sector is moving towards a multi-dimensional object-oriented design in a similar way to the building sector. Many believe that this will inherently encourage the production of ‘objects’ designed for manufacturing, especially if data can be sent directly to the fabricators. Construction is a ‘low information intensity’ industry compared to banking or finance (Hu and Quann, 2005). Nevertheless, structures are complex entities formed by various sub-systems and diverse components. The continued reliance of the civil engineering industry on using paper-based drawings as a means of recording designs and fabrication data is inhibiting offsite innovation. Theoretically, with the ‘digitalisation’ of construction data it is expected that advanced automation in design, manufacturing and erection through BIM will increase offsite (Eastman and Sacks, 2008). BIM is the technology that allows construction data to be ‘machine readable’ and manufacturing of components without human intervention possible (Eastman and Sacks, 2008). Nevertheless, for any technology to be implemented in the industry there is a series of factors to be considered including staffs' attitude toward the technology, the firms' structure and culture, the level cooperation between the supply chain partners, leadership and senior management support and the firm's ability to change (Iacovou et al, 1995 Irani and Love, 2008)

METHODOLOGY

Grounded theory was applied in this research to allow for insights into investigating the emerging industry processes while avoiding adjusting or steering the data towards previous theoretical frameworks (Glaser, 1998). The grounded theory used focused on a phenomenological approach and deductive derived theory (Strauss and Corbin, 1990). Unlike other qualitative approaches, grounded theory begins focusing on the conceptual scheme through a contextual way avoiding any predetermined theory (Cassell and Symons, 2004). This investigation did not intend to focus on a distinct area but rather to allow the research to unravel through a continuous comparative analysis of incoming data that enabled a conceptual development. The data collection period lasted six months and data was considered sufficient when ‘theoretical saturation’ occurred (Glaser and Strauss, 1967). The conceptual theory was initially established through a series of discussions with industry experts. When the exact research question was identified, a thorough and focussed literature review was conducted including published research, industry reports and government regulations. Twelve semi-structured interviews were conducted with BIM leaders and directors from leading UK construction contractors and consultants, software vendors, industry institutions and the UK Government. The interviews were thematically analysed.

FINDINGS

For this research, twelve experts first explained what each term meant to their organisation. BIM was seen by all as a platform for communication and collaboration. Although the focus is on data and information, attention was drawn to the way the design or modelling processes are managed and controlled. Recurring terms such as ‘correct’ or ‘improve’ show a positive attitude and enthusiasm towards this innovation. In summary, in this research, BIM is an umbrella term for object-oriented modelling that relates to both vertical (i.e. buildings) and horizontal (i.e. railway, highways, etc) infrastructure where the objects have extended attributes that can be leveraged to understand the content of a design and allow for a consistent platform of communication throughout the supply chain.

In contrast, the offsite definitions were more diverse. Contractors saw offsite as a construction process, where components are fabricated in a factory or somewhere near-to-site and are transported to site for installation. For consultants, offsite is more of a means to achieve increased efficiency where products, bespoke or off a catalogue, that are manufactured in a controlled factory environment are assembled on-site. There was confusion between the terms standardisation, prefabrication and preassembly.

Past Government Initiatives

Whilst offsite has been promoted by the UK government for generations, albeit using different terms such as prefabrication (Murray and Langford, 2008), the focus on high-powered information and communications technology has been somewhat more recent. In 2002, The Department for Trade and Industry (DTI) combined with the Engineering Physics and Science Research Council (EPSRC) to develop a programme of works, the Innovative Manufacturing Initiative (IMI). The IMI funded a theme called Meeting Clients Needs through Standardisation (MCNS) which orchestrated a group of focused calls for research programmes. The last two programmes funded were Avanti and ProSPa. Avanti’s core aim was to encourage the use of Computer Aided Design (CAD) by arguing that managing information databases was more

efficient than managing 'drawings in a cabinet'. Avanti supported early access to information from all parties of the supply chain and work protocols promoting improved communication and common information models. Similarly, ProOSPA aimed to encourage offsite solutions across the construction sector (Goodier and Gibb, 2007). ProOSPA was the predecessor to the industry-focussed organisation BuildOffsite and Avanti developed into the BIM initiative.

ManuBuild

ManuBuild was a good example of European funded research on combining BIM type technologies with offsite prefabrication. Briefly, the research team included 22 partners from 8 countries focusing on building concepts from a design perspective and production technology from a construction perspective. The aim of the research was by combining the two processes to achieve an increase sustainability, quality and durability without increasing costs. Some participants interviewed would define the project as 'one-system-manufacturing, that required standards and component catalogues, automated factories and manufacturing'. Participants in ManuBuild believed that to achieve these efficiencies it was critical to explore how other industries approached similar challenges therefore the automotive industry was explored. Traditionally, the construction industry has 'trouble with precision and efficiency', not as much with regards to structural design but with time, cost, material usage, man-hours, etc. Model based information such as model driven scheduling and costing was the solution to address the problem. Some issues occurred with large corporate software firms, 'although they say there are keen to collaborate they do not want to be limited by standards because they see this as making their customer base available to the competition'. Other issues focused on the project management of the research project. The participants interviewed claimed that there are examples of large R&D projects funded from the European Union that have serious issues with project management. The claim that when research is conducted in the construction industry, at least from an industry perspective, the exact outcome or output of the research is 'unsure'. There is a continuous change of data therefore different targets and expectations. Conventional project managers, which have work of research projects find it exceptionally difficult to work in such a 'fluid' research environment. Rigid ideas of industrial partners in research projects create frictions. In cases where there are many partners from the supply chain working on the same research project, the situation becomes even more complex from a project management perspective. There are examples of partners, when under pressure, they become 'disillusioned and back off'. Partners who are running into difficulties need a particular handling in order to maintain focus and continue to work collaboratively. Participants interviewed concluded that ManuBuild did not have the desired impact to the industry nevertheless there are few publications available (Gibb et al, 2007, Long et al, 2007).

BIM and offsite in the Civil and Building Sector

Both the Avanti and PROSPA programmes focused their work predominately on the building sector rather than infrastructure or civil engineering. Despite the downturn in the current financial situation in the UK, offsite is employed in many large scale building projects varying from hotels and hospitals to prisons and student accommodation. Certain aspects, such as precast concrete elements, have also been widely employed in the civil engineering sector, but other applications have had little deployment (Gibb, 2001, Goodier and Pan, 2010) and this view was supported by the interviewees in this current survey. Some claimed that the civil engineering sector

‘thinks less of their process and data possibly due to the size and duration of the projects’. Others debated that, in the building sector, learning from project comparison is less challenging as you can analyse, for example, the cost on a functional breakdown and compare the cost of a system from one project to another. Whereas, in civil engineering projects, one cannot compare the contractor’s breakdown neither at a project-by-project basis nor a contractor-by-contractor basis because of its arbitrary nature due to the work breakdown and the different tasks delegated to different sub-contractors on site. Some consultants claimed that offsite was easier to develop for the building sector due to ‘object libraries’ and ‘catalogues of components’.

With regards to BIM, and similarly to offsite, most participants agreed that the building sector is currently leading in its implementation. The main reason was due to the software available being more focused on vertical construction. The software providers interviewed claim that ‘the building sector has instant gratification from BIM and it is less challenging compared to horizontal infrastructure where segmenting the model is a complex process’. Consultants argue that despite software for the building sector being ‘more mature’, the real challenges occur when large geographical areas demand the combined utilisation of Geographic Information Systems (GIS) and BIM. Government experts claim that less research on processes and data transfers is undertaken by the civil engineering sector which ‘lacks comprehensive data systems, such as Industry Foundation Classes (IFCs)’. Although most firms contributing to this research are involved in large scale infrastructure projects, only one participant claimed that ‘some key civil projects (i.e. CrossRail) are using much more superior BIM techniques than any building project’. To conclude, it was evident that the building sector is utilising BIM on a wider scale and it is more aware of BIM processes (National BIM Report, 2013), however, in civil engineering there are some best practice examples demonstrating the applicability of BIM within a complex infrastructure environment.

All participants agreed that consultants used to lead the way in BIM technologies and methods, ‘starting from a position of strength’, predominately because of ‘their familiarity with the visual aspect of the software and the rapid production of drawings’. During the last few years contractors however have been accelerating their BIM awareness, using BIM as an opportunity to achieve greater savings. In addition, large UK contractors’ main client is the UK government, therefore contractors are ‘forced into rapid BIM implementation’ in order to maintain a competitive advantage. Nevertheless, consultants interviewed claim that contractors use BIM to focus more on the detailed design and the construction phases of the project and less on the operational and the maintenance phases. The UK government representative interviewed highlights the importance of BIM for the lifecycle of the project and claims that the benefits of BIM in the design and construction phases are minimal in comparison.

ANALYSIS

Considering BIM’s effects on offsite, most participants thought that by the UK Government mandating BIM by 2016, the usage of offsite in the civil engineering sector will increase. Some were very enthusiastic, claiming that offsite is the missing link without which there are no easy mechanisms to ensure that design intent is translated into a fabrication intent that is manufactured affectively. In addition, it was claimed that only through BIM ‘one that designs precise digital objects can then fabricate them in factory conditions’. Others were more cautious, stating that there are

many parameters that determine where and how to use offsite but ‘BIM helps designers take into account all these factors and make a more informed decision’. Notwithstanding, it was made clear that it all depends on how organisations implement BIM and offsite in the model that they operate. Despite the uniform opinion of most participants that BIM will positively affect offsite, one consultant claimed that BIM does not enable nor hinder offsite because BIM applies equally to on- and off-site work. The consultant believed that ‘offsite is on an upward curve and I don’t think that curve will become steeper since BIM was formally introduced to the industry’.

CONCLUSION

Both BIM and offsite as concepts are not fundamentally new, but terms referring to the ideas have changed over the decades to reflect industry trends. During the past few years a number of successful case studies of offsite within a BIM environment have been published (BIM Handbook, 2011). The majority of them are focused on the building sector with the United States leading BIM implementation. Within the UK, early adopters such as the Ministry of Justice are using BIM with offsite for prison blocks and some ‘best practice’ examples are producing promising results (MoJ, 2013). Despite all the high expectations from the literature and some practical success in the building sector, very limited application of offsite through BIM is witnessed in civil engineering. The participants in this research attempted to identify evidentiary examples to prove that BIM enables, promotes, increases or improves offsite, but apart from some aspects of ‘key infrastructure projects’, no evidence could be provided. The UK Government provided examples where ‘projects started using BIM from the RIBA-Stage C phase and this was deemed fundamentally flawed’. Therefore, based on this principle; some participants’ examples were dismissed as their ‘BIM’ elements were merely 3D visuals or the BIM implementation was encouraged not for its efficiencies but for commercial reasons. When participants were not able to provide evidence they claimed that the statements were going to materialise during BIM level 3. Nevertheless, as the UK Government confirmed during the interview, currently BIM level 3 is yet to be clearly defined.

Offsite is a more ‘familiar’ concept to the civil engineering sector, with precast concrete elements and bridge construction or tunnelling often employing offsite (Vernikos et al, 2012). However, throughout the data collection process many participants confused the terms ‘standardisation’ with ‘prefabrication’ and the term ‘offsite’ was not clearly understood. Economies of scale are achievable through standardising offsite elements and BIM may influence the process drastically, yet one does not automatically lead to the other. One contractor emphasised the distinction, claiming that ‘standardisation is an aspect of BIM, but a minor percentage of civil engineering works is standardised’, as parametric and logistical flexibility is needed. With consultants saying that ‘contractors don’t know what they want’ and contractors claiming that consultants give them ‘empty models’ the confusion is not limited to offsite terminology but also to BIM implementation.

After analysing the responses of twelve of the BIM and innovation directors representing leading UK consultants, contractors, software vendors and construction industry institutions, it is evident that there is a clear belief that BIM will improve and increase offsite construction in civil engineering. Nevertheless, there is still little evidence that this is currently the case. It appears from the findings presented here that BIM has the potential to improve the quality of existing offsite methods and solutions.

This may raise industry confidence and therefore it could indirectly increase the overall application of offsite technologies.

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MAKING BIM A REALISTIC PARADIGM RATHER THAN JUST ANOTHER FAD

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There has certainly been progress in the use of Building Information Modelling (BIM) around the world, especially in the last decade. In several countries BIM have been put into practice and employed. The UK industry has not yet fully implemented or made use of BIM but there is a strong drive from the government to adopt BIM Level 2 on all UK public projects by 2016. However, there is as yet no clear roadmap to ensure the adopting of BIM is accepted and progressed in the correct methods. The complexity and nature of BIM needs to be addressed and outlined to ensure all participants are “BIM ready” before 2016. The aim of this paper is to outline a clear understanding of the barriers and hazards surrounding the use of BIM to give comfortable consideration on the implementation of BIM. First, the current implementation of BIM around the world is explored to outline the process of BIM across different countries and understand their practices. Then the key concept of BIM including advantages and disadvantages within the current AEC industries is investigated. Followed by a comprehensive research on the challenges of implementing BIM and why it is important for all participants to understand these challenges especially within the current timeline of the UK BIM strategy. This research is based on broad literature reviews, along with results of two recent questionnaire and Interviews to present a qualitative illustration of the current situation and the concerns of implementing BIM within the UK.

Keywords: Building Information Model (BIM), Virtual Design and Construction (VDC), n-Dimensional Modelling, Parametric Modelling, Facilities Management (FM).

INTRODUCTION

Technology was first introduced into the industry in the early 1980s under the Virtual Building concept by Graphisoft’s ArchiCAD now known as ArchiCAD. This was the start of the software revolution that allowed architects to create virtual, three dimensional (3D) designs of their project instead of the standard two dimensional (2D). Since then, new technologies and updated software were developed and used. However, this use of technology was only limited to the design stage, until the concept of Building Information Modelling (BIM) was introduced. This advanced system was established to assist architects, engineers and construction professionals in storing and communicating all the amounts of datasets such as the building geometry and spatial data as well as the properties and quantities right from the inception of early stages throughout to demolition.

The use of BIM is aimed for much more than just performing a model to see what the building should look like; BIM intend to create a model that contains all kinds of information, from spaces and geometry, to costs, personnel, programming, quantities, specifications, suppliers and other information types. To be well-managed and qualitative this information is contained in such a model where it is all related and built on each other to provide the best solution, enhance decision making, improve production to high level of quality, enhance prediction of building performance, major

time saviour, and control the budget in a safer environment within an organised collaborated way of working.

In the last decade BIM stood out as a very beneficial process due to the excellent benefits and the successful use around the world; therefore, later in 2011 the UK government proposed to implement BIM by 2016 to eradicate many inefficiencies within the industry and to bring in a modern way of working to make it a pleasant working atmosphere as well as making shared information easy to visualise and understand, providing greater efficiency and quality. However, this technology on its own cannot provide the final solution as the industry has always been managed by the current “Fragmented” way of working. Therefore, it is essential to initially change the current way of working in order to adapt with the use of BIM. The UK Government has published a BIM strategy plan in March 2011, which outlined the importance of BIM use and implementation contents. However, this strategy cannot be used for implementation guidance. The need for an implementation plan is not only required for the sake of giving a clear roadmap for the industry but also to give viable information on what to be considered before using BIM.

“Change without a plan ultimately ends in chaos. If we fail to plan, we will have squandered the tremendous opportunity that is available to our industry.”
(Henry, I. JBIM. 2009)

CURRENT PRACTICES OF ADOPTING BIM AROUND THE WORLD

BIM have rapidly spread around the world. Many countries around the world have exposed great interest towards implementing BIM within the construction industry but each country has its own arrangements and progressed differently.

BIM in the USA

The USA was the earliest initiator of BIM especially within the public sector. In late 2006 the US General Services Administration (GSA) issued a BIM-guideline outlining an implementation plan to accompany the integration of BIM use within the US AEC sector in general and the Public Building Service (PBS) in particular. Following that, in 2007 the US GSA issued a mandate to obligate all planners to use BIM while applying for GSA’s funding schemes (GSA, 14).

In addition to the widely recognised benefits of BIM that the public sector was mainly profiting from, the US AEC sector established BIM’s policies by addressing the allocation of risks associated with the implementation of BIM, outlining the roles and responsibilities of each participating party while avoiding any conflicts with the existing construction contracts policies. This has encouraged many stakeholders to use BIM as proved by the American Institute of Architects’ report on the Business of Architecture (2010), confirming that 60% of US architects are using BIM throughout their projects.

BIM in Finland

The Implementation of BIM within Europe was initiated later than the USA but showed a faster and wider improvement within the industry especially in Finland (as shown in Figure 1). According to the Finnish ICT Barometer for all architects in Finland (2007), 93% of architects are using BIM in current projects with 33% of that usage at BIM level 3. In the same survey it was observed that nearly 60% of Finland's engineers are using BIM in both the public and private sectors (Kiviniemi, 2007).

This spectacular spread of BIM use within Finland is due to increased interest by the Architectural Engineering and Construction (AEC) and Facilities Management (FM) companies in profiting from the benefits of BIM. Starting from 1st October 2007, they focused on using BIM's model technology within common project works. In 2009, they established detailed modelling guidelines to assist the use of BIM during the design stages. This was used by the governing body of public properties to run several pilot projects, showed a great impact in making decisions for Senate Properties' investment processes and enhanced developments within the private sector (VTT, 2007).

BIM did not only reach the public sector but also the private sector, where several major companies such as 'Skanska Oy' and 'Tekes' have taken the lead in working with BIM (Kiviniemi, 2009). Numerous researches with local Universities such as Tampere University of Technology were also highly involved in investigating the benefits and outcomes of BIM practice within the industry to promote the potential implementation of BIM, developing technical tools and investigating the potential of BIM in providing solutions sustainability within the industry. (Leicht et al. 2007) (Huovila, 2008).

BIM in Singapore

BIM concept was first introduced in Singapore in early 1995 by Singapore's Ministry of National. This gave organisations such as 'Development Construction and Real Estate Network' (CORENET) an early involvement to develop and implement BIM within government projects.

Singapore's government was successful in pushing for BIM implementation and BIM standards on various kinds of projects in the public and private sectors with the help of CORENET's BIM Guideline "Integrated plan checking" (Khemlani, 2005). This has noticeably enhanced the number of public-private initiatives to encourage the use of BIM in a number of large pilot projects.

BIM in India

India's fast growth of population and economy has generated a boost in the building environment which provided the perfect platform to implement BIM. India has a strong workforce of Qualified, Trained and experienced BIM specialists who are not only implementing BIM technology in India's Construction Projects but also assisting on the implementation of BIM in Canada, USA, UK, Singapore and Middle East regions.

BIM in Canada

The Institution of BIM in Canada (IBC) has taken the responsibility to lead and facilitate the full Implementation of Building Information Modelling (BIM) into the Canadian built environment, their main interest is to focus on the primary stakeholders allowing them the right method and pace to understand their roles and responsibilities and to assess their capacity to contribute in this process.

BIM in the UK

The UK Government has already shown their awareness of BIM's benefits in controlling cost, time and quality and the advantages it could offer to everyone involved in the construction industry, including clients, designers, contractors, suppliers and facilities managers. On 31st May 2011 the Government showed its interest in BIM by publishing a construction strategy report that announced that the Government aims to adopt BIM technologies, process and collaborative behaviors into all stages of the life-cycle of public projects worth more than £5 million by 2016. This is expected to advance the use of BIM as shown in figure 1.

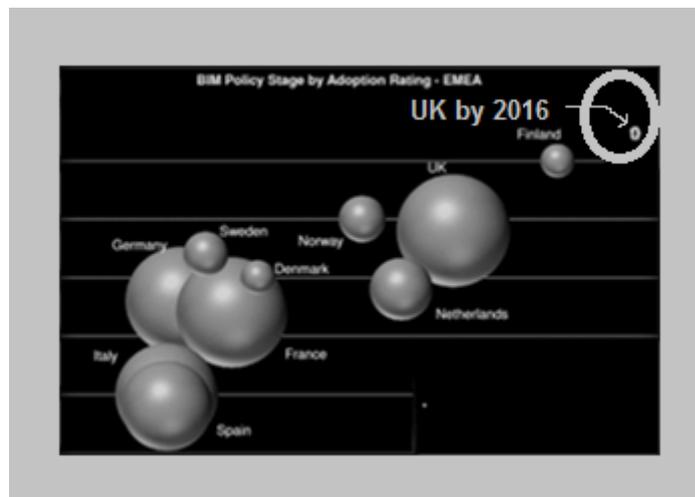
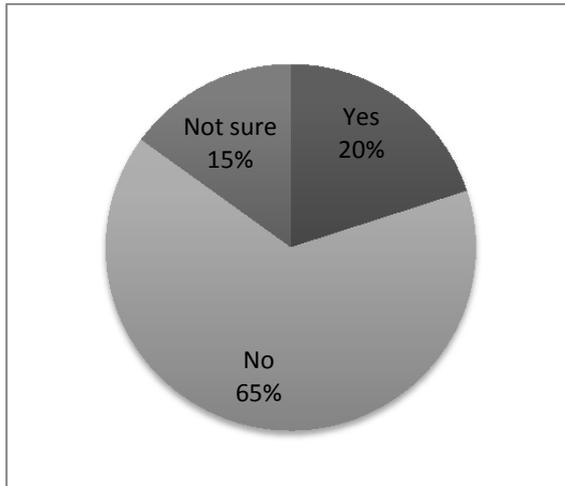


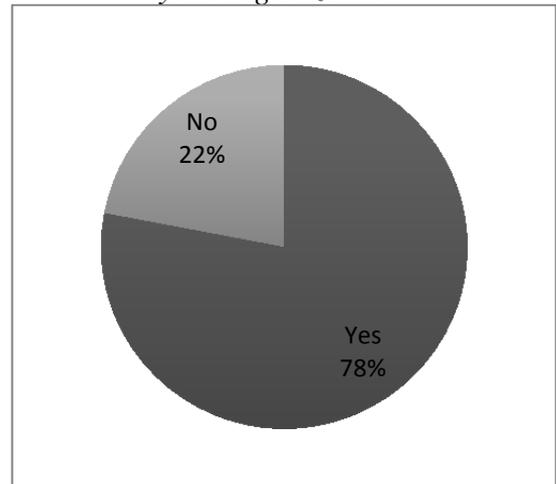
Figure 1: Levels of BIM implementation within Europe

However, to reach these expectations, everyone within the industry will have to step up quickly to reach the required BIM awareness level. Questionnaires were distributed in March/ April 2013 to a large number of professionals in the UK alongside interviews with different Academics. 84 participants flagged the concern of misunderstanding BIM and its concept. The response showing in the graphs below expresses the tardiness of many practitioners and organisations towards BIM understanding and adoption.

Are you or is your organization aware of the challenges of implementing BIM?

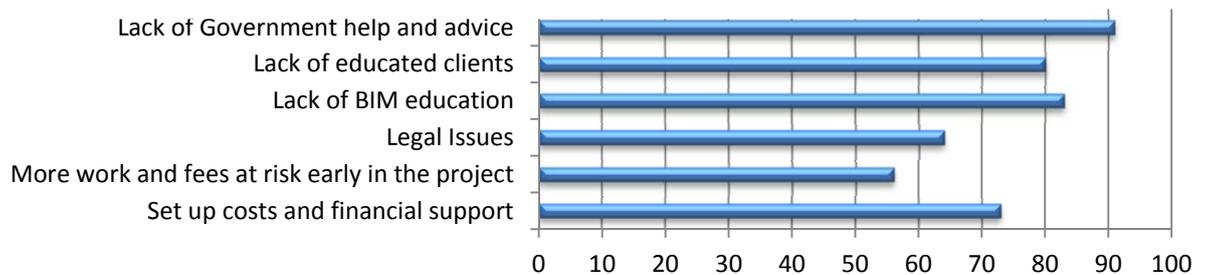


Are you concerned about BIM adoption in your organization?



Those participants who were concerned with BIM adoption were asked an additional question to rate their concerns of BIM adoption challenges. From the results showing below and the comments that were obtained from this research and interviews, an outstanding distress was discovered on the concern of BIM adoption and many professionals seemed to know about BIM but fail to have any knowledge of how and when to adopt it. Also, many realise that adopting BIM is a challenge to many organisations but don't seem to know what the real challenges are. Therefore, a detailed manuscript is required to outline all the challenges of BIM adoption in the UK.

Rank the following BIM adoption challenges



ISSUES OF BIM

No doubt, BIM can be of extreme benefit to the industry and potentially improve the industry; however, the use of BIM in the UK could raise a vast number of issues that deserves serious consideration. In essence, it is only as good as the people using it. Many clients are still hesitant toward the implementation of BIM as they are still uncertain and puzzled on what BIM really is. This is due to the nature of all participants within the industry and the high costs of BIM implementation owing to the required extensive training of the different professionals, cost of technical expertise, costs of organising protocols and managing a network server to store and access the model.

Other issues stopping the Implementation of BIM are the Legal barriers surrounding liability, uncertainties to the Intellectual Property Rights, digital information exchange and ownership of the program, which could all be resolved in time.

These issues might appear to be barriers to implementing BIM but many researchers concluded that these issues could be controlled with the support of the government.

EMERGING PROBLEMS DURING THE IMPLEMENTATION OF BIM

Most of the above mentioned issues would only arise while using BIM level 3. Implementing BIM level 2 should not create significant additional risks; nevertheless some amendments might be required to smooth the implementation of BIM.

BIM level 1 only contains the use of design software feature within the design stage; this level is currently used and widespread within the UK without any major implementation issues. BIM level 2 is an increased method in using software technologies within separate disciplines. Few matters need to be amended and improved before the implementation of BIM Level 2 could take place within projects:

- The great need of intense awareness campaigns and training courses throughout the industry to clear the doubts and debates surrounding BIM and fully training all the professionals towards their responsibilities and roles throughout the use of BIM.
- Level 2 Implementation will require the removal/major amendments to the intellectual property legislation.
- Contractual amendments and software measures to be arranged to protect from Data corruption and software tool failures especially when different stakeholders use particular tools.
- Organisations operating on level 2 BIM might become limited during tenders when level 3 BIM is fully implemented by others.
- BIM protocol is recommended to be set up during the procurement stage to address risk sharing, detailed responsibilities of all users, technology level of each model, level of definition and an exclusion of liability. All to be clearly outlined within the agreements between the Employer and those responsible for the BIM model (Beale and Company Solicitors LLP, 2013).

Level 3 BIM implementation is not just a step up from level 2 in terms of using software tools; it is also an elevation to a new way of working. BIM level 3 will require using 3D, 4D, 5D and 6D tools within one collaborated platform, this will require many amendments and considerations in order to make the industry ready for this evolution. As detailed below:

1. Barriers to implementing BIM on existing buildings

There have been attempts to use BIM for older/ pre-existing facilities. This can only be done if the existing facility was built through BIM or been converted into the form of BIM. However, converting an existing building into a BIM model would require numerous assumptions such as the standards and codes of the existing building design, the used construction methods and the materials used at the time of construction. (Boeykens, S. et al. 2012).

2. Barriers to implementing BIM on New buildings/ Projects:

- Cost – BIM level 3 will require significant investment from those across the industry. Taking into account the costs of BIM's software and hardware as well as other costs, such as the extensive training of the different professionals, cost of technical expertise, costs of organising protocols and organising a network server to store and access the model. These costs raise the concerns of many small/ medium enterprises within the industry. Failure of these enterprises in fulfilling the cost requirements will generate a large gap between them and other BIM using enterprises in terms of work quality, winning tenders, saving time and money etc.
- Industry mind-set - The current traditional way of working will not easily adjust to the high-tech collaborative way of working that BIM offers to the industry. BIM level 3 will completely change the way that professionals approach their day-to-day duties, from the fragmented paper method to having to work within an informational collaborated model that requires regular communication between different participants from early stages. Therefore, all project team members that have responsibilities; duties should be considered and drafted within the contractual documents to ensure services are carried out according to the collaborative nature of BIM.
- Information control - BIM level 3 considerably relies on information technology and software systems. This reliance raises many concerns as to the need of various control procedures in order to limit and control access and inputs, data protect with firewall systems, data backup features in case a corruption of data appears, provide technical support facilities and professionals etc. The BIM model is the core data platform of the project; one error within the model can be very costly and time wasting.
- Ownership - so many debates currently surround this topic; all the stakeholders within the industry are concerned with who should obtain the final version on the model and surrounding data. These debates are mostly due to the misunderstanding of the concept of BIM; if they correctly categorise the model generated by BIM as a product then legally it should only be retained by the buyer i.e. client. However, the data contained within the BIM model is a separate issue. This data is generated from contributions of various team members; they should be authorized to obtain a copy of their contribution for future records. These issues should be considered and discussed by the government to outline and verify the legal regulations towards ownership of the BIM model and surrounding data during and after construction.

- Liability exposure - different professionals from various enterprises contribute toward the BIM model throughout different stages of the product's life cycle through a collaborative software system, this new way of working may create irregular liability issues. BIM's software system is protected by "blanket limitation of liability" clauses that generate the question of who is liable for any software errors caused by the software. Another concern is who is reliable if works were carried out incorrectly due to inaccurate information given by a different professional in the early stages? This risk should be dealt within contractual protocols and carried out accordingly to distribute risk and liability evenly.
- Insurance - few insurance companies currently offer to insure BIM. But due to the limited use of BIM and doubtful impressions surrounding BIM's benefits and risks, it seems to be incredibly expensive to insure but it is expected to reduce once BIM is successfully implemented within projects. For the time being, it is important for parties to consider taking out the appropriate insurance to cover their engagement in the BIM process to obtain their usual coverage and protect themselves against liabilities and risks.
- BIM within contractual documents – BIM level 3 offers new roles and responsibilities for existing and new professions such as BIM managers and Architects and Draftsman etc. Therefore, all projects should include a detailed brief of these roles and outline the duties of each profession role to suit the use of BIM within projects. Making sure the same set of BIM privileges and requirements are flowing through the different contracts to avoid clashes between the clauses of the principal contract and the legal terms of the BIM protocol.

CONCLUSIONS

It is arguable that the future of the construction industry can benefit from the integration of BIM in order to improve the current fragmented way of working, overtake the overpowering issues and possibly provide potential solutions and advantages to the industry. As of the undertaken literature review and case studies, BIM implementation can possibly provide enhanced products throughout the industry by:

- Reducing errors and omissions, this will make works smoother, reduce RFIs, reduce professional liabilities and insurance costs.
- Provide opportunities to discover errors in early stages, earlier error discovery reduces repair costs in comparison to discovering them once project design progresses.
- Reduce time. Where involved managers, designers and drafters can spend less time developing designs and more time providing creative solutions for clients.
- Have a positive impact on firm's reputations with an increased number, scale and variety of opportunities
- Enhance the reputation of the industry towards sustainability and efficiency
- Increased client satisfaction through visual verification of design intent

- Enhanced way of working with knowledge sharing and virtual Design before construction.

Although these benefits might appear astonishing, they are currently only presented on paper because in reality BIM could just be another idea that could not proceed due to the lack of valuation and misunderstanding. Therefore, detailed implementation plans and arrangements are required to assist with the government's strategy of working with BIM by 2016, which is currently realistically impossible due to the many unclear points surrounding BIM and the obstructions of BIM Implementations. The query of a well-built implementation plan was raised from the research due to finding the necessity of outlining and applying the required procedures throughout all participants within the industry, such as:

- Communicate and enhance the understanding of BIM, this could be done by providing a wide range of seminars, conferences, workshops and training courses to existing professionals in all sectors. As well as promoting the publication of articles and carrying researches on BIM.
- Organise and provide many educational and training sessions to allow the new professionals to have the correct knowledge and skills to blend with BIM applications to ensure the new and old professionals within the industry are ready for the 2016 digital BIM switchover.
- Set up clear definitions of roles and responsibilities of each different participant within the new way of working.
- Locate who is responsible for setting up the level of BIM and model standards applied within a project, and when.
- Outline the required outcomes from the use of BIM within projects.
- Examine the contractual and legal issues to find solutions to ownership, sharing, copyright, IP allocation and Insurance and issue a framework to outline the legal process and procedures of BIM.
- Establish BIM guidelines for the UK that can also be integrated with international BIM guidelines.

These brief bullet points needs to be broken down and investigated to outline a proposal plan to make the implementation process of BIM clearer and closer to reality in the eyes of all involved parties within the industry.

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EXPLORING THE PROBLEMATIC NATURE OF BUILDING PERFORMANCE FOR BIM REPRESENTATION

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Building performance has been of interest for many years to facilitate better the operation of buildings and to prevent buildings not working as intended. Approaches include Building Performance Evaluation, Post Occupancy Evaluation and Total Building Performance. The advent of Building Information Modelling (BIM) has driven a desire to accommodate building performance into models for use during design. This paper will review the suitability of the various approaches to Building Performance for this task. It will be argued that to be successful for this then a multiple perspective analysis is required to accommodate users, facilities managers and designers viewpoints of performance. It will be concluded with a discussion on the possibilities of this and the research required to demonstrate it.

Keywords: BIM, Building Performance. POE, TBP, BPE

INTRODUCTION

Building performance has been an area of major research interest to understand its nature (Gross, 1996). This interest in building performance has been driven by the fact that buildings do not always (or often) work as intended. Thus, there was a need to establish approaches that can help to measure and evaluate the performance of buildings. The first approaches to this determined building occupants' satisfaction of the building they worked in and was commonly known as Post-occupancy evaluation. Other research, such as BPE (building performance evaluation) and TBP (Total building performance) sought much more pro-active approaches to accommodate the whole building life cycle. These approaches have not been fully adopted because they are time consuming, costly and are difficult to understand because of the complexity and amount data. These techniques also suffer because, to analyse the building, it has already to be designed and constructed with any inadequacies built in. What is required is an approach which can manage the complexity of building performance analysis during design.

BIM (Building information modelling) with its ability to handle large quantities of data and give rapid feedback during design provides the opportunity to undertake this building performance analysis during design. BIM provides a powerful tool to support and enhance collaboration, data management and provide fully integrated design for a building. Currently it has supported several aspects of building performances such as energy, sustainability and building behaviour. In addition, the 3D interface which BIM provides has helped to detect clashes within the integrated systems in the building and simulate several aspects (e.g. amount of sun light) which affect the building externally and internally. These are very limited aspects of building performance.

This paper will review the different approaches to building performance and analyse how they can be implemented in a BIM design environment. It will identify that the physical aspects of buildings that BIM excels in does not adequately represent building performance. In reviewing the success of buildings it is identified that as well as these physical aspects that designers can address, buildings need to be manageable in the long term and this is addressed by facilities managers and to be comfortable for users. Thus the successful performance of a building as it is realised is a result the multi-perspective of the designer, facility manager and occupants of the building. The paper explores these multiple perspectives from the literature and presents research that will contribute to their inclusion in BIM representations.

BACKGROUND TO BUILDING PERFORMANCE

Over the years, the concept of evaluating building performance has been undertaken by many researchers (Wong and Jan, 2003). Davies (1990) claimed that it is critical to generalize a definition of building performance which can match various interdisciplinary views met by contractors, managers, owners, engineers, architects, programmers and policy makers. All approaches to building performance recognise that it requires calculative aspects associated with the building form and fabric in its location and indeterminate aspects associated with the way the people in the building perceive it and experience it in their activities. According to Duffy (1990), buildings are typically evaluated based on the perception of measuring output (e.g. design awards for the architect) where another perception of evaluating performance is observing the behaviour of the product in use (Douglas, 1996). It is argued by Cooper (2001) that performance of the building can only be evaluated after it has been occupied to understand if the building is truly effective. In support of this, approaches like Post-occupancy evaluation (POE) have been developed where it's aim is to deliver an ideal building that can satisfy occupants (Khan and Kotharkar, 2012). However, although this approach has successfully been implemented, a need for proactive approaches was necessary like Building Performance Evaluation (BPE) and Total Building Performance (TBP). This section will explain these techniques as the most commonly used for evaluating building performance.

Post-Occupancy Evaluation (POE)

Preiser, (1989) claimed that POE was introduced in response to significant problems faced within building performance in 1960s, and emphasised the occupants' perspective as shown in figure 1 (Preiser, 1995). The concept of POE is based on the assumption that buildings are built to enhance and support occupants' goals and activities. Preiser *et al.* (1988) definition of POE is:

“Post-occupancy evaluation is the process of systemically comparing actual building performance i.e., performance measures, with explicitly stated performance criteria. These are typically documented in a facility program, which is a common pre-requisite for the design phase in the building delivery cycle. The comparison constitutes the evaluation of both positive and negative performance aspects”.

Moreover, Vischer (2001) stated that POE identified architectural and social problems that arose in a building through a systematic assessment of the physical environment in terms of how people were using them. It was not until later that POE

was seen as a mechanism for collecting useful information for the building industry which could impact on design and construction for the long term (Preiser and Vischer, 2005). Thus the RIBA (1991) could claim that building performance evaluation using POE results in delivering invaluable information about the design performance of the building.

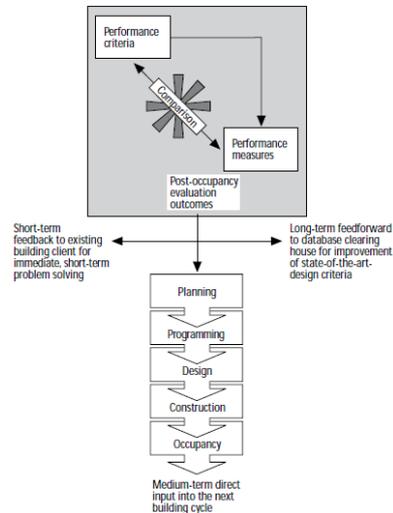


Figure 1: Performance concept in the building Delivery Process (Preiser, 1995)

Building Performance Evaluation (BPE)

BPE has been evolved from POE (Preiser *et al.*, 1988). The basic approaches of BPE were presented by Preiser (1989) in his book *Building Evaluation*. Preiser (1989) believed that there was a need to broaden the range of decision makers and improve quality of decisions in buildings by providing an evaluation which has interfaces with all phases of building delivery (Preiser and Schramm, 1997). BPE is defined as the systematic approach to comparing the actual performance of buildings, places and systems to their expected performance (Preiser and Vischer, 2005). It adopts a process-oriented approach that accommodates relational concepts. This implies that it can be applied to any type of building or environment (Preiser and Vischer, 2005). The goal then of BPE is to improve the decision quality at every phase of the building life cycle (see figure 2) from planning to programming, design and construction, to facility management and adaptive reuse. Using an Activation Process Model (Preiser, 1997), BPE presents a holistic, process-oriented approach towards building performance evaluation. Since the 1990s, interest and activity in BPE has diminished as there was insufficient interest in public and private sectors; however POE has continued to expand in industrialized nations such as the USA.

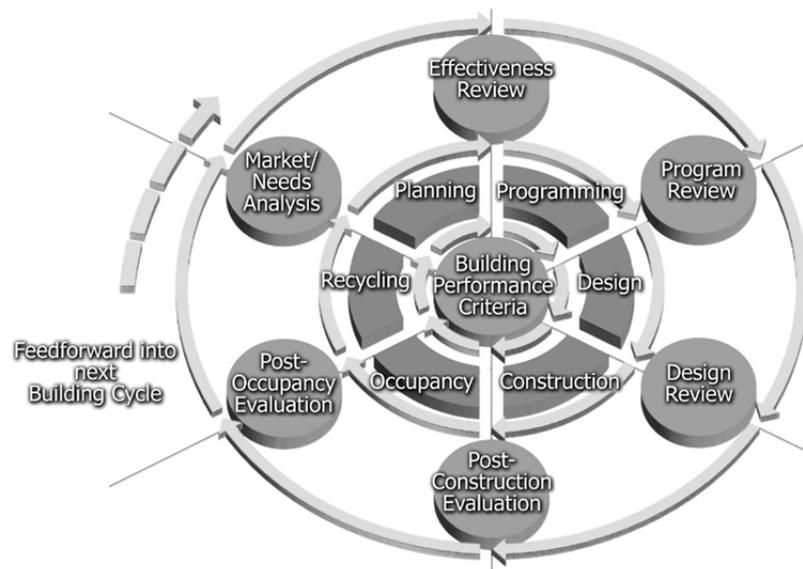


Figure 2: Building Performance Evaluation (BPE) process model (Preiser and Vischer, 2005)

Total Building Performance (TBP)

Total Building Performance is the most comprehensive tool for evaluating buildings in use and considers performances on many different levels (see figure 3) (Douglas, 1996). The two other approaches to measuring performance in buildings limited their analysis to calculative aspects of: noise control, fire safety, thermal efficiency and internal air quality. This approach drove an expanded understanding of the importance of the critical balance that is required to fulfil successful building performance (Douglas, 1996). In addition, total building performance addressed a growing need for an effective future prediction of the performance of a building.

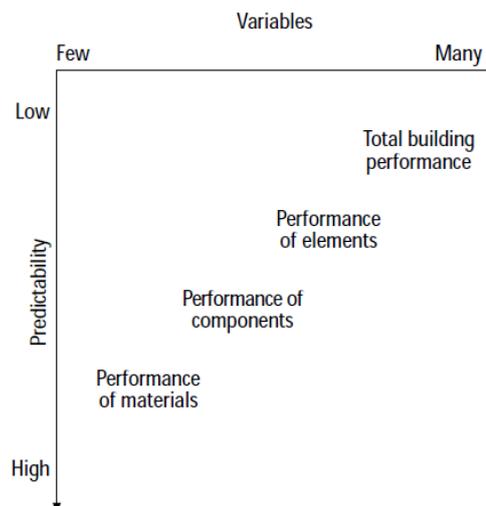


Figure 3: Total building performance compared with other performances (Douglas, 1996)

The TBP framework identifies and evaluates all performance areas (Wong and Jan, 2003). It consists of six performance measurements: spatial performance, acoustic performance, thermal performance, indoor air quality, visual performance and building integrity. In addition, each of these performances is defined by psychological,

sociological, physiological and economic needs for users' satisfaction (Low *et al.*, 2008). TBP provides the needs of the users by considering several building mandates simultaneously in order to achieve a healthy environment which will facilitate the functioning of the space for the occupants (Low *et al.*, 2012).

BIM CONTRIBUTIONS TOWARDS BUILDING PERFORMANCE

Information technology has helped to solve several complex issues through structuring problems and providing simple interfaces with people and working in a real time environment (Gleick 2011). The use of information technology in the construction industry has been accelerated with the availability of BIM (building information modelling) in an economic and manageable form (Yan *et al.*, 2011). According to Porwal and Hewage (2012), BIM provides a full design model by integrating all systems (structural, architectural, MEP and HVAC) within one whole model (see figure 4).

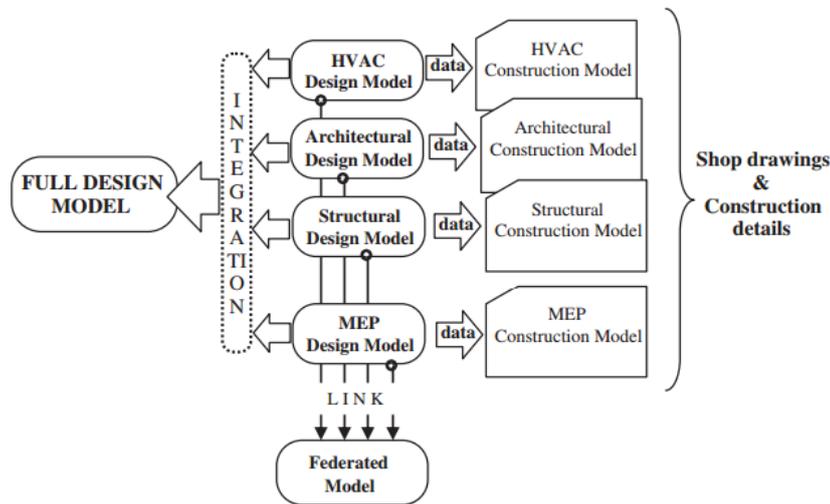


Figure 4: Diagrammatic representation of model definitions (Porwal and Hewage, 2012)

It is claimed by Motawa and Carter (2013) that BIM can transform the way that the built environment operates by storing, linking and exchanging the project based technical information for use over the whole project life-cycle and in so doing, benefit all stakeholders. It is obvious that this can be extended to building performance and there has been some BIM-based packages developed to analyse different building performances. For example, EnergyPlus and Ecotect consider energy performance allowing the dynamic calculation of the effects of thermal insulation, natural ventilation and many other aspects (Cho *et al.*, 2010). Yuan and Yuan (2011) have created several interfaces to BIM to provide an effective data management platform which allows building energy saving design to be undertaken by modelling design performance using the information on building type, construction materials, system types (Heating/Cooling), room type (zone management), project location (weather files), etc. . In a similar way, BIM has the future potential to support the delivery of sustainability (Barlish and Sullivan, 2012). Referred to as Green BIM, Azhar *et al.* (2011), have developed an integrated design model that provides inter-disciplinary simulation and analysis in a single model. Furthermore, Green BIM has helped in

estimating the percentage of carbon emissions which affects occupants and the environment towards overall sustainability.

BIM excels in situations that require quantitative geometrical based data. Thus BIMs current contribution towards building performance mostly focuses on energy performance. Currently, Autodesk BIM can simulate full energy analysis and provide full zone HVAC-based information with an enormous amount of data that mostly are not used, but can be presented in BIM. However, the design of successful buildings-in-use, through concepts like building performance, requires the use of not only this calculable data but also indeterminate judgements. The latter data is qualitative in nature and involves subjective psychological evaluations. Currently no BIM model can represent these and so cannot compute a building performance evaluation.

In addition, the interface and information provided by the BIM model is a single perspective contributed by the designer. Building Performance requires a multiple perspective in terms of project stakeholders' evaluation of building performance. An outline of this is shown in figure 6. What is required then is data to provide different perspectives contributing towards an overall building performance not only for designers, but also for facility managers and users as well.

MULTIPLE PERSPECTIVES IN BUILDING PERFORMANCE

In acknowledging the need for multiple perspectives in order to assist the design of successful buildings in use, this research is providing an original contribution to the development of BIM. The selection of just three perspectives at this stage is necessary to accommodate the major differences in perception of these stakeholders but sufficient because of the complexity of the problem. The nature of the differences is provided here.

Designer

A designer would evaluate a building based on the full integrity of its form. Their perspective on Building Performance considers energy and lighting aspects (e.g. HVAC and lighting system) which can be calculated in BIM. Looking at one of the building performances, energy performance is associated with the orientation and shape of the building, with consideration given to the amount of sun light and the energy consumption of the building where all these factors affect the EPC (Energy performance certificate) rating. In BIM environment, energy analysis has been conducted using many packages such as Autodesk Ecotect Analysis and DesignBuilder (Somboonwit and Sahachaisaeree, 2012). Nevertheless, it is important to acknowledge the significant impact that facilities have on energy performance where this yet represents another conceptual level of understanding of energy performance evaluation in the building. However, the interoperability issues within BIM has set limitation for having a full integrated systems within single model (Porwal and Hewage, 2012) although other platforms such as Cloud BIM (Redmond *et al.*, 2012) have been developed for information exchange in BIM.

Facility Manager

The facility manager would evaluate a building based on its manageability in terms of access and space uses, its maintainability in terms of its fabric and systems and its utilities usage. The latter is well represented in BIM; however the others are

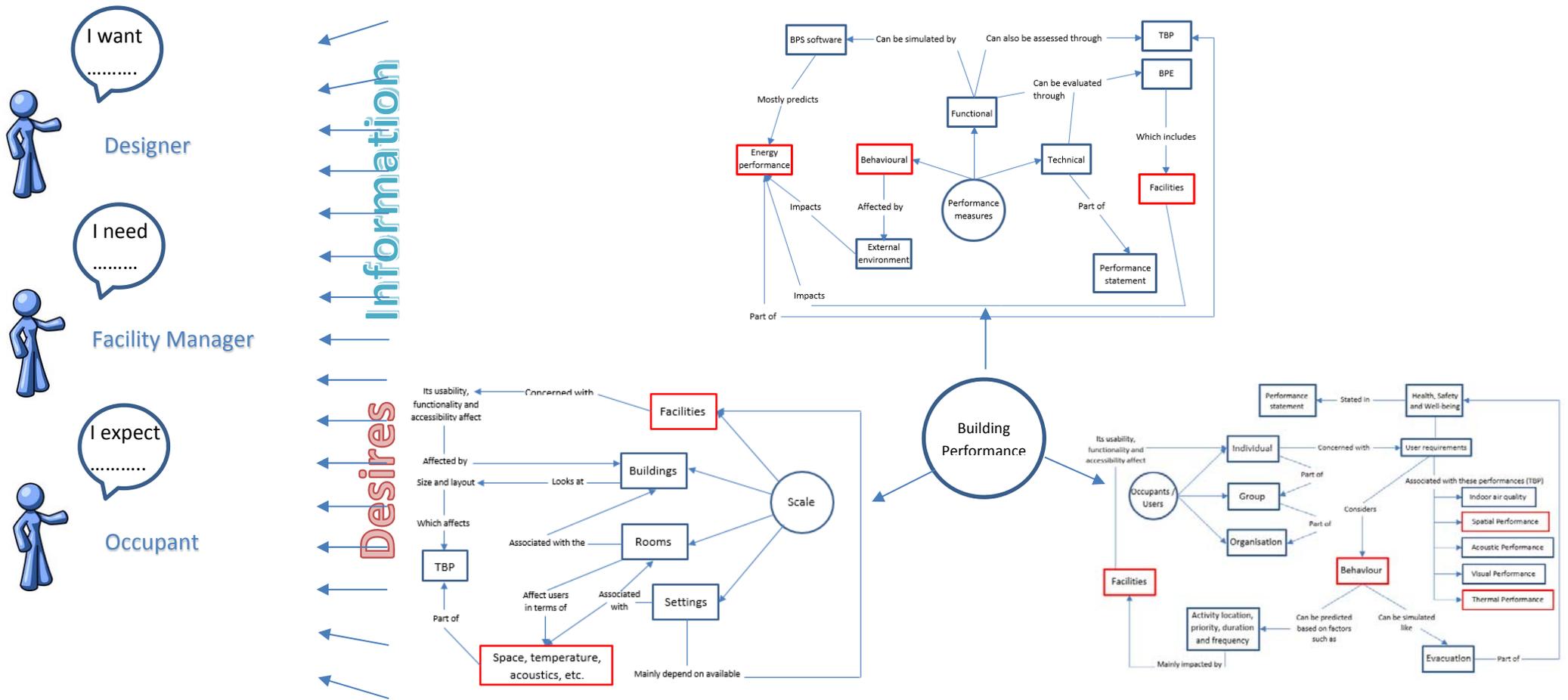


Figure 5: The interdisciplinary information and several perspectives related to building performance based on the performance variables model (Preiser and Vischer, 2005) to reflect the complexity of building performance nature.

merely seen as data offered by packages such as CoBie (Construction operation building information exchange). However a spreadsheet with great amount of data does not adequately represent the performance of a building from a facilities managers' perspective as it does not show the problems of building management and maintenance.

Users

The user is concerned with different performances (especially at the work place) in terms of facilities, energy and space. Currently, the occupant requirements in a building are done based on the occupant guideline and standards. In addition, these requirements are in terms of their safety (e.g. fire exits, evacuations and emergency situations) within the building where most of them have been simulated through BIM interfaces such as evacuation simulation (Ruppel and Schatz, 2011; Song *et al.*, 2013). For instance, facilities would be rated on the basis of its functionality, accessibility and usability within the building which have a direct impact on the users' behaviour and satisfaction. Similarly, a good energy performance for the user is mainly associated with the thermal comfort (e.g. room temperature and humidity) which can be simulated in BIM based on the analysis of energy software(s) such as Ecotect. In terms of space, spatial performance is both concerned with the ergonomic arrangement of the space (Robertson and Courtney, 2001) and with aesthetic impact together which contribute to user's satisfaction. This is important since it has a direct impact on the quality and quantity of the occupant outcome (Low *et al.*, 2008). Some aspects of space such as acoustics can be simulated through virtual reality using BIM model although the full acknowledgement of performance can only be determined through sensors which could only be done after the building start operating. On the other hand, looking at a higher level than an occupant, group and organisation are too complex to be considered in building performance evaluation, and this requires compiling additional factors like culture, politics and management role which are qualitative data that currently cannot be computed by BIM.

THE FUTURE OF BIM IN PROVIDING MULTI-PERSPECTIVE VIEW IN BUILDING PERFORMANCE

The views drawn in the previous section have expressed that the nature of the problem lies in the multi-perspective view of evaluating building performance. This has been highlighted with drawing some emphasis on elements like facilities management, space utilisations and energy performance in order to compose the overall picture of building performance. The occupants and facility managers perspectives in the evaluation of building performance is yet to be provided through BIM representations due to the type of information required compared to the input data which mostly serve designer perspective. Therefore, there is a need to model and manage the different perspectives for several elements within building performance (see figure 5 'highlighted red boxes') in BIM to maximize overall satisfaction and improve manageability of the whole building life cycle. It is believed that BIM can provide the desired multi-perspective view of building performance (see figure 6), but there are still obstacle in terms of representation of qualitative data and the subsequent interoperability as such data systems as IFCs (International foundation classes) do not accommodate such data. This can raise a question whether multi-perspective views in building performance can be delivered using a single model or a multiple model. The decision has yet to be made as this depends on required data and the representation of the output.

The ability to provide multi-perspective representation in BIM will expand the chance of applying different scenarios (e.g. effect of facility maintenance on the occupants in a particular zone) to the design evaluation. What level of accuracy can be expected or required high as more parameters and fuzzier parameters are considered has yet to be determined. Such assessments of buildings are complex and this level of complexity increases when the interaction between building facilities and users is high (e.g. hospitals or hotels). Such situations will require more psychological and sociological factors to be considered. Therefore, the desire is for BIM to have the capability to provide qualitative data analysis from soft as well as hard information and to generate multiple perspectives in order to fully evaluate building performance.

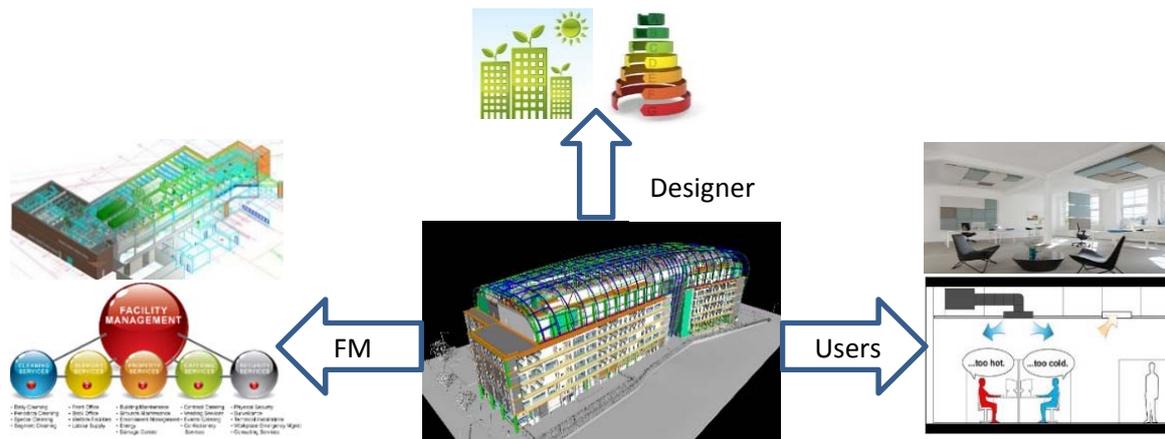


Figure 6: featured view of BIM to provide multi-perspective view for building performance

CONCLUSION

Building performance is a complex area that requires not just calculative analyses but the assessment of qualitative data and the acknowledgment of multiple perspectives. This paper has provided an overview of building performance through the most commonly used techniques of Post Occupancy Evaluation, Building Performance Evaluation and Total Building Performance. Through this review, it was realised that each of the techniques focuses on certain views where this has created a barrier to understanding of the concept of building performance. The capabilities of BIM in addressing building performance were evaluated. BIM has supported many aspects in building performance such as energy performance, sustainability and facility management (through CoBie). However, it was noted that the aspects of building performance such as facilities, energy performance and space require a multi-perspective view not the single view as offered currently by BIM. Therefore, the multi-perspective view was developed for users, designers and facility managers. It is believed that BIM can provide a great shift in the conceptual understanding of building performance, but the question to be raised is to what extent BIM can provide the multi-perspective view in order to satisfy all building stakeholders?

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SOCIOTECHNICAL ALIGNMENT AND INNOVATION IN CONSTRUCTION: THE CASE OF BIM IMPLEMENTATION IN A HETEROGENEOUS CONTEXT

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Many believe that the advancement in the application of Building Information Modelling (BIM) and the concomitant process innovation presents an opportunity to increase the level of integration of the various professionals involved in a project, thereby creating a more interactive and information sharing space. In reality however, the current trend of BIM utilisation is below the functional capabilities embedded in the concept. The purpose of this paper is to explore the implementation of BIM through a sociotechnical systems (STS) perspective, with particular focus on multidisciplinary intra-organisational construction organisation. The paper uses a case study approach to analyse the introduction of BIM in a multidisciplinary construction organisation. It examines the extent to which the structured approach to a sociotechnical requirement and its application are outlined. The STS approach demonstrates how technological implementation and its effects cannot be understood separately from the contextual issues embedded within the implementing organisation. The findings reveal some measures for managing the innovation activities. These include: double-loop interactive learning; alignment of different BIM (competitive or collaborative) authoring technologies with open standard specifications to maintain complementary knowledge resources and competence. Also, patterns of existing functions are disturbed as a result of the dynamics in the evolving BIM solution. This is resolved by a launch of successive planning and restructuring of business processes by the interest groups. The paper concludes that collaborative BIM users need to become learning partners, employing new ways of working, in which informed choices are exercised in time and space to maintain the systems' equilibrium.

Keywords: Building information modelling, construction organisation; sociotechnical systems, Leavitt's systems model, case study.

INTRODUCTION

It is inherent in the process of BIM implementation that the end result or aim is to introduce relevant, effective and efficient construction technologies and processes that improves the organisational ability to perform its tasks and interact in a relevant manner with other project organisations to enhance the project delivery processes. Linderoth (2010) has acknowledged that the implementation of BIM is shaped by the interplay between the technology's features and the context in which it would be used. This necessitates a more encompassing view of the process that would include both the social and technical aspects - i.e. a sociotechnical perspective. As Mina et al (1999) said, if there is only business specialist input then the plan is likely to be technically unworkable, and if there is only the concept of IS/IT determinism then the plan will be overly technical. The work of Mina et al (1999) implies that there needs to be a balance from all parts and from

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all levels of the organisation in terms of involvement. Nevertheless, many researchers have shown that what is not always apparent in the performance of technological initiative is the concept of optimisation of both people and technology.

The concept of technological determinism that yields to innovation failures in complex work systems is based on a set of assumptions that, the application domain is stable, and that most work is routinized, therefore it is possible to introduce technology with predetermined functions to assist in the work process (Creanor & Walker, 2011). In many cases the optimisation of the technology has been at the expense of the people concerned, and this has often resulted in the failure of the initiative (Mumford, 2006). The process of BIM implementation should therefore be a process of balancing these social and technical subsystems within an organisation in order to ensure joint optimisation of both subsystems. In particular, the architecture, engineering and construction (AEC) sector is highly collaborative and requires cooperation amongst multiple interest groups, thus, it fails to exhibit the underlying assumptions that seem to govern technological systems deployment. There is therefore a need to examine different conceptual approaches for analysing BIM implementation that is based on a different set of assumptions than the stable and routinized perceptions of the work context that govern the conventional work practices in IT implementation. One approach which has been rarely discussed in relation to ICT uptake in the AEC literature is to view the analysis from a sociotechnical systems' lens.

The main goal of this paper is to illustrate the applicability of a sociotechnical approach to BIM uptake in a multidisciplinary intra-organisational construction organisation, where construction professionals in different sets of knowledge boundaries carry out specialist tasks but towards a common project goal. This will highlight the implicit multidisciplinary working relationships that exist in a BIM-enabled construction environment. The paper will discuss the STS approach and why it might be particularly appropriate for analysing BIM implementation in the AEC domain. To illustrate the usefulness of sociotechnical requirements in this context, the paper presents a case study of a construction organisation that has deployed BIM across various intra-organisational units. The company is based in the West Midlands in the United Kingdom. The study reveals that sociotechnical components are embedded in the work system and they play a very important role in how the system is deployed. The paper highlights why gathering and analysing STS requirements are essential steps in designing a work system that fully supports the end users to achieve the intended organisational goals.

BIM CONCEPTUALISATION IN THE CONSTRUCTION SECTOR

Construction is often considered to lag behind other sectors in terms of its ability to take on new innovative technologies (Nicolini et al 2000). A number of the sector's characteristics have been offered as the rationale for this problem. These include the heterogeneous nature of its knowledge boundaries, and the largely bespoke nature of its products and services. The complexity associated with the delivery of construction projects by a transient project team made up of individuals with different knowledge backgrounds makes the implementation challenging (Anumba & Pulsifer 2010). Nevertheless, in more recent years, it is the impact of evolving technological solutions, specifically, the capabilities of BIM, which are implicated to contribute to the reformation of the AEC sector (e.g., Eastman 2011). The introduction of BIM in construction is purported to address a range of industry issues such as inter alia: producing predictable project outcomes from design phase through to construction with the use of BIM tools and concomitant processes; advocating a collaborative working culture model;

overcoming team coordination deficiencies; promoting interdisciplinary collaboration among various project participants to optimise the project delivery process; and improving the effectiveness of information sharing among project stakeholders (e.g., Korkmaz et al 2012).

This notwithstanding, how BIM is defined and what it means is subject to variation and confusion between professionals in the construction industry (Sing et al., 2011). Some see the acronym BIM as standing for Building Information Model or Building Information Modelling, while others refer to it as Building Information Management. There are also those that prefer not to use the tag BIM at all because their definitions of BIM do not consent to the 'tag'. Aranda-Mena et al (2009) surmised that, for some, BIM is a software application or a process for designing and documenting building information, and for others, it is a whole new approach to practice for advancing the profession, hence, requiring the deployment of new policies, contracts, and relationship management among project stakeholders.

Despite this variety of interpretations, generally, the various definitions of BIM may be legitimate because it depends on the specific discipline or context within which it is being used. It has been conceded that the construction sector is not a homogeneous entity, but several specialised firms, each with its own distinguishing characteristics (Ive & Gruneberg 2000), yet there is a considerable overlap in the activities of these firms. Thus, the perception of BIM varies depending on the context in which it is being applied. Perhaps, for designers and the clients, their interest in BIM might be because of its aesthetic nature plus the 3D augmented and coordinated reality, and yet, for others, the importance of BIM is in the rich information which accompanies the 3D object geometry in the federated models and the ability for analyses gained through this information. In such a wide array of usage, it might be difficult to compromise on a single definition to capture its essence for the multifaceted views of construction professionals.

Thus, throughout this study, the term "BIM" is used to describe an activity (i.e., building information modelling), rather than an object (building information model). This reflects the belief that BIM is not a thing or a type of software, but an innovation-focused, socially-shaped human activity that ultimately involves broad process change in design, construction and facility management (e.g., Eastman et al 2011). Innovation-focused approach to BIM implies two things; a basic distinction is between product innovation (related to the various BIM tools and artefacts) and process innovation (related to the required BIM processes) (e.g., Utterback & Abernathy 1975). Both the product innovation and the process simultaneously condition the strategic limits and opportunities for the effective build-up of a BIM-enabled organisation or project. In such an implementation situation, the process and technologies play such an important part in such a way that, the boundary between them is blurred, and thus, constituting the single realm of sociotechnical alignment, shaping the content and the direction of the strategic decisions of the implementing organisation. This conceptualisation of BIM elaborates the sociotechnical intent that calls for joint optimisation of construction practitioners' knowledge and work routines with that of the available technological artefacts in order to maximise both the capabilities entrenched in the technologies, and that of the competencies of knowledge workers to enhance the project delivery processes.

THE CONCEPT OF SOCIOTECHNICAL SYSTEMS (STS) ANALYSIS

The case for the role of social logics in the development of new technologies grew out of work conducted at the UK Tavistock Institute on the introduction of coal mining

machinery. The introduction of new machinery into coal mines without analysis of the connected deviations in working practices highlighted the need for consideration of behavioural issues during the design and implementation of new technologies. These and other similar studies identified the interrelated nature of technological and social aspects of the workplace (Trist & Bamforth, 1951). This brought to the fore an increased interest in the social and political implications of new technologies and helped to establish the sociology of technology as a vibrant field of inquiry thus moving research beyond technological determinism (Pinch & Bijker 1984). The STS approach represents an important stream within the sociology of technology literature. The original concept of STS advocates the consideration of both technical and social factors when seeking to promote change within an organisation, whether it concerns the introduction of new technology or a business change program (Cherns, 1976). Designing a change to one part of the system without considering how this might affect or require change in the other aspects of the system will limit the work system's effectiveness, or may yield 'sub-optimal' results.

The underlying principles and applications of STS have evolved to reflect the changing nature of work, technology and design practices. The broad understanding gained through the continued study of technological design has enabled a reinterpretation of socio-technical principles to reflect the challenges of contemporary information and communications technologies (Clegg, 2000). Nevertheless, the basis of STS methods still focuses on how strategies can be devised in order to jointly optimise the social and technical subsystems in a work system context (e.g., Clegg, 2000; Mumford, 2006).

A number of different methods for applying a socio-technical concept to wide ranging circumstances have been developed; for instance, the Soft systems methodology (Checkland, 1999); cognitive work analysis (Rasmussen et al., 1990); work system framework (Alter, 2006); social construction of technology (SCOT) (Bijker et al., 1987) and Leavitt's sociotechnical model (Leavitt, 1964). The STS principles have achieved some success in helping inform the design of technology-led organisational changes (e.g., Baxter and Sommerville, 2011), redesign of work roles (Challenger & Clegg 2011), and user-controlled autonomous work groups (Grant et al., 2011; Wall et al., 1986). The STS framework has also provided insights on how new technology may be used and integrated within existing work systems (e.g., Mumford, 2006).

This study particularly focuses on Leavitt's (1964) system model for sociotechnical analysis. Leavitt (1964) presents a sufficiently rich STS analytical tool which he developed through his experience of undertaking organisational change and focused on a balanced approach to the integration of work system's components. This STS model examines the mutual constitutions or co-development of people and artefacts, socio and technical or human actors and non-human actants – to avoid the situation where one outcome is supported or privileged by one element over another. Typically, it depicts the mutual dependency in four sociotechnical components which comprise, people, tasks, structures and technologies. Thus, the work system will comprise actors (with varying attitudes, requirement and abilities), who use a range of technologies and tools, and work within a context with structures and regulatory framework to achieve assigned tasks. Leavitt argued for the interrelatedness of these system components and for the need for their joint consideration.

According to Leavitt (1964), the four elements are highly interdependent and a change in any one of the elements results in a compensatory (or retaliatory) change in the other elements so that the system maintains equilibrium (Lyytinen & Newman 2008). Each of

the sociotechnical components can become the source of the system's misalignment (e.g. Lyytinen & Newman 2008) because the entity or forces that impinge on everyday practices of the system are coproduced by the system's elements within the confines of the work system. At any particular time, the work system is either in equilibrium where the system is balanced or, it is not in equilibrium and the system is not balanced. When it is in disequilibrium, the system contains a gap between one or more of its elements (i.e., either there is an issue with the task, the technology, the actors or the structural arrangements) that call for action - an intervention event to remove the gap, thereby reverting to its equilibrium state (Mumford 2006).

The Leavitt framework has, subsequently, been used by others in different sociotechnical contexts, including, for example, Handy (1993), Scott (1991), Lyytinen and Newman (2008), and Challenger & Clegg (2011). The potential value of applying the Leavittian model is that it provides a structured and systematic way of analysing a variety of complex work systems. Also, it is simple, yet, reasonably well defined and sufficiently broad for analysing the STS implications in the construction context as demonstrated in the featured case study. It is not the focus of this paper to describe in detail how the framework is deployed in any particular context. However, an overview of the major steps involved in applying the framework to analysing and understanding a work system is presented.

SOCIOTECHNICAL ALIGNMENT IN A BIM-ENABLED MULTIDISCIPLINARY CONSTRUCTION CONTEXT

Given the complex sociotechnical context of the industry, embedding new processes and technologies is inherently problematic (Murray & Langford 2008). Thus, it is not simply a focus upon innovations that is required, but also an examination of the existing work systems where the BIM technologies are introduced. Leavitt (1964) seems to suggest that if the roles of the sociotechnical elements (i.e., actors, tasks, technology and structure) are more fully understood, then the implementation of existing and emerging BIM products, and the concomitant processes can be better managed.

Though the concept of BIM is nascent, it is evolving rapidly. Singh et al. (2011), proclaim that BIM has the potential to fundamentally change how construction is documented and performed. Eastman et al. (2011) as well as Suerman (2009) held that organisations have to change their processes to adapt to this development. This is because transition to BIM is not a natural advancement from CAD. It involves a paradigm shift from drawing on two-dimensional media to modelling, which is akin to actual construction in a virtual environment. Thus it requires a new set of skills, new ways of thinking and new approaches to intellection.

Korkmaz et al (2012) made the point that, where multidisciplinary collaborative relationships are required in a particular work system, it is not sufficient to ensure successful implementation of innovation if the alignment between structure, tasks, technology and actors is not channelled across the various knowledge-departments in the work system. In project-based industries such as Architecture, Engineering, and Construction (AEC), innovations in technological products and related approaches to project delivery highly demand coordination among participating parties (Homayouni, et al., 2011). Though sharing a common interest in project success, knowledge workers differ greatly in their skills, motivations, roles, responsibilities and contribution in the work system. In particular, successful change initiatives in intra-organisational work systems are theorised to require continual nurturing of actors' motivation to buy into change, including evidence of supportiveness tailored to each units to foster cooperation,

and countering of incentives to break the status quo amongst the actors who are expected to, but struggle to cooperate (Higgs & Rowland, 2011).

Contrary to popular believe that BIM brings efficiency and collaboration to the construction sector (Eastman et al 2011; Singh et al. 2011), the Leavitt STS model seems to theorise that, being part of the work system's components, BIM tools only act as a main platform for correlating different datasets. The consistency in the data and the intelligence in the model are confirmed through the mutual alignments and interactions between the task, structure, technology and actors. Thus, in reconfiguring the work system to accommodate BIM, there is a need to be sensitive to the collaborative activities and needs of its various users; introducing a new sociotechnical element, whether it be technical (e.g., new software version) or social (employing new staff member) impacts on the collaborative process. One way to gain a better understanding of the STS approach to help in future work system design is to examine similar systems that have been successfully deployed (Reddy et al 2003). The next section introduces the case study and expands on sociotechnical analysis by presenting an STS analysis of a BIM-enabled multidiscipline construction organisation drawing on Leavitt's (1964) framework. The analysis illustrates how the BIM concept was applied to support collaboration among various construction workers to enhance work delivery.

RESEARCH METHOD

The main purpose of collecting the empirical data has been to develop deeper understanding of the change processes in the work system where BIM is implemented. Case study research has been strongly advocated as a suitable and established method for obtaining rich insights within a context (Yin, 2011). The empirical case study allows the research team to trace BIM implementation from the origin of a particular construction organisation that has recently embraced the BIM concept into their work processes. Because sociotechnical requirements are rooted in the work contexts of individuals, the case study techniques presents a unique approach for observing and extracting these requirements within the work context (Hughes, 1994). The study occurred in a single multidisciplinary construction organisation setting in the UK. The purpose is to focus on drawing lessons from a novel approach to BIM uptake from a specific case. This approach is consistence with Yin's (2011) argument that, because of its revelatory nature, a novel circumstance of a location can justify the condition for selecting a single case study. Whilst the study is not intended to be statistically generalizable across the AEC industry, it reveals deeper insights of the causal influences of BIM implementation in a multidisciplinary construction context.

Data collection and analysis strategy

Data was collected in the natural setting of the organisation. To enable triangulation and reveal contradictions and agreements in the reporting of events, three sources of data were collected, and integrated into a data corpus and analysed. These include, interview transcripts, BIM documents, and notes from observations (e.g., Lyytinen & Newman 2008). The engagement with the case study organisation continued for nearly nine months. Ten semi structured interviews lasting between 60 to 120 minutes were conducted with senior and middle managements, and the questions focused on respondents' backgrounds and experiences, and strategies for and consequences of BIM implementation in the organisation and on the workforce. Additional information was garnered via informal discussions with technical team members and management staff over the duration of the case study. This played an important role in the verification

process by enabling the validity of the interpretation of the emergent findings to be tested with the research participants.

All the information gathered were coded and transcribed verbatim. Strauss and Corbin's (1998) 'microscopic' technique was followed. The approach calls for a detailed scanning of each paragraph of the transcript data, looking for events that relate to BIM implementation. In the end, a full narrative of events and their interactions in a visual form was constructed (e.g., Langley 1999). This chronicles the implementation process from its start to its end as a sequence of events that affect the sociotechnical alignment (or otherwise) of the work system.

Case description

The company in which the study was accomplished is a branch of one of the leading construction companies in the UK. The company's turnover in the 2011 financial year was 1.5 billion euros, with employees of circa 4,700. The company specialises in building low-carbon infrastructure projects from power plants, roads and bridges to housing, schools and hospitals. The company is however, well-known for its investments in high performing energy-efficiency building envelope solutions and insulation products. The research team had access to the West Midlands branch of the company, hereafter, referred to as W-Mid. It is composed of five functional departments, that include; design and engineering; commercial; planning; production; and customer service department. These intra-organisational units work towards fulfilling the overall strategic mission of the organisation, and are served by a common BIM repository.

Findings and discussions

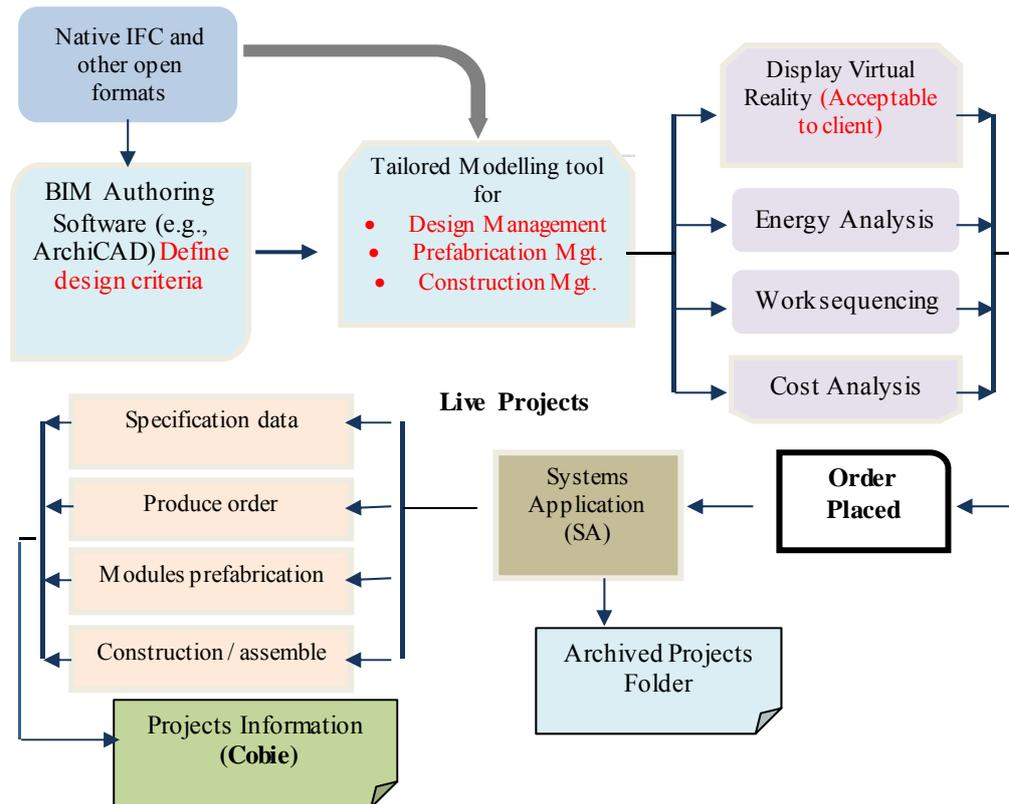
The findings are discussed below under three subsections, namely: Deployment of BIM tools and accompanying change processes; actors' roles definition and learning-curves in the work system; and contextual issues and technological limitations. W-Mid has collaborated with the National Building Specification (NBS) to author five of its insulation product ranges as BIM objects and host them on the National BIM Library (NBR). These library objects are available in industry-neutral IFC formats and formats compatible with ArchiCAD, Revit, Vectorworks and Bentley. Their scope of operation and extent of use of BIM tools thus represent a useful reference point that could offer learning opportunities in terms of BIM implementation processes.

Deployment of BIM tools and accompanying change processes

At the very start of the transitional process, the design and engineering division was equipped with BIM platforms, compliant work stations and associated trainings to drive the implementation across the broader organisational context. The company relies on different BIM authoring software for different jobs. Each BIM software package tends to be more inclined to a specific purpose. Thus, the organisation has a number of relationships with different external BIM vendors to help incorporate technical competences and artefacts into the various internal functional units. Previously, W-Mid's typical project documents had been maintained separately by the different functional departments, among which there were overlaps and inconsistencies. One of the main criteria for BIM introduction was for the teams to work on a centralised intelligent platform with BIM parametric integrity, thereby coordinating the works of the disparate knowledge boundaries. A respondent described their BIM implementation strategy as "BIM-enabled process map", providing "one complete BIM solution" that affords the integration across the intra-organisational units, extending to the management of various phases of their BIM projects (i.e., design, manufacturing, and construction): "[...] the

system is a bespoke BIM system [...] you can refer to it as BIM-enabled process map (BPM)” (Technical manager). Based on the respondents’ responses on how BIM is deployed, explanations on how the BPM is configured to work, and the implicit observations of the respondents in their work context, a visual image has been developed to capture the extent of BIM configuration in W-Mid. This is shown in figure-1. This arrangement is described in the organisation as BIM-enabled process map (BPM). The description of the BPM has been reported elsewhere (Sackey et al., in press). The essence of the BPM is to show the whole-sale changes that accompany BIM implementation in a collaborative project environment.

Figure 1: BIM-enabled process map (BPM) at W-Mid



The BPM presents a platform that has sufficient information to support design operations of object model creation, editing, and modification. It also supports multiple tools for 3D modelling, drawing production, energy analysis, site coordination, fabrication, generating specifications and quantity takeoff for costing and/or scheduling. The BPM also carries parametric rules for maintaining the correctness of the federated models. This approach is a complete shift for the various departments in terms of new work processes and use of new technologies.

Each of the departments tends to favour a different BIM application from the other. These different BIM vendor platforms cannot, however, directly exchange model information without losing data intelligence. Almost all the major BIM vendors are in compliance with the open-model data exchange format (Industry Foundation Classes). The BPM configuration thus includes the various preferred BIM applications and the native IFC which allows the various departments to be able to access, and also sync their parametric models with that of the other departments. A sharable building model in a neutral format such as IFC enables collaboration via easy transmission and generation of data across the team. Beyond the technological and structural configurations, however, there lie other

elements which have to be reconfigured to ensure that the work system functions as planned. The system cannot function as planned if the actors are not trained on how to use it to perform their tasks. One respondent for instance emphasised that:

“... You provide the mechanism for everyone to dip into the right software they need but at the end of the day you still got to be looking at people being trained in the use of that software because, left to the devices, it is going to be quite a long hard task to get up to speed” (Head of design and engineering).

That is to say, it does not only take the configuration of the technology to realise the intended change – it is also a question of learning and application - how to reinvent the workflow, how to train staff and assign responsibilities, and changing from 3D paper-centric practices toward an integrated and interoperable object modelling, where the tasks interlink to a common repository.

Actors' roles definition and learning-curves in the work system

It was clear from the responses of interviewees that before fully committing to the BIM process, there should be a change in "people's attitudes" and introduction of new knowledge concerning the use of the selected technological platform to the users.

“[...] this thing that we are anticipating is change management. That is, changing people's attitudes and working in a collaborative environment rather than the silo style of working - which is, I will do my bit and then throw it over the wall to the next person who will probably catch half of it. Then you have this series of dead data” (BIM Manager).

The technical team was considered by the other departments as the “in-house trained BIM team” that arranged technical support and systemic trainings for individuals' needs and their collaboration tools by which they could better integrate with other organisational members, all in keeping with STS alignment as proposed by Leavitt (1964). Staff development and practice-based training through in-house learning and the regular use of the BPM as a working platform contributed to the new process progressively taking shape. This continued in an incremental fashion as new experiences and behaviours were gradually accumulated and as the various users embraced the knowledge.

The responses of the interviewees indicated that, BIM solutions keep developing in parallel with evolving technologies which are “constantly (often annually) upgraded”. Thus, there is no end in sight for the learning of existing (and emerging applications) and relearning of revised versions of these BIM solutions. The implication of this is that, BIM-enabled actors must position themselves on a constant loop of learning to act decisively towards the common goal of their work context, creating the condition for present, as well as future success, and also, taking into consideration the fluidity of current technologies as they continue to develop in content and in form. Moving forward, it reinforces the notion of a double-loop learning approach where latest versions of BIM tools can effectively be used to avoid the repeat of any on-going deficiencies. This is consistent with Korkmaz et al's (2012) assertion that innovation is more likely to be adopted in the intended manner if actors have skills to master the innovation, have incentives to implement, and are beneficiaries of managements' efforts to remove structural and procedural obstacles to implementation.

Contextual issues and some limitations of the BIM technologies

While W-Mid was showing commitment to support the development of BPM via the use of the best available BIM applications, the shortfalls in the existing BIM platforms and their impacts on the use of the BPM could not be ignored. The challenges to the effective

use of the BPM were found to be related to some limitations associated with the existing BIM platforms and some change management issues accompanying the technologies.

Compared to the use of the 3D CAD, BIM models contain both 3D geometry objects (for design purposes) and additional properties (for analysis of design objects) and their parametric relations (for intelligent linkages and automatic updates). The number of data types represented in a typical model has thus grown tremendously hence, calling for “top-of-the-range” computer workstations to operate BIM effectively. However, despite the necessary trainings, and the use of “powerful computers”, users often find it very difficult to develop complex models on a typical personal workstation, let alone, port models on a sharable, public server domain. As the level-of-detail (LOD) of a model increases, the speed of the workstation begins to significantly reduce in proportion. Also, data synchronisation on the BPM platform is often found to be “frustratingly slow”, and “sometime it takes hours” to port a model from a personal workstation onto the BPM’s public repository and vice versa - notwithstanding the use of 64bit and i7 Intel core computer processors and operating systems. This poses a concern for the model development at the personal workstation level, and coordination management at the open-platform level. Respondents however, believe that memory and processing issues may decrease as computers get faster and higher spec workstations become cheaper and affordable.

A concern was also raised with regards to the issue of interoperability. Being a multidisciplinary construction organisation where different knowledge workers use different task-specific BIM tools, a natural desire for W-Mid is to “mix and match” software tools to provide functionality beyond what can be offered by any single BIM platform. In this case, interoperability, or the consistency across tools is very important. Interoperability can be achieved via easy and reliable exchange of project data between BIM applications. This however, is not the case for W-Mid. Thus, a technical manager complained that:

“The key technical issue for us is about software interoperability. The software vendors sell us the line that the next piece of their software or app will solve all our problems. However, what we need as an organisation is open, interoperable software that can communicate well”.

This suggests that, BIM tools, including the open standard IFC formats, do not adequately support the management and tracking of changes to models that are created using different vendors’ application platforms. Eastman et al (2011) have also raised similar concern that the development of industry-neutral open-model exchange format such as IFC has been relatively slower compared to the pace by which the commercial vendors such as Autodesk or Bentley develop their BIM software applications. This weakens the IFC as a non-consistent model exchange platform, and often, the ‘model intelligence plus some information is lost’ during the exchange. Eastman et al (2011) further warned that, until the interoperability gap is closed, the issue of “non-conforming” data interchange may remain unresolved. A respondent who uses the IFC on a regular basis for data exchange also emphasised that the “IFC don’t deliver information very well-it is not very well done yet - They really need to step-up, whoever do the IFC, and sort it out” (BIM coordinator). Nonetheless, respondents indicated that, in their latest product versions, the BIM vendors often attempt to address the common technical problems users often complain about. For instance, a BIM coordinator who very much relies on the IFC to interoperate/coordinate different models acknowledges that, some data is often lost when transferred with the aid of the IFC, but he indicated that, “I am looking forward to the

version IFC4.0”, with the hope that, some of the identified limitations and concerns may have been resolved.

CONCLUSIONS

The sociotechnical approach (Baxter & Sommerville 2011), particularly the Leavitt (1964) model, and the BIM practice in W-Mid reveal that moving towards BIM-oriented practices is not just a simple case of substituting a dormant antiquated piece of a system with a more appealing suite of technological tools. The case demonstrates some of the unforeseen consequences of, and complexities involved in, attempting to engender new practices. In the case of W-Mid, an attempt to implement BIM is beyond simple utilisation of material artefacts as tools or add-ons to existing processes. The nature of the organisation, bridging diverse knowledge and professional boundaries, presents a unique challenge for the BIM uptake. Of interest to W-Mid were attempts to gain full benefits from the existing BIM tools to integrate the creation, sharing and representation of information for the design and construction processes, and to digitally mediate the design and construction activities amongst the heterogeneous knowledge workforce. There were technical and organisational challenges of software and data interoperability as well as the need to create appropriate business and social practices and processes.

Leavitt’s (1964) model highlights the importance of understanding the interrelations between organisational, social and technological constituents of any given work system and also the environment in which it operates. The model recognises how misalignment or a gap can occur in any of the four components of the work system, and it depicts a subtle interplay between technology, actors, structure and task as the main drivers for work system’s disruption, maintenance and stability.

In the case of W-Mid, based on the capabilities of the selected BIM technological platforms, new tasks were defined, which otherwise would not have been possible in the past, using the conventional CAD platforms. These new tasks (e.g., as shown in figure-1) include, the ability to create a coordinated 3D model for drawing production, energy analysis, cost data and scheduling data generation, site coordination and prefabrication information as afforded by the capabilities ingrained in the various BIM applications. The change in tasks, and the technology created a knowledge gap among the actors, because they had to readjust into the new work configuration, concomitant to the BIM applications. This knowledge gap is addressed ultimately, by providing learning opportunities and management support for everyone affected. Some technical limitations of the BIM products were also obvious, including the lack of direct interoperability among BIM applications; the very slow nature of the recommended computer workstations when running complex models; and the inability of the current IFC to ensure accurate object model exchange across IFC-compliant BIM platforms. It however emerged that, the BIM vendors often attempt to address some of the technical deficits in the latest releases of their products. The regular releases and upgrades of these BIM products also imply that, the construction practitioners and BIM users have to revert into ‘double-loop’ learning mode, in order to be able to capture, retain and apply each improvement in the latest BIM platforms, thereby, avoiding any repeat of on-going inefficiencies in the previous BIM products’ versions. This analysis draws attention to the interrelation amongst the work system components, where a change-event in any one of the elements results in a compensatory or retaliatory change in the other elements. This particularly calls for action – an intervention events to address any spin-off issues associated with the introduction of BIM.

Extending beyond this study, both the Leavitt systems model and the case organisation offer some insights in three facets. Firstly, the study makes the case for the development of a more suitable theory-to-practice which favours BIM uptake in construction organisations. Secondly, it elaborates on the importance of the application of a sociotechnical approach in construction contexts. And thirdly, it uses a sociotechnical approach to understand and analyse BIM implementation in a multidisciplinary construction context, helping to identify key lessons and problematic areas in the frames of actors, structure, technology and tasks-in particular, pinpointing significant issues requiring management attention during BIM uptake. Ultimately, the study provides learning opportunity for inter-organisational project organisations aspiring to implement BIM.

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THE BIM INFORMATION NEEDS FOR SUSTAINABILITY IN CONCEPTUAL DESIGN

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Sustainability in construction has attracted considerable attention from scholars as well as from regulatory bodies. However, early design stage sustainability analysis remains problematic because of the conflicting factors affecting sustainability, the limited and fragmented project data in hand at early design stage and deficiencies of existing sustainability analysis software for quick evaluation of conceptual design alternatives. BIM's building information management and integration capabilities present opportunities to support early design sustainability analysis. In this paper, early findings of an on-going BIM based early design sustainability analysis application development project are presented. Through literature review and in-depth interviews conducted with a sustainability professional, a categorization of the information needed for quick evaluation of different conceptual design alternatives from a sustainability point of view is developed. The categorization developed and presented in this paper aims to guide further stages of the project of the development of the application and also to support the writing of a BIM Execution Plan for projects where holistic early design sustainability analysis is intended.

Keywords: design, information management, information technology, sustainability.

INTRODUCTION

A widely accepted definition of sustainability is given by the Brundtland Commission as “Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). The energy consumption of buildings contributes significantly to global CO₂ emissions that cause global warming which threatens the future of our planet. This fact makes the energy performance of buildings an important issue for their sustainability. It is stated that 40% of global CO₂ emissions results from building operations (Park et al. 2012). However, El-Alfy (2010) states that economical, functionality, durability, aesthetics, ecology, health and sociocultural aspects of a building design are all together the factors affecting a building's sustainability. A building's sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different players of a construction project can be in conflict (Anastas and Zimmermann 2003). The inter-relations and inter-dependencies that should be considered for a meaningful sustainability analysis require the collective evaluation of the design information created by different players of the project design team. Therefore, a collaborative and robust building information management system is desirable to support such analysis (Lam et al. 2004).

Building Information Modelling (BIM) can be defined as the process of development and use of a digital model of the facility intended to be built. The resulting product of BIM, the Building Information Model, has the ambition as being the central hub for all information about the facility from its inception onward. This information may take on

many forms (e.g. visual and numerical) and has many roles to play for the whole life cycle of the facility (BIM Industry Working Group 2011). The conceptualization and use of the Building Information Model as the central hub for all information requires all stakeholders of the project to contribute to and exploit this building information in an inter-disciplinary collaborative effort during its whole life cycle. Therefore, BIM is increasingly considered as an Information Technology (IT)-enabled approach that allows better management and representation of building information during its whole life cycle (Fischer 2004). Consequently, it is argued that information management capabilities of BIM, create new opportunities for sustainability evaluation and decision-making in building design (Bank et al. 2010; Nguyen et al. 2010).

This paper presents the early findings of a BIM application development project which aims to provide sustainability professionals a BIM based building sustainability analysis tool for the evaluation of different conceptual design options quickly. One of the authors took part in the initial stage of the project for one month as part of a European Union funded Pioneers into Practice placement program. The work, which will be reported here, focused on exploration of current challenges for quick evaluation of different conceptual design options from sustainability perspective as well as determination of what main categories of information are needed to conduct BIM based sustainability analysis at conceptual design stage in order to enable this evaluation. These challenges are explored through a literature review and in-depth interviews with a sustainable design professional. The main challenges are identified and a framework which categorizes the information needed by sustainability professionals for quick evaluation is developed and presented.

CHALLENGES OF BIM BASED SUSTAINABILITY ANALYSIS AT CONCEPTUAL DESIGN STAGE

A building's sustainability is dependent on several inter-related and inter-dependent factors and these factors are affected by the design decisions made by different players in a construction project (Anastas and Zimmermann 2003). In the traditional, non-BIM design workflow, performance assessments of the design are generally undertaken after the completion of architectural design when the design is almost completed (Soebarto and Williamson 2001; Schlueter and Thessling 2009). Such performance assessments consists of several independent (Bank et al. 2010) detailed analyses made by expert software using the detailed design information. Crucially, this detailed information is not available at the early design stages and also involves considerable interpretation by experts (Schlueter and Thessling 2009). These independent analyses hinder having a holistic understanding of sustainability issues and presenting a holistic sustainable design solution (Bank et al. 2010).

The performance assessments made at late stages of the design may lead to design of buildings that have only limited sustainability e.g. in terms of services but not in architectural aspects (Schlueter and Thessling 2009). The performance assessments that are undertaken at late stages of design also lead to adoption of bolt-on solutions rather than holistic solutions for the unsatisfied target criteria found out by analyses. This is due to the impossibility of making big design changes at late stages of design development because of the concerns about cost and time. Sustainability and environmental impact issues of a building really require to be considered before the conceptual design stage and these considerations should be reflected in the conceptual design alternatives to achieve the sustainability targets (Ding 2008). It is widely acknowledged that most of the key design decisions affecting the building's sustainability are made during early design stage

and these decisions that are made at early design stage have the greatest impacts on the cost as well (Bank et al. 2010). Therefore, one of the challenges is to find a design evaluation method suitable for early design stage that provides enough understanding of the design for decision making (Brahme et al. 2001).

Sustainable building design is a matter of optimization of several different aspects of a building because of the conflicting nature of some of the factors affecting sustainability (Anastas and Zimmermann 2003). This creates several challenges for early design sustainability analysis. First, information from different players of the design team needs to be integrated, reachable and exploitable in order to conduct an inclusive automated sustainability analysis (Nguyen et al. 2010; Wong and Fan 2013).

Second, a sustainability professional is required for the translation of client needs and project specific constraints to determine the target sustainability performance criteria. These sustainability professionals know about the different aspects of building sustainability and their relations at systems-level and so can interpret results to support decision making. Mutis and Issa (2012) stated that users from different backgrounds of an integrated and shared building model may have problems making sense of the information embedded into the model due to semantic gaps between the ways this information is presented to them and the way they need to use it to perform their tasks. This means that, in order to enable sustainability professional to benefit from the information embedded into the model for his/her analysis and interpretation; design information should be presented him/her in a way he/she makes sense of it. In a similar way, for sustainability analysis at conceptual design stage, analysis method and criteria should be configured in a way so that it does not rely on detailed design information before that has been generated by the designers (Ding 2008).

Third, building assessment schemes to guide sustainable building design such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) were not designed to be used as design guidelines. The fact that they are increasingly being used as such (Cole 1999) is also an important deficiency in sustainability analysis. The credit-weighting approach of building assessment techniques is the heart of these approaches which compound to the final score of the building being assessed and there is no consensus for the weightings used (Cole 1998; Lee et al. 2002). Ding (2008) criticizes that “the overall performance score is obtained by a simple aggregation of all the points awarded to each criterion. All criteria are assumed to be of equal importance and there is no order of importance for criteria”. Mainly due to conflicting nature of some of the factors affecting sustainability, he adds that the criteria should be developed according to each project’s aims and conditions (Ding 2008). It can also be argued that, pre-defined criteria (i.e. criteria which are not project specific) of building assessment schemes may hinder some sustainable design avenues, making designers focus on high and relatively easily gained credits provided under some pre-defined headings of the scheme while disfavouring some others.

Two approaches are identified in the literature for BIM based sustainability analysis applications. Some research concentrates on integration of existing and widely accepted sustainability performance analysis tools (e.g. Integrated Environmental Solutions-Virtual Environment) with other widely accepted collaborative BIM tools (e.g. Stumpf et al. 2009; Azhar et al. 2011) whereas some other research aim to develop new analysis tools which are able to communicate with widely accepted collaborative BIM tools (e.g. Schlueter and Thesseling 2009; Nguyen et al. 2010). Park et al. (2012) make the point

that high development costs, usability and interoperability issues of adapting existing energy analysis software need to be considered when deciding between the two approaches.

BIM INFORMATION NEEDS FOR SUSTAINABILITY IN CONCEPTUAL DESIGN

The challenges identified in the previous section led the application development project team to create a new early design sustainability analysis application for quick evaluation of different conceptual design options. There were several reasons behind this decision. As stated in the previous section, although there is on-going research and development that aims to provide seamless interoperability between collaborative BIM tools (e.g. Autodesk NavisWorks) and widely used sustainability analysis software (e.g. Integrated Environmental Solutions-Virtual Environment), there are still interoperability problems. Transfer of the building model from collaborative BIM tools to proprietary sustainability analysis tools causes loss of information in many instances. Therefore, development of a new application using the Application Programming Interfaces (APIs) to communicate with dominant collaborative BIM tools in the market was preferred.

There are also some other important issues regarding the usability of existing applications. Firstly, from the interview with the sustainability professional, a wide range of factors is required to understand the outputs of the analyses conducted by existing, widely used sustainability analysis tools. This is seen as a deficiency considering the fact that at conceptual design stage the effects of different building sub-system configurations (e.g. type of external fabric, heat generation and distribution systems) and their advantages and disadvantages need to be shared with the client and other design team members in a way they can make sense of it. Thus, it is believed by the project team that development of a new early design stage sustainability analysis tool would allow them to present the outputs of analyses in a more meaningful way for client and other design team members.

Furthermore, from the interview with the sustainability professional, the existing sustainability analysis tools don't provide enough flexibility to easily change the architectural and functional building sub-systems' configurations (e.g. type of external fabric, glazing percentage, energy generation and distribution systems) at level required (i.e. systems level) for conceptual design evaluation. Many objects of the model in the sustainability analysis tool need to be selected individually and dropdown menus need to reconfigure the model to evaluate the effects of systems configuration alternatives. It is believed by the project team that development of a new early design stage sustainability analysis tool would be more convenient as it would allow the project team to group the information embedded in the collaborative building model according to their needs and therefore provide a more flexible and suitable working environment for evaluation of different building sub-system configurations.

Finally, because of the deficiencies in their credit-weighting approach and their pre-defined criteria that don't reflect project peculiarities; development of a new information framework that suits early design holistic sustainability analysis is preferred rather than following an existing building assessment scheme (e.g. LEED) for information categorization and sustainability evaluation.

CATEGORIZATION OF INFORMATION FOR EARLY DESIGN SUSTAINABILITY ANALYSIS

Sustainability and environmental impact issues of a building need to start to be considered even before the conceptual design stage and these considerations should be reflected in the conceptual design alternatives to effectively achieve the sustainability (Ding 2008). This view is supported by the interviewed sustainability professional who stated that building functionality, site conditions, target building performance criteria, budgetary and time limits should be understood and documented during RIBA (The Royal Institute of British Architects) Stages A (Project Appraisal Stage) and B (Design Brief Stage) to enable an efficient sustainable design starting from RIBA Stage C (Conceptual Design Stage).

Through the in-depth interviews conducted with the sustainability professional, RIBA Stage C is divided into three consecutive stages from sustainability point of view of RIBA Stage C. These stages and their aims are presented in Figure 1. The first stage is for selection of building system (e.g. timber frame, reinforced concrete frame, pre-fabric etc.). The interviewee stated that clients generally want to know about time and cost implications of different building systems before development of multiple conceptual design alternatives. This also helps development of more easily comparable conceptual design alternatives. Thus, high-level building functionality, site conditions and target building performance criteria of each building system alternative need to be presented to the client together with their budgetary and time implications before proceeding with multiple conceptual design alternatives. It is stated by the interviewee that this task can be performed using spread sheet applications because at this stage of the project, evaluation of each building system alternative mainly depends on experience as well as insight about the historical data and limited project specific information in hand.

Following the building system assessment, a sustainability pre-assessment meeting needs to be organized. This meeting is important to inform design team members about the sustainability criteria established during RIBA Stages A and B and therefore to enable development of comparable and satisfactory conceptual design alternatives.

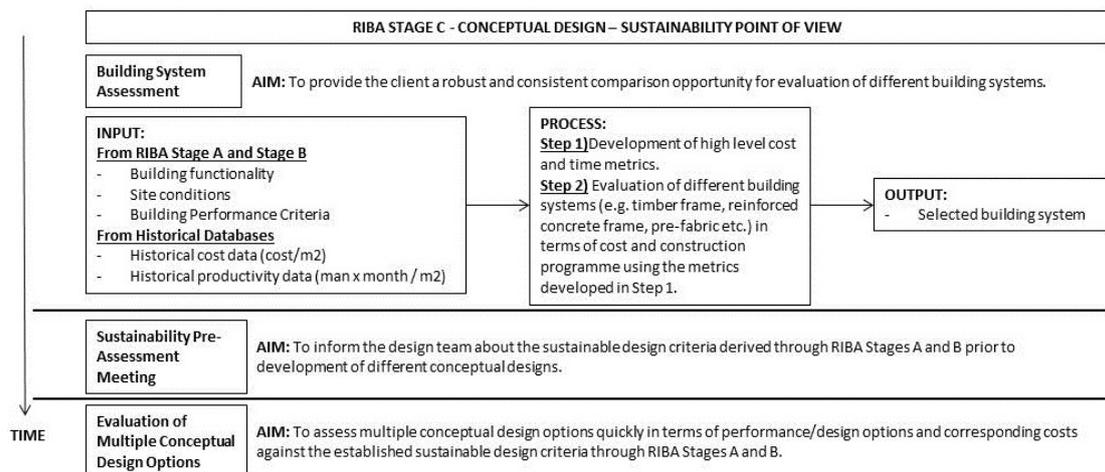


Figure 1: RIBA Stage C (Conceptual Design Stage) from sustainability point of view

The third stage is the evaluation of the multiple conceptual-design options. It was decided that it is this stage that can be leveraged by the computer application to be developed. As stated in the previous section, it was decided that the new application would use the information embedded in the building information model created by different contributing

parties and merged under a collaborative BIM tool. This means that the model doesn't need to be transferred into the application to conduct sustainability analysis with the application extracting the information needed for sustainability analysis from the collaborative building model. This requires the robust structuring of the information to be entered into the model for later use by the sustainability professional and other analysis applications to enable quick evaluation of multiple conceptual design alternatives.

Analysis of how the structuring (i.e. identification of parameters and attributes to be assigned to objects and/or sub-systems in the model) of the information should be is not in the scope of this paper and will be undertaken at later stages of the application development project. Moreover, the structuring of the information to be entered into the model will change according to the collaborative BIM software that the application would be integrated with. However, a general framework which categorizes the information required for quick evaluation of multiple conceptual design alternatives from sustainability perspective has been developed to guide future BIM tool development in order to support sustainability professional's and analysis application's needs. This framework is presented in Figure 2.

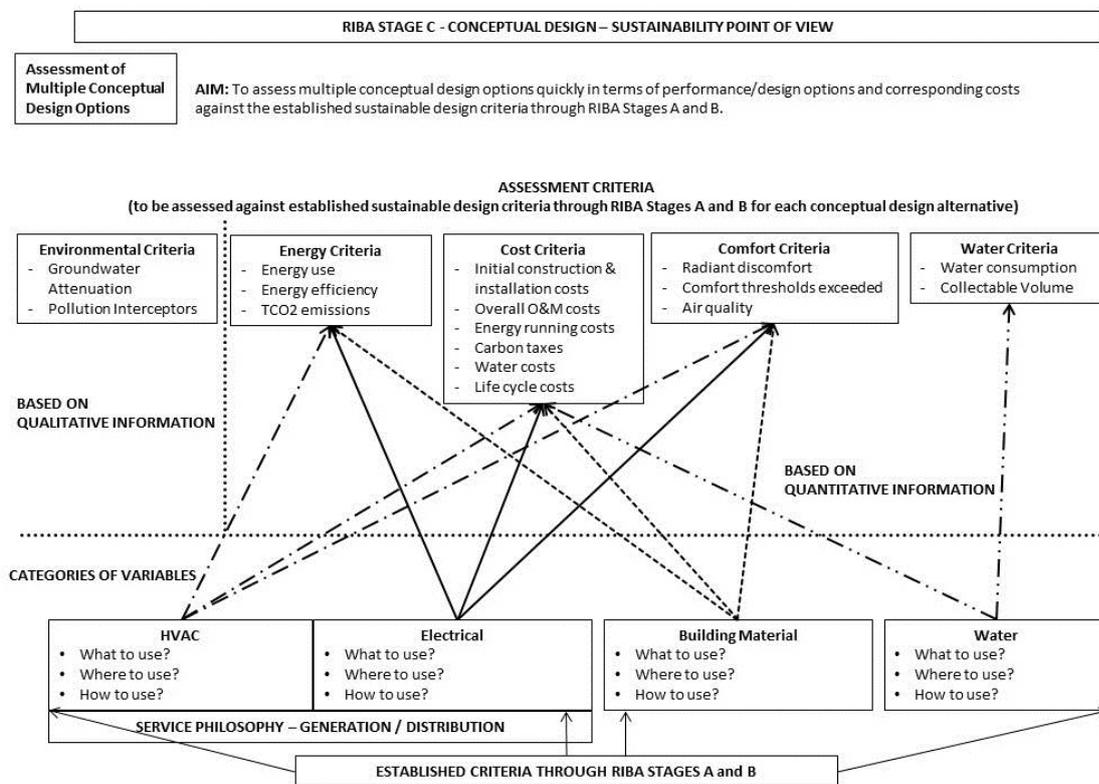


Figure 2: Categorization of the required information for sustainability analysis

The assessment criteria categories identified through the interviews represent the different aspects of sustainable building design which are needed to be evaluated for each conceptual design alternative at RIBA Stage C. Among them, the "Environmental Criteria" category is mainly based on qualitative information at RIBA Stage C; therefore, it was decided that this would be kept out of the analysis application. The arrows drawn between variable categories and assessment criteria categories show the contributions of each variable category to different criteria categories.

The answers to the questions under each variable category determines the required level of detail (i.e. what question) and contextual information (i.e. where and how questions)

for each variable category in order to satisfy application's computational needs and sustainability professional's application usability needs. The sustainability professional, as the application user, would be able to quickly and easily reconfigure different sub-systems of conceptual designs to see the effects of different sub-systems' implications on sustainability. Thus, through understanding sustainability professional's needs and point of view allows them to satisfy user requirements. The interviews revealed that sustainability professional wants to be able to evaluate different sub-systems under four categories: HVAC, electrical, building material and water fittings at conceptual design stage. The level of information needs to be identified to address "what, where, and how" questions for each variable category. For example in the HVAC category, the "what" question should distinguish whether the whole system or distribution system and heat generation systems should be addressed? Again for HVAC category, the "where" question would answer whether the different heating/cooling zones in the building should be addressed or the positions of the spaces identified according to building orientation? Again for the HVAC category, the "how" question should identify the performance information needed for each element identified under the "what" question? It is argued that, answers to these questions would give a clear understanding of expectations of sustainability professionals from the application to be developed.

CONCLUSIONS

Sustainability in construction has attracted considerable attention from scholars as well as from regulatory bodies. However, early design stage sustainability analysis remains problematic because of the conflicting factors affecting sustainability, the limited and fragmented project data in hand at early design stage and deficiencies of existing sustainability analysis software for quick evaluation of conceptual design alternatives from sustainability perspective. BIM's building information management and integration capabilities present opportunities to support early design sustainability analysis. However, in order to benefit from BIM's capabilities, the requirements of early design sustainability analysis need to be well understood.

This paper, reporting on the early findings of an on-going BIM based application development project, outlined these requirements to enable sustainability professionals to quickly evaluate multiple conceptual design alternatives. The challenges of early design sustainability analysis stated in the literature and the findings of in-depth interviews conducted with a sustainability professional, were considered to develop a categorization of information needed for this application. This categorization was developed to guide the future stages of the application development project when the detailed information needs will be refined. Furthermore, this categorization can also be used as a support tool for creating a BIM Execution Plan for the projects where a holistic early design sustainability analysis is intended to be conducted. The limited results used in the paper may mean that the conclusions are not generalizable and so will be validated further through more interviews and workshops. Furthermore, such future research to validate the categorization presented in this paper will lead to a better understanding of early design sustainability analysis and better applications supporting it.

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TOWARDS DIGITAL INFORMATION EXCHANGE WITHIN THE CONSTRUCTION SUPPLY CHAIN: SHARING AND EXCHANGE BEHAVIOUR ON BUILDING INFORMATION MODELLING (BIM) ENABLED PROJECTS

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Building Information Modelling (BIM) will demand collaborative information exchange systems for digital information sharing across the construction Supply Chain (SC). Critical issues of uncertainty particularly relating to legal and contractual concerns and information related risk however make SC reluctant to participate in such electronic data exchanges compared to traditional paper-centric communication. The presence of perceived or real risk will inevitably affect organisational behaviour especially willingness to share information which may impinge on adequacy of shared or exchanged data. Such behavioural dynamics have been proven by studies in other industries (including manufacturing and logistics) where collaborative electronic data exchange is more extensively used. Similar studies are however not apparent within BIM literature despite growing recognition for more organisational and people centred approach to the adoption of BIM to complement the current focus on technical aspects. An argument is advanced in justification of the role of information sharing and exchange behaviour as a facilitator of inter-operable organisational practice. It is argued that knowledge on information sharing is critical in facilitating collaborative relations within the SC as well as effective BIM based SC information integration through a synthesis of concepts and insights from diverse socio-technical perspectives. A proposed research framework for empirical investigation is proposed for filling the knowledge gaps.

Keywords: Building Information Modelling (BIM), Supply Chain, Information Exchange, Information Sharing Behaviour

INTRODUCTION

Building Information Modelling (BIM) has been proposed as a tool for the realisation of the ambitions of the construction change agenda through the management and sharing of information in virtual 3-D environments (BIS, 2011). BIM is expected to revolutionize information exchange and flow through increased automation. This will result in greater exchange and sharing of digital data such as a project model through more centralised communication models allowing various levels of access to the entire SC. Kalny (2007) describes in **Figure 1**. the current state of information flow and an envisaged BIM information flow (exchange) situation. Still persisting however are uncertainty concerns relating to legal and data security which affect willingness of SC to participate in such electronic data exchanges due to perceptions of greater risk compared to traditional paper-centric communication (Hassan *et al.*, 2004; Aranda-Mena *et al.*, 2009; Ibrahim, 2013). Such unresolved issues potentially increase the vulnerability of SC participants and expose them to opportunistic behaviour that may endanger confidential and strategic information exchange and sharing on these collaborative BIM systems (Hassan *et al.*, 2004; Ibrahim, 2013). These indications have been recognised among the core challenges that could hamper efforts towards multiparty collaboration through BIM (Gu and London 2010; Harty, 2012).

While efforts are being made to mitigate technical challenges in integrating heterogeneous pieces of Information Systems (IS) and software, research evidence acknowledges that this must be complemented by inter-operable organisational practice (Taylor and Beirnsstein, 2009; Grilo and Jardim-Goncalves, 2010). Such practice will however require the ability of the people behind the technology to similarly interact through strategic alignment and organisational coupling which will require collaborative relationships where data will be shared on a more open basis (Taylor and Beirnsstein, 2009; Grilo and Jardim-Goncalves, 2010). The presence of perceived or real risk associated with electronic data exchange across organisational boundaries however impedes the openness required and hence influences organisational behaviour especially propensity to share with BIM (Harty, 2005; Adriaanse *et al.*, 2010). This is in line with evidence of similar consequences reported in other industries including manufacturing and logistics where similar collaborative IS platforms have been used for integration (Aljafari and Sarnikar, 2010; Eurich *et al.*, 2010; Du *et al.*, 2012; Zeng *et al.*, 2012). Bao and Bouthillier (2007), describe SC information behaviour as an organisational attitude towards information exchange between collaborators towards achieving a common goal. It is gaining popularity owing to recognition of the significance of organisational behavioural dynamics in successful collaborative IS adoption both within information science and SC information integration literature. This makes it indispensable to the construction SC as it prepares to adopt BIM for integration and collaborative exchange.

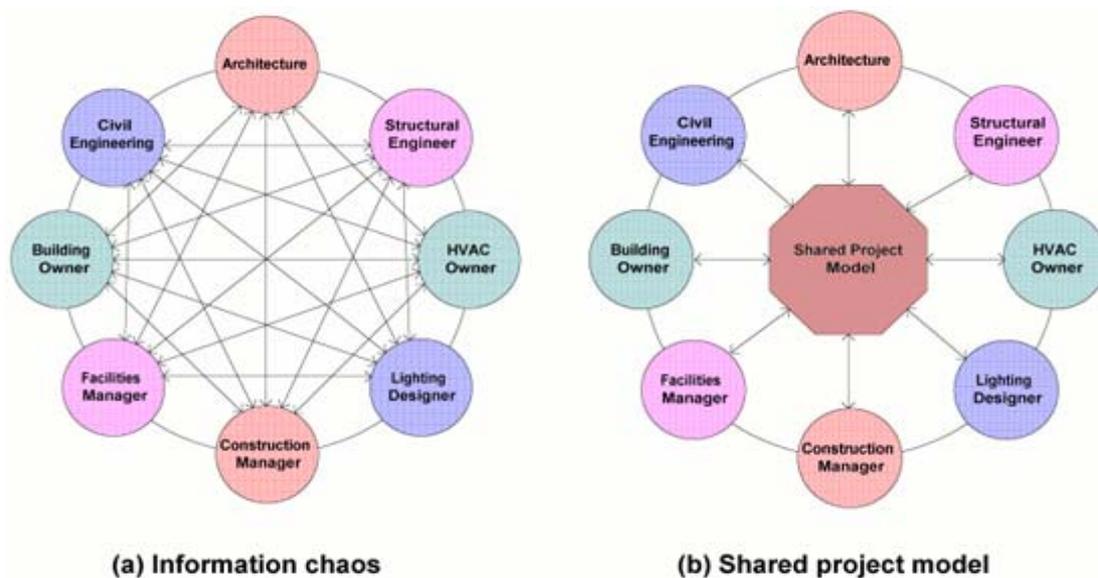


Figure1. The concept of BIM after International Alliance for Interoperability (Kalny, 2007) Available From: http://www.aecbytes.com/viewpoint/2007/issue_31.html

DIGITAL INFORMATION EXCHANGE AND INTER-ORGANISATIONAL ISSUES

The use of Information Technology (IT) for information exchange across organisational boundaries is influenced by many issues relating to both the characteristics of the technologies deployed as well inter-organisational dynamics. BIM exhibits similar characteristics and is explored below.

The Technological Perspective and Information Risk

Electronic information exchanges are inherently difficult to secure, making organizational intelligence and copyrightable knowledge more easily accessible to unintended recipients within collaborative IS (Clemons and Hitt, 2004; Aljafari and Sarnikar, 2010). Electronic datasets often include embedded attributes such as copyrights, parameters and ‘*inventive design configuration*’ which may have Intellectual Property (IP) value to protect (Wang *et al.*, 2006 p.149). It is also viewed as more easy to replicate or poach for unintended use making data security, privacy and ownership very challenging within such environments (Clemons and Hitt, 2004; Aljafari and Sarnikar, 2010). Several studies have highlighted IP breaches due to the above issues on collaborative IS where inter-organisational exchanges often occur (Clemons and Hitt, 2004). These issues directly relate to technology and IS capability to provide security and data integrity. Significant advancements have been made in the development of technologies to counter these challenges, yet according to Zeng *et al.*, (2012), perceptions of risk in relation to unresolved technological issues discussed above, remain among the most critical barriers to effective use of collaborative IS for data exchange.

The organisational perspective

Many inter-organisational Information Technology (IT) and IS failures have been linked to lack of consideration of organisational issues. According to Clegg *et al.*, (1997), 80–90% of IT implementations do not meet their performance objectives due to disregard for organisational behavioural issues in the U.K. The complexity of interaction between players with diverse interest within the construction SC makes such organisational issues even more imperative for study (Harty, 2005; Xue *et al.*, 2010). The structure, power and control dynamics, trust, social and cultural context of relationships and their relative influence on collaborative information exchange need further investigation (Taylor and Bernstein, 2009; Xue *et al.*, 2010). While significant technical (technological) factors (system security and inter-operability) could be attributed to this phenomenon (Aranda-Mena *et al.*, 2009; Singh *et al.*, 2011), many other studies have highlighted other organisational (cognitive) factors which significantly influence the situation (Harty, 2005; Taylor and Bernstein 2009; Xue *et al.*, 2010). Such factors include trust of SC participant capabilities, perceived control over the exchange process or trust of partner SC firms integrity (ie. believe that partner will not engage in opportunistic behaviour) (Adriaanse *et al.*, 2010; Xue *et al.*, 2010; Du *et al.*, 2012).

The critical role of trust: trust is an attitudinal construct which has increasingly been recognised as a key element in collaborative relationships where greater inter-organisational information exchange is required (Khalfan *et al.*, 2007; Adriaanse *et al.*, 2010). It is regarded as effective in curbing opportunistic behavioural tendencies, towards better coupling of SC with less formal or stringent contracting (Khalfan *et al.*,

2007; Manu *et al.*, 2010). Wong and Cheung, (2005) identified four typologies: 'Performance' which refers to partners' perception of competence and ability corresponding organisations (whether or not exchanged data is safe in their care); 'Permeability' which represents partner organisations openness in sharing; 'Relational' represents trust based on familiarity due to association or relationships; and 'System based' which represents reliance on specific measure such as rules or legal measures. All are regarded as critical in facilitating communication across organisational boundaries such as construction project environments or SC particularly where issues of vulnerability or perceptions of risk exist (Xue *et al.*, 2010; Harty, 2012).

External and Environmental influences

Issues such as industry standards, protocols and leadership could be influential in collaborative IS/IT usage (Younge *et al.*, 2008). In the case of the construction SC, critical guidance and technical regulation is expected to affect participant's involvement including new guidance on contractual and procurement regimes for BIM deployment (McAdam, 2010; BIS, 2011; Ibrahim, 2013). Harty (2012) and Ibrahim (2013) argue that effective participation of SC members will still be influenced by respective subjective perceptions of the influencing mechanisms in relation to industry level influences.

The Legal Arguments: Legal issues consistently emerge as critical when multi-party interactions are mediated by IT systems in a data intense business environment (Hassan *et al.*, 2004). Specific interests will therefore need to be catered for and moderated from the legal perspective to ensure success (McAdam, 2010). Most of the outlined issues have legal dimensions in view of peculiar characterisation of construction SC where relationships are mainly mediated by contracts. It is argued that SC members' choices among several causes of action within exchange scenario is based on their subjective disposition towards legal implications (Schieg, 2008). The conceptual ambiguity in the definitions of the BIM process and misperceptions in practice however create significant legal uncertainties (McAdam, 2010). The assembling and alignment of contractual frameworks and supporting organisation structures will therefore need apposite consideration of behavioural dynamics with full cognisance of the influencing factors in order to sustain the required controls or motivational atmosphere (Hassan *et al.*, 2004). This is expected to adequately forestall adverse information sharing behaviour in view of inherent risks or perceptions therein (Hassan *et al.*, 2004; McAdam, 2010).

Inter-organisational information behaviour and exchange effectiveness

The perceptions of risk and insecurity have been identified as factors influencing willingness to participate in SC information sharing including possible detrimental effect on data adequacy as tendency to hold back on strategic aspects of information increases (Eurich *et al.*, 2010; Du *et al.*, 2012). According to Du *et al.*, (2012) organisational willingness to share through collaborative IS affects adequacy of shared data regardless of contractual requirements, data standards or protocols in place. In the Architecture, Engineering and Construction (AEC) sector, data adequacy including timeliness, completeness or quality are essential at each phase of the lifecycle and vital for successful delivery of projects (Zhao 2009; Singh *et al.*, 2011). According to Zhao (2009), asymmetric conditions in AEC information exchange often relate to inadequacies in the amount of shared information. He asserts that while IS could facilitate effective sharing it must be structured with full cognisance of social industry divisions and fragmentation. Bao and Bouthillier (2007) identified significant relations between extent

of relationships between supply chain members (distance and width of relationships) with the levels of detail they were willing to provide in shared data. Other studies have argued that such adequacy is dependent on perceptions of risk and vulnerability particularly associated with exchange through electronic mediums (Du *et al.*, 2012; Nicolaou *et al.*, 2013).

INTER-OPERABLE ORGANISATIONAL PRACTICE AND BIM: THE ROLE OF INFORMATION EXCHANGE BEHAVIOUR

There is acknowledgement of the need for organisational '*inter-operable*' practice to complement current efforts towards technical inter-operability caused by excessive fragmentation of the construction SC. Such practice includes the ability of SC firms to align and interact at a collaborative level (Taylor and Bernstein, 2009; Ibrahim, 2013). This relationship is however highly dependent on information sharing tendencies making such studies paramount in filling the knowledge gaps. Progressively, construction industry research has recognised the vital role of attitudes and behavioural dynamics within project environments with successful collaborative working mainly contingent on these issues (Harty, 2005; Adriaanse *et al.*, 2010). In the context of supply chain, it is advocated that collaborative IS or data exchange systems be viewed as an enabler and complementary mechanism for integration of people and organizations (Taylor and Bernstein, 2009). To this end information sharing behaviour is a key determinant of the creation of the necessary interactions within the SC (Bao and Bouthilier, 2007; Zhao and Ding, 2010). This requires SC members to establish effective and efficient sharing or exchange culture for easier interaction through collaborative working culture (Xue *et al.*, 2010), a proposition echoed by Taylor and Bernstein, (2009) and Harty (2012) who identified it as key for successful implementation of BIM in the AEC. According to Zhao (2009), SC member congruence is critical in facilitating information exchange in order to mitigate the influence of perceived risks. This makes knowledge on antecedents and consequence of effective information exchange important as the industry prepares to exchange more digital data through BIM.

Technical inter-operability is often used to refer to the inability of inter-organisational IS to interact and is estimated to cost the AEC up to \$15.8 billion per year from estimations of projects in the USA (Aranda-Mena and Wakefield, 2006). Such lack of interactivity is identified as the most daunting challenges in BIM implementation (Ibrahim, 2013). The perspectives from more sociological theories such as *social exchange theory* however posit that social cognitive (behavioural) factors that affect effective information sharing could be as costly to any attempts towards electronic information integration (Adriaanse *et al.*, 2005; Du *et al.*, 2012). This makes behavioural issues such as perceptions of risk, vulnerability and willingness to share or exchange information, important in establishing inter-operable SC engagement.

A REVIEW OF PREVIOUS RELATED STUDIES

The theoretical foundations of most related studies have been diverse. For example, the more resource and economic inclined theories including *transaction cost theory* (Wei *et*

al., 2012) generally take a view of efficiency and financial gains that result from collaborative exchange through IT adoption such as BIM. The cognitive and social relational theoretical perspectives have taken a more behavioural approach, looking at how humans interact or are influenced through their cognitive and subjective appreciation of associated issues on the use of IT for communicating across institutional boundaries (Constant *et al.*, 1994; Du *et al.*, 2012). According to Xue *et al.*, (2012) research on IT applications in AEC SC must increasingly engender and integrate both dimensions of thought for more successful outcomes to be realised.

Various related theories have been used to investigate the phenomenon of inter-organisational related IT application. Some of the theories have been used to study adoption or use of IT particularly within the AEC like *Technology Acceptance*, *Unified Theory of Acceptance and Use of Technology Theory* (Adriaanse *et al.*, 2010) and *Technology Diffusion* (Peansupap, 2004). Others have been specifically used as a foundation for researching inter-organisational information sharing aspects of IT application in general (including other industries): *Social Exchange* (Constant *et al.*, 1994; Du *et al.*, 2012; Wei *et al.*, 2012); and *Planned Behaviour* (Adriaanse *et al.*, 2010). A common feature of the various theoretical perspectives has however been that, individual or organisational behaviour on information exchange is influenced by antecedents and results in specific consequential actions. These include motivation (intention) to act which may be based on performance expectancies and usage behaviours which may be dependent on perceptions of behavioural control over exchanges or facilitating conditions (Constant *et al.*, 1994; Adriaanse *et al.*, 2010; Nicolaou *et al.*, 2013). These studies have collectively highlighted IT based information sharing as a consequence of the interaction among the highlighted factors that inform the subjective cognition of participants especially where such information may expose incompetence, strategy or IP (Hassan *et al.*, 2004; Eurich *et al.*, 2010). Many of these studies have however been conducted within other industries where electronic information sharing is at a more mature stage. Striking similarities and parallels with AEC's bid to adopt BIM technologies exist but remain unexplored. Also, most of the studies have been used to explain adoptability of IT for collaborative exchange rather than effectiveness of usage. This study aims to confront these constructs with peculiar characteristics of the AEC towards investigating information sharing and exchange behaviour which is viewed as key in understanding the effective usage of BIM technologies for enhanced digital information exchange in the SC.

Empirical studies on some of the related issues exist but are rather fragmented. However, they have proven the existence of relationships between the key issues such as between inter-organisational trust and effective electronic information exchange and vice-versa (Nicolaou *et al.*, 2013). Others have established significant relationships between perceived risk and willingness to share and subsequent effects on adequacy of information as well as SC performance (li and lin, 2006; Bao and Bouthilier, 2007; Du *et al.*, 2012). These studies discovered issues such as technology related (technical IT system security or privacy concerns) influences on perceived risk and socio-cultural (trust, power and leadership) inter-organisational information integration effectiveness. However, as reiterated, most of these studies are not in the AEC necessitating empirical verification of these positions within the context of construction information sharing through BIM.

The emergence of evidence from early BIM adoption indicates the existence of most of the highlighted concerns. Some of the studies have highlighted perceived information risk from a legal perspective including IP, ambiguous data ownership and lack of adaptive contracts that may increase perception of vulnerability of SC to share information through BIM (Ibrahim, 2013; McAdam, 2010). Others have highlighted unresolved data security, integrity and system capabilities on BIM exchange platforms (Amor and Faraj, 2002; Gu and London, 2010; Singh *et al.*, 2011; Ibrahim, 2013). Despite a recognition of the role of trust in SC relations, (Manu *et al.*, 2010; Khalfan *et al.*, 2007) only a cursory acknowledgement has been made of its role in information exchange aspects. Another stream of research identified reluctance of collaboration including information sharing due to expected changes in roles and power structure within SC (Xue *et al.*, 2010; Harty, 2012).

According to Grilo and Jardim-Goncalves, (2010); Xue *et al.*, (2010); and Ibrahim (2013) these issues are collectively resulting in significant reluctance of some sections of the SC to participate in BIM based collaborative exchanges; a situation they postulate will hamper current efforts towards inter-operable organisational practice. Harty (2012) extensively analysed the implication of digitisation of AEC information through BIM. The study was however limited to architecture rather than SC in general and project perspective. Despite highlighting some of the key issues, Harty's (2012) study had a different focus (management role of architects) and resultantly did not adequately explore SC exchange behavioural aspects. Some of the advanced theoretical positions (planned behaviour and technology acceptance and diffusion) have been used in AEC research, but mostly focussed on adoption and decision to use rather than information sharing behaviour or attitudinal determinants of effective data exchange (Adriaanse *et al.*, 2010). Inter-organisational information sharing behaviour has been cited as key to such inter-operable practice. Hence, this research aims to consolidate the fragmented pieces of evidence towards a holistic and socio-technical investigation of the antecedents and consequence of inter-organisational information sharing behaviour with a view to examining its implications on effective utilisation of BIM for collaborative and digital information exchange.

TOWARDS CATEGORISATION OF EMERGING ISSUES

This study proposes a research framework that incorporates three domains (Technology; Organisational; and Environmental, Legal and Contractual) for investigating digital information exchange behaviour within the construction SC. This is consistent with categorisations in studies on the adoption and usage of collaborative IT systems (Bouchbout and Alimazighi, 2009) despite slight variations in nomenclature. In view of the multidimensional nature of influencing attributes, appropriate categorisation will aid effective reduction for analysis and synthesis. From the review of literature, the emerging issues can significantly be aligned within these broad categories as depicted in **Figure 2** and consistent with main domains of the emerging BIM research field (Ibrahim, 2013). While not claiming exhaustiveness, it is envisaged that this framework will provide a wide scope for interrogation of the knowledge gaps which interrelate these categories.

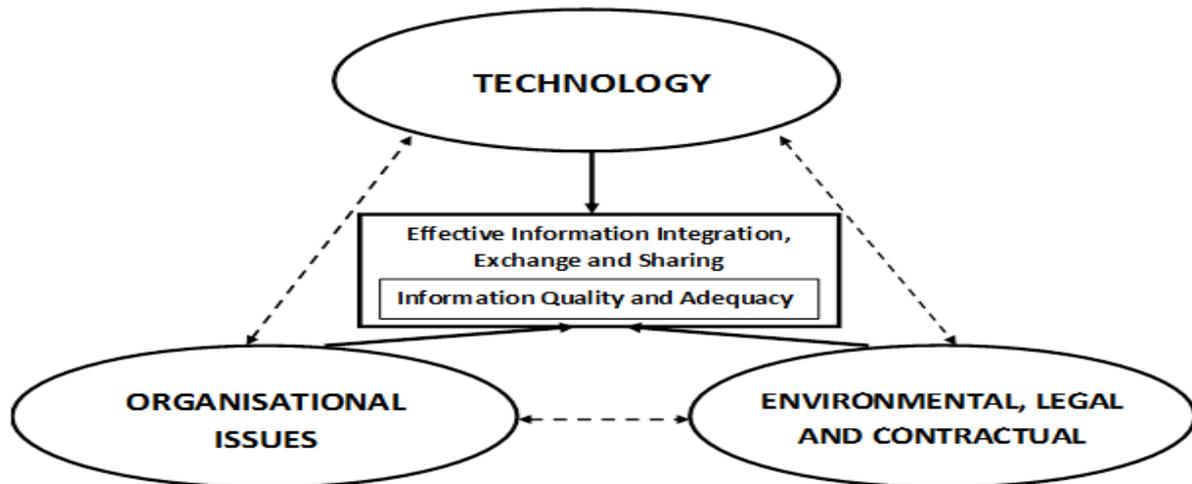


Figure 2: Conceptual representation of categories of influencing mechanisms on construction supply chain digital information exchange

The *technology domain* will include the technical aspects of BIM particularly in relation to software, infrastructure and standards. This will therefore include security, privacy, integrity and confidentiality issues as well as the required protocols and documentations therein.

The *organizational domain* will encompass all related issues to intra and inter-organisational arrangements that affect collaborative exchange. These often relate to structure, social, power, politics and cultural issues which have been found as important determinants for deployment of collaborative IT within the construction SC.

The *external influences, environmental and legal domain*; generally influence SC operations including adoption of such an industry-led endeavour like BIM. This may include wider market and industry conditions including government regulations. Procurement, industry, leadership, policies and protocols and their relative influence will be considered in this category.

IMPLICATIONS FOR RESEARCH

Based on the outlined discussions, the following pertinent questions need further investigation towards development of a deeper understanding of the phenomenon:

- *Do SC members feel vulnerable in information sharing on BIM platforms? If so, what are the behavioural consequences?;*
- *What is the role of trust and technology related risks on these consequences and how does it affect willingness to participate in information exchange or integration?; and*
- *How do such relationships affect the quality and adequacy of shared technical data across critical lifecycle phases?*

The Way Forward

The ensuing arguments necessitate a critical examination of the implications of digitisation on information exchange in the SC within BIM based collaborative

environments (projects). The establishment of the critical role of perceived risk and inter-organisational trust on willingness to participate in electronic data exchange within BIM enabled projects is also imperative and must engender interrelated concepts in both IS/IT research and inter-organisational theory. This consequence of the relationships to be established such as the impact sharing behaviours on the adequacy of shared information within the SC is also desirable in view of the knowledge gaps.

It is proposed that these are addressed by pursuing the following outlined objectives:

1. Review literature to develop an understanding of information exchange through collaborative IS/IT in the SC drawing from evidence and theories in both information systems and organisational behaviour (studies);
2. Develop a conceptual model from the evidence and triangulation of theories in the above disciplines to typify influencing mechanisms, their interrelatedness and dependencies on SC information sharing and exchange as well as expected outcomes in terms of effectiveness of BIM based technologies for collaborative information exchange;
3. Explore these issues and relationships in practice including elicitation of perspectives of practitioners in the SC on BIM enabled projects;
4. Ascertain the role and impact of these issues on effectiveness of BIM based collaborative information exchanges including data adequacy and quality through empirical verification;
5. Establish the critical role of perceived risk and trust on these relationships; and
6. Develop and validate an enhanced model of mechanisms influencing inter-organisation information exchange and sharing and their influence on BIM as an effective tool for SC information integration.

Towards A Proposed Methodological Approach for Research

Methodological pluralism, which encourages the use of multiple methodological approaches, is proposed as an appropriate research method to break the barriers of limited literature and data sources due to novelty of the research area (Creswell *et al.*, 2003; Knight and Ruddock, 2008). In this regard, both qualitative and quantitative methods are appropriate in addressing the outlined objectives towards investigating the identified knowledge gaps.

A case for Case Study approach: This method of research is advocated for study of relatively novel concepts which are embedded in their context (Yin, 1994). It allows sufficient flexibility for the incorporation of the various research strategies (qualitative and quantitative) for in-depth analysis in defined context. It therefore suits the research objectives and project orientation of the construction industry where a group of SC members can be investigated based on the same project parameters.

The qualitative approach (interviews and observation): approaches are often embedded in interpretive philosophical stance and offers fluidity which enables exploration of highly contextual issues (Knight and Ruddock, 2008). It is viewed that these methods will aid contextualisation of the key issues which are currently more prevalent in other industries.

The quantitative approach: aspects are to allow empirical verification of the positions and relationships to be identified in the conceptual mapping of emerging issues to be developed into a conceptual model from literature and qualitative enquiries. Based on positivist tenets it is often regarded as objective and allow computational establishment of relationships, and is recommended due to relatively high objectivity (Fellows and Lui, 2008).

The mixed method approach: the multidisciplinary nature of the construction industry requires a balanced approach to research where frameworks incorporate multiple theoretical and methodological frameworks. Inter-organisational IT issues generally reflect such multidisciplinary outlook in view of technological, organisational and external environmental nature of influencing attributes. According to Adriaanse *et al.*, (2010) and Xue *et al.*, (2010) there is increasing need for incorporation of behavioural complexity in examining a highly technical field (IT) posing new research challenges due to diversity in epistemological foundations which could be mitigated by a holistic research approach. Resultantly an integrated approach is advocated to allow effective integration of theoretical dispositions of the various fields and concepts. Such approaches and methods have been recommended as appropriate for multidimensional research by Cresswell *et al.*, (2003) in general; Amaratunga *et al.*, (2002) for built environment research and Xue *et al.*, (2010) and Adriaanse *et al.*, (2010) for collaborative IT research such as BIM. A compelling argument for such multi-attribute nature of the framework is that it provides an extensive and powerful platform to explore and navigate multi-dimensional issues like inter-organisational and information behaviours which engender multiple levels of abstraction and influenced by a wide range of socio-technical factors (Constant *et al.*, 1994; Bao and Bouthillier, 2007; Wei *et al.*, 2012).

Delivering Objectives 1 and 2: Previous knowledge, experience and typologies from research and theories broadly in relation to inter-organisational IS/IT adoption and use including behavioural theories will be vital in development of conceptual framework in view of relatedness to organisational information sharing behaviour. This will aid effective establishment of conceptual relations and propositions for empirical verification.

Delivering Objectives 2 and 3: Case studies, as recommended by Creswell *et al.* (2003) and Yin (1994) have proven effective in similar research (Peansupap, 2004; Singh *et al.*, 2011; Harty, 2012) and will therefore be vital for empirical verification and contextualisation of the conceptualised propositions to be derived from theory and previous studies which have mostly been in other industries.

Delivering Objectives 4 and 5: It is proposed that the framework be further tested through solicitation of data from a wider sample of SC stakeholders through methods such as questionnaire surveys to enable quantitative analysis and determination of issues such as criticality of associations and interdependencies of attributes for the model. This will therefore aid establishment of the key antecedents and influencing mechanisms to information sharing, their moderators as well as consequence in the key domains of the research framework.

Delivering Objective 6: A synthesis of the data collected through the recommended methods as well as any empirically established relationships will aid the development of a model explaining mechanisms influencing inter-organisation information sharing and their influence on effectiveness of BIM based SC information integration. These should be based on modification of conceptual models and propositions identified previously

from research and primary evidence as proposed in preceding objectives. This will aid validation from experts in the field based on the construct of the model and its performance through similar methods as proposed for investigating the phenomenon such as expert workshops or interviews.

CONCLUSION

A justification has been provided on the role of information sharing and exchange behaviour as a facilitator of effective BIM based SC information integration through a synthesis of concepts and insights from diverse socio-technical perspectives (theory and empirical evidence). A strong case exists that antecedents and outcomes of SC information sharing and exchange behaviour is multidimensional but critical in filling knowledge gaps on inter-operable organisational practice identified as a challenge requiring both behavioural and technical approaches. Hence, the integration of socio-psychological theoretical concepts with technology (BIM) as well as integrated approach (mixed method design) to research is proposed as capable of providing a robust research framework taking cognisance of peculiar characteristics of the construction SC in navigating this complex issue. This will aid research towards contributing key knowledge on BIM implementation strategies and effectiveness and to benefit SC firms by providing insights into how organizations can deal with the uncertainties related to participating in digital data exchange. This includes legal and procurement structuring to facilitate effective digital information exchange through BIM as well as an original contribution to knowledge on its impact and contribution to effective inter-operable business practice in the construction SC.

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USING A MOBILE BIM BASED FRAMEWORK TO ENHANCE INFORMATION PROVISIONING SUPPORT IN HEALTHCARE PROJECTS.

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Abstract: This paper investigates the relevance of mobile BIM in health care projects theoretically. The research will present health care and its design and construction aspects, utilising building information modelling and its technologies. The literature review identifies and highlights how BIM is utilised within a healthcare environment and gives a brief account of how this process has been implemented, with case study overview. Moreover, the review also indicates and discusses any advantages and disadvantages this process has within such a scenario. From this, the paper discusses the relevance of Mobile BIM for better information provisioning, information flow and decision making. Conclusions are drawn about the future impact of emerging mobile BIM technologies to enhance construction processes.

Keywords: Building information modeling, cloud system, health care, mobile computing.

INTRODUCTION

In recent years, the construction industry has come under increasing pressure from its clients to improve its productivity and to address communication and coordination challenges that often result in projects missing their golden triangle (i.e. cost, time and quality) targets. Also, new demands have been put in place on construction projects because of increasing complexity of design, sustainability, health and safety and other increasingly stringent regulations. Rapid uptake of building information modeling technologies has resulted in major changes in organisational structure, processes and technology uptake within construction organisations. While BIM is defined as “the provision of rich, integrated information-from conception through design to construction and demolition of a building over its life cycle”, Eastman (2008), industry is still in early stages to fully materialise life-cycle information management benefits offered by BIM. This paper focuses on implications of BIM uptake on healthcare design and construction. Section 2 discusses how BIM has come into being, and how it is being utilised within various sectors of the construction industry, particularly within healthcare. Section 3 reviews relevance of mobile technologies and parallel developments in cloud-computing, intelligent interfaces to ensure better connectivity of field personnel in existing workflows and access to information stored in BIM databases. The final section draws conclusions about possible future impact on construction processes.

USE OF BIM IN HEALTHCARE DESIGN - LITERATURE REVIEW

BIM “represents a migration in the architectural design field from two dimensions to three dimensions by creating intelligent, multi-dimensional building models” Reddy

(2007). It is widely proposed to be a suitable method to manage all design and construction issued within current IT orientated building projects and process environments. Thomson and Miner (2007) highlighted the dynamic nature of a BIM platform and how it allows multiple geographically dispersed groups to work collaboratively on projects. Such dynamic collaboration is particularly relevant for health care project which are inherently complex by their very nature.

The effect of building information modeling within healthcare design has been known for quite some time, particularly with emphasis on various stages of design, and how it affects the construction process in the overall project. Ulrich (2000) proposed and looked at the effects of healthcare environmental design on medical outcomes. It focuses on the improvement of healthcare design and suggest various parameters within healthcare outcomes such as noise, sunny rooms and their impact on patients, multiple occupancy vs single rooms, flooring materials and furniture arrangements. The paper would indicate from its findings, a need for a BIM contingent/process to be considered, which would encompass most if not all factors discussed throughout the text. Barista (2012) identified improved coordination of ultra-complex building systems and ability of real-time visualizations as key advantages of using BIM for healthcare facilities design. Sullivan (2007) highlights advantages of BIM to support various construction processes such as health and safety, planning, constructability and coordination, risk and so forth. He also highlights the benefits of a fully coordinated BIM to reduce risks associated with health care industry projects. Similar views has been expressed by Pommer et al (2010), who have looked upon favorably on relevance of lean construction methods in BIM healthcare design.

Manning & Messner (2008) discussed case studies in BIM implementation for the programming of healthcare facilities. They drew attention to a rising cost of construction and inherent complexity of healthcare construction projects and highlighted the opportunity of BIM-based information and analysis early in the development of healthcare construction project. In a similar study, Pommer et al (2010) highlighted various complexities of healthcare projects particularly related to building systems such as indoor environmental quality, cooling and heating loads, quantity of medical equipment and relevance of BIM to address these complexities.

Chanfeng et al (2007), introduced and presented a case study in developing a space centred CAD tool which gives designers an insight of how to effectively manage information and user requirements during conceptual design. They focused on areas related to healthcare, using BIM within an Alzheimer clinic, paying particular attention to how all design criteria can be stored and shown within building space areas, focusing on how the use of information mediums such as pictures, how photography can be transmitted in an effective way, and suggests it is a good way of remembering a room or structure, as it can be seen like a photograph visually. They also highlight and make an emphasis on what space in a building is and how it affects any or all activities being carried out, including limitations dictated by existing space and surroundings. Oloffsen, Lee & Eastman (2007), discuss a case study relating to the advantages seen by implementing virtual design models for the coordination of elements, such as mechanical, electrical and plumbing (MEP) within a healthcare facility. This discussion brings to the attention the advantages of BIM and how it can be used to integrate the various disciplines such as MEP within healthcare to be coordinated. Particular emphasis was made to how costs could be reduced using this overall process, and the type and level of information that needs to be attained using BIM. Leading from this, benefits of such an

appraisal within a healthcare facility are also shown and discussed in a case study presented by Chen, Dib & Lasker (2011). They bring to the attention initially the benefits of building information modelling in healthcare facilities, and indeed do concur with Oloffsen, Lee & Eastman (2007), the importance of this process within MEP. However, they bring to attention its role in the commissioning process and discuss how this is related to the buildings lifecycle, suggesting that commissioning and validation process starts as early in the buildings acquisition process as is possible, and through its lifetime. These benefits looked favourably at the healthcare establishment used to present this case study.

Leite, Akinici & Garret (2009), presented a case study to discuss the identification of data items needed for automated clash detection in MEP design coordination. The authors highlight a similar vein of thought regarding MEP, however emphasis is placed on the use of clash detection within the MEP contingent. It compares a manual method of clash detection using 2D drawings, to a BIM process, and suggests that the BIM process was far more accurate. Rizal (2011), identifies and discusses the challenging roles of clients, architects and contractors through BIM, paying attention to how these disciplines correlate within a BIM environment. Building information modeling has seen to be a very useful and creative tool within the AEC industry and healthcare design, to centralise all information within one model and to be able to see a functionality of the components within such a model. Generally, this process could be seen to have advantages and disadvantages, and are generally seen as;

- Drawing reduction – a continuous 3D CAD model for all stakeholders to view the single model on one central network , Chanfeng et al (2007);
- To improve productivity – time saving measures with centralised information;
- Reduces conflicts and changes during construction – adds value to the project because of minimal errors during production of the BIM model;
- Clash detection – advises the end user of any structural clashes that have taken place or are about to take place, design can be reintroduced into that are of construction;
- Group members should be able to communicate any and all technical developments and design, and be able to implement any changes;
- Be able to assign responsibilities;
- Contractor can use BIM, and have the appropriate software to read drawings either remotely, i.e, from a laptop on site, to full operation and input of information from the main contractors original software and access from a central web server, Chanfeng et al (2007);
- Insurance - design mistakes, errors puts the project out of time and so compensation and/or liquidation damages/ costs could be incurred.

Howell & Batcheler (2005), highlight that lessons were also learned from the early preconception of such systems, within it's development, and also concurs to what was suggested by Yan & Damion (2007) - "BIM has its flaws". The points highlighted in their paper are indicated;

- The size and complexity of the files that BIM systems create, Kaleigh (2009) also concurs to this observation, and carries on, for complex projects, the scalability and manageability of a fully loaded BIM project database represents a major challenge;
- Sharing BIM information as drawing files;
- The need for increasingly sophisticated data management at the building object level;
- A contradiction in work process when using a single detailed BIM to try to represent a number of the alternative design schemes under consideration;
- Managing "what if" scenarios for engineering design – Using a single BIM model for building performance modelling (i.e. energy analysis, sun-shade studies, egress simulation, etc.) does not provide the flexibility needed by consulting engineers to conduct a multitude of "what if" scenarios to study alternate approaches and to optimize design alternatives in order to maximize energy efficiency, ensure fire and life safety compliance, achieve structural integrity at minimum cost, etc;
- The expectation that everyone on the project team will adopt one BIM system.

RELEVANCE OF MOBILE BIM TO SUPPORT ONSITE WORK

This section discusses relevance of mobile computing with a focus on construction phase of healthcare projects. As identified previously, construction projects are relatively complex in terms of their scale. Sites for major healthcare facilities, such as hospitals are hazardous and dynamic by their very nature. Also, specialist nature of various health-care projects make projects quite information intensive. Key advantage of mobile computing for such large projects include reliable and updated information, decrease time and cost in construction operation, decline in faults, accidents, increase in productivity, better decision-making, quality control, etc.

Fragmented nature of various construction operations coupled with site conditions pose challenges to free flow of information to and from the construction site. Even though in recent years there has been a great deal of automation and use of sophisticated BIM programmes to support design work, benefits of such automation are usually limited to design offices. Out on the construction site, printed drawings are still most prevalent method of communication. Recent developments in the area of broadband wireless technologies, mobile technologies and cloud computing provide tremendous potential to enhance construction management practices by readily providing relevant information to concerned professionals. A key challenge in construction management has always been lack of communication and collaboration between key stakeholders. Developments in technologies and corresponding processes promises to address these challenges by

bringing improvements to the whole project starting from initial design to the lifecycle of the facility through an integrated approach to information management. As highlighted by Shen et al (2009), “these technologies provide a consistent set of solutions to support the collaborative creation, management, dissemination, and use of information through the entire product and project life

cycle”. The use of mobile BIM particularly for the construction phase will make more improvement to project management mainly by reducing the uncertainty and limitations and overcome the challenges by organising and controlling as-built with as-planned progress in construction project. ”The emergence of mobile computing has the potential to extend the boundary of information systems from site offices to actual work sites and ensure real-time data flow to and from construction work sites” Chen et al, (2011).

Mobile Computing also plays a key role in management of information generated during a construction project. Construction projects are very information intensive and a typical project generates tens of thousands of documents in the form of drawings, change orders, request for information, etc. For effective communication and coordination, it is important to manage this information flow in an effective manner. Wilkinson (2005) defines ‘construction collaboration technology’ as a combination of technologies that together create a single shared interface between two or more interested individuals (people), enabling them to participate in a creative process in which they share their collective skills, expertise, understanding and knowledge (information) in an atmosphere of openness, honesty, trust and mutual respect, and thereby jointly delivering the best solution that meets their common goal. Using mobile BIM it is possible to create such a collaborative platform bringing together site-based and office based personnel. Mobile computing technologies provide engineers unprecedented opportunities to innovate the existing processes of construction projects Kim et al, (2011).

However, a lot of recent implementation of mobile technologies within construction has failed. A key reason has been technologies have been implemented without adequate consideration of organizational need and corresponding process change. If technologies are not implemented without corresponding process change, they may automate existing workflows without bringing any tangible process improvement. In his landmark report, Egan (1998) advised construction industry, stating that, “New technologies can simply reinforce outdated and wasteful processes. The change should be approached by first sorting out the culture, then defining and improving processes and finally applying technology as a tool to support these cultural and process improvements” Egan (1998). Thus, for effective implementation of mobile computing and BIM technologies, it is important to understand the organizational and process context prior to implementation of technology.

In order to ensure good alignment between BIM technology and corresponding processes and organisational strategic objectives, it is imperative to explicitly outline how the needs and requirements of the project will be mapped to technical standards, team member skills, construction industry capabilities, and the technologies that will be used. Through the development of this plan, the project team members and project management outline their agreement on how, when, why, to what level (e.g. site supervisor, foreman, worker) , and for which project outcomes BIM modeling will be used Autodesk (2012). Having such plan in place will ensure that there are adequate supporting processes in place to support implementation of BIM technology. Integration mobile construction workers in the BIM workflow and information distribution chain, the decision-makers’ obtains reliable data and real-time from point of work to speed up workflows and enable informed

decision making. However, industry needs to overcome various technological challenges to enable smooth workflows. Industry Foundation Classes (IFCs) are currently the key method of data exchange. However, the initial problem with IFCs is that it is not intended to store and carry relevant data for all multi-featured construction processes. Furthermore, not all relevant data can be structured in a single super schema Redmond et al, (2012). This may necessitate learning from experiences in other industries to ensure smoother data flows.

Recent developments in the area of cloud computing can also support uptake of mobile computing. Mobile platforms are limited by their size and memory. By making only relevant bits of information available from the cloud using intuitive interfaces has the potential to further drive uptake of mobile BIM in construction. This will allow construction project information to be much lighter, easily reached from any computers or tablets such as iPad and iPhone, and are easily updated. The function of this system is simply store the project information in the cloud computing and access it by for example, the project team in the field or where and when they want, even without the internet. In the meanwhile, the internet operates with computer and other devices and combined with cloud-based tools which would make data and information more accessible to the staff, yielding key benefits such as cost/time savings, owner satisfaction, improvements in information access, sustainability, team integration and access to BIM visualisation Bringardner & Dasher (2011).

CONCLUSIONS

The review indicates huge potential to improve current delivery of healthcare projects using mobile BIM technology and processes. The case studies discussed in the review highlight and give an indication of how BIM is being utilised, and suggests any and all impacts this process may have within a healthcare environment. While a key emphasis of existing BIM deployments has been on certain low hanging fruits such as trade coordination and construction documentation, the future possibilities of a multitude of applications using analytical capabilities of BIM technology are enormous. The dominance of VDC and BIM in the design and construction industry will “tip” when it becomes measurably more efficient, productive and profitable to use that project process” Strazdas (2011), has proposed and highlighted that BIM is becoming more “mainstream”, and also suggests that, “one expects to build the models with much more information on a systematic basis as time goes on”. Parallel developments in the area of mobile computing, cloud computing by providing real-time information and applications to and forth from field personnel. However, it is important to realise uptake of mobile BIM will require industry to address various process and organisational level challenges and take adequate steps to facilitate uptake of improved processes using improve technologies.

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ENHANCING TEAM INTEGRATION IN BUILDING INFORMATION MODELLING (BIM) PROJECTS

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The worldwide thrust for efficiency improvement in construction project delivery process led to the adoption of a diverse range of collaborative working arrangements. The latest movement in this agenda is adopting building information modelling (BIM). Although the term BIM means different things to different people, which ranges from tools, technology and process; it works as a unifier of people, process and technology. The core proposition of BIM is to adopt a fully collaborative project delivery process throughout the whole lifecycle of a project. However, a number of issues are increasingly becoming relevant with the progression of BIM adoption. Moreover, technology-driven BIM approach does not necessarily require face-to-face interaction among the parties; which is deemed to be invaluable for decision making, leadership, motivation and teamwork; given that different parties will have different organizational cultures with their own sets of behaviours and working practice. Such pragmatic barriers are argued to hinder effective collaboration among the parties, which in turn deters the efficiency improvement within the project delivery process. Additionally, the contract parties are seen to have diverse objectives, frequently of opposing nature, accomplishment of which is dependent on the cooperation of other parties. Such interdependency for success demands a suitable framework to improve collaboration, by attaining appropriate culture, leadership and motivational attributes within the project-based organization, and among the competing contract parties. Competing Values Framework (CVF), an influential model for organizing and understanding various aspects of organizational and individual phenomena, appears to aptly address the issues relating to project-based construction organizations. The purpose of this paper is to draw a research plan to develop a suitable collaboration framework, to allow contract parties to improve their levels of collaboration and thereby enhance team effectiveness in BIM-based projects. A construction specific collaboration framework will be developed, along with a set of solutions for differing leadership, managerial, integration and cultural orientations. Relevant data is planned to be collected by questionnaire survey and the framework will be developed by considering the appreciation of the behavioural change of the project team due to the variable management actions resulting from CVF analysis. The adjusted and validated framework can then be used to analyze and identify the appropriate management tools necessary for any specific stage or situation of the project, including shifting the culture of the temporary project organization towards fully collaborative practice, for improved efficiency.

Keywords: Building Information Modelling, collaboration framework, Competing Values Framework, efficiency improvement, project-based construction organisations.

INTRODUCTION

Many reports have identified that the construction industry is underperformed and clients are not getting optimum value (Latham, 1994; Egan, 1998, 2002; Cain, 2003; Fernie *et*

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al., 2006; CO, 2011). This issue stimulated the mounting pressure for improving efficiency in the construction project delivery process (Jackson, 2000; Elmualim, 2008). Fleming and Koppelman (1996) and Cain (2003) agreed that the major reasons of declining efficiency in construction project delivery process are process fragmentation, adversarial culture, and ineffective planning. Efforts had been spent on finding out the solution to improve efficiency. The major focus of the initiatives was to attain collaborative practice in the project delivery process. Consequently, various collaborative working arrangements (CWA) were prescribed such as Partnering, Private Financing Initiatives (PFI), and Integrated Project Delivery (IPD) (Latham, 1994; Egan, 1998, 2002; Cain, 2003; HMG, 2008). However, the extensive practice of collaborative project delivery process did not take place in the industry (Khalfan and McDermott, 2007). As a result, the declining trend of productivity still exists in the construction industry (Ilozor and Kelly, 2012). As such, the construction industry spends continuous effort to achieve a fully collaborative process throughout the whole lifecycle of the project; the latest movement is implementation of BIM (Cain, 2003; Arayici *et al.*, 2011; CO, 2011).

The core proposition of BIM is to attain a fully collaborative practice in the project supply chain and achieve optimum project value (Philp, 2012). Nevertheless, the degree of potential benefits of BIM relies upon the level of integration takes place among the players in the process (AIA, 2007b; Andre, 2011; NBS, 2011). The multi-skilled team requires to integrate by developing and sharing new ideas, tools, and innovations (Egan, 2002; Khalfan and McDermott, 2007; NBS, 2011). However, Rosenberg (2007), Andre (2011), and Udom (2012) agreed that simultaneously with the progress of the model, relationships between the parties become more closed, border of responsibilities becomes blurred, and more critical issues are raised. These issues hinder frequent interaction between the parties. Furthermore, it is difficult to flourish inter-organisational collaboration in a team because each party efforts to achieve own objectives and avoid their economic loss (Latham, 1994). BIM provides technical framework for the product model to be developed but does not necessarily address the project management issues. As higher level of interdependency exists among the parties of the BIM project team (Clough *et al.*, 2008), the success of teamwork depends on the cooperation of other parties. Such unique characteristic and higher interdependency of BIM project venture necessitates suitable framework to improve collaboration among the competing parties by attaining appropriate organisational culture, leadership, and motivational approach. Competing Values Framework (CVF) is one of the prominent and influential framework to assess different aspects of organisational phenomena (Cameron and Quinn, 2006; Cameron *et al.*, 2006), might be one way of addressing the issues in BIM project organisations.

CVF was developed to measure and shift culture of stable economic organisations (Cameron and Quinn, 2006; Cameron, 2009); whereas project-based organisations are temporary and dynamic (Akintoye *et al.*, 2000). Additionally, culture in construction a project is combination of diverse cultures of the individual contract parties (Toor and Ogunlana, 2007); where cultural conflict often occurs between the parties (Abeysekara and Lata, 2002). Thus, culture in a construction project is attributed by functional adversaries (Fleming and Koppelman, 1996; Cain, 2003; Macmillan, 2011). This adversarial culture needs to be shifted to a collaborative culture to improve efficiency in construction project delivery process (Egan, 1998, 2002). The purpose of this paper is to draw a research plan to develop construction specific collaboration framework (CSCF), which will offer a set of solutions to measure and shift the culture of construction project organisations. The framework will demonstrate the technique of selecting divergent

leadership, managerial, integration and cultural orientations. Relevant data will be collected by suitable established research methods and the framework (CSCF) will be validated by using System Dynamics (SD) modelling (developed by J. W. Forrester)(Forrester, 1971). SD modelling will be used to understand the complex system of project-based organisational behaviour and validate the appreciation of the behavioural (cultural) change due to variable management actions. The validated framework can then be used to analyse and identify the appropriate management tools to initiate shifting the culture of the project-based organisations towards fully collaborative practice, for improved efficiency.

BIM AND CULTURE IN THE CONSTRUCTION INDUSTRY

Does BIM potentiate IPD?

Among the CWAs, IPD is one of the most influential and effective approaches which accommodate dominant intellectual collaboration in a specific project (AIA, 2007a). However, IPD does not embrace the whole life cycle of the project and information flow remains fragmented (Glick and Guggemos, 2009). According to AIA (2007a), AIA (2007b) and Ashcraft (2008), IPD can be implemented without BIM but implementation of BIM requires an IPD team. Nevertheless, AIA (2007a) also recommended that to achieve effective collaboration through IPD, BIM is essential. Hence, BIM emerged out through the implementation of IPD to attain effective collaboration. Literature review suggests that BIM potentiates IPD and vice versa, or, BIM encompasses IPD integrally; the maximum benefit can be achieved when both are functionalised concurrently (Ashcraft, 2008; Wickersham, 2009; Ilozor and Kelly, 2012). BIM enabled IPD offers effective process to embrace all the participants in the whole lifecycle of the project, including integration of people, process, and flow of information. Moreover, it allows the essential changes of delivery process by applying cutting edge technology in all spectrums of building project such as design, construction and facilities management (Rosenberg, 2007; Arayici *et al.*, 2011; Malleson, 2012).

Teamwork in BIM environment

Construction projects are accomplished by project-based temporary organisations (i.e. project team); representatives from multifunctional contract parties are gathered at the beginning of the project and work as a team (Davis *et al.*, 1992); the team members are dispersed at the project closure (Akintoye *et al.*, 2000). To achieve the goal, essential skills, knowledge and talents are harnessed effectively (Davis *et al.*, 1992; Macmillan, 2011). Alongside the own organisational objectives, culture and working practice of each contract party, the deployed individuals can have diverse origin, background, and culture (Toor and Ogunlana, 2007; Macmillan, 2011). As such, in a project-based organisation, inter-organisational teamwork is functionalised; which obviously differs from typical teamwork in a stable economic organisation or department (Davis *et al.*, 1992; Fong and Lung, 2007). The key attribute of BIM project team (project-based organisation) is cross-functional and cross-cultural assembly embraced by modernised technology. The team is focused on a shared objective; whereas the individual organisational objectives of the contract parties remain behind. Numerous authors frequently argue that such kind of teams are inevitably complex and often encourages adversarial culture due to lack of trust and cultural empathy (Harvey *et al.*, 1998; Steele and Murray, 2001; Macmillan, 2011), along with the other influential factors such as communication difficulties, inappropriate

planning and team direction, lack of loyalty and commitment, poor leadership, inappropriate recognition and reward provision, silo thinking, and social loafing (Mickan and Rodger, 2000; Parker, 2007; Kreitner and Cassidy, 2012).

The major purpose of implementing BIM is to attain collaborative project delivery process by unifying people, process, and technology (Hardin, 2009; Gu and London, 2010; Arayici *et al.*, 2011; NBS, 2011; Philp, 2012), which involves a fundamental change in the way of working in the current project delivery process (Eastman *et al.*, 2011; NBS, 2011). Andre (2011) argued that the successful adoption of BIM necessitates the team members to reach an agreement on using the technology and providing combined effort. According to different authors (NBS, 2011; Redmond *et al.*, 2012), BIM will create a shared platform for all different stakeholders to interact frequently, solve problems and make decision together. Philp (2012) asserted that by performing computer trials, team members can detect the conflicts between the building components and constructability challenges, and thereby mutually find the answers of the critical questions for the entire project lifecycle. Such a feedback loop will obviously save time and cost. However, to extract the best value through fully collaborative process, BIM have to be implemented effectively (Ahmad *et al.*, 2012). Succar (2009), Philp (2012) and other authors (Eastman *et al.*, 2011) agreed that implementation of BIM involves fundamental change in the working procedure in the project delivery process; which is a cultural shift, the key challenge.

Barriers in adopting BIM

Beside the versatile usage and tangible benefits of BIM, number of barriers increasingly arises during the adoption of BIM. While progressing with BIM adoption, complexity of the process is intensified, distribution of responsibilities and risks becomes unclear; more critical issues such as habitual resistance, fragmented information flow among the parties, contractual, and interoperability of software are raised (Rosenberg, 2007; Dossick and Neff, 2010; Sebastian, 2010; Andre, 2011). Ashcraft (2008), Andre (2011), and Udom (2012) asserted that the model related legal issues that make frontline obstruction in the open collaborative process are: data copyright, ownership of intellectual properties, confidentiality of data in a blended state, and signing the documents. Furthermore, the other legal issues which often hinder BIM adoption include inappropriate distribution of risks and rewards, responsibility of model development, model reviews and updates (Rosenberg, 2007; Sebastian, 2010; Andre, 2011; Azhar, 2011), undefined guidelines and insurance provision for software related error, data access, and model security (Ashcraft, 2008), lack of standard documentation and proven protocol (Gu and London, 2010; Andre, 2011; Udom, 2012). The major technical barrier is highlighted as interoperability (Ashcraft, 2008; Gu and London, 2010; Sebastian, 2010; Azhar, 2011). Number of authors claimed cultural barrier as a critical hazard, as it involves potential obstacles that are human related (Ashcraft, 2008; Gu *et al.*, 2008; Yan and Demian, 2008). The human related barriers involve habitual resistance, inappropriate training, lack of shared understanding (Ashcraft, 2008; Yan and Demian, 2008).

Furthermore, parties interact in large construction projects are assembled from different organisational culture and individual social needs (Toor and Ogunlana, 2007; Macmillan, 2011); those are often seen as opposing nature to secure their own economic interest (Latham, 1994). Such kind of adventure reinforces the above issues which in turn encourages adversarial culture and hinders effective interaction among the parties (Fleming and Koppelman, 1996). These pragmatic barriers cause knockdown effect on

the efficiency in project delivery process. It is argued by numerous authors that application of technology is not sufficient to obtain desired process improvement through BIM; it is essential to harness the diverse skills and functionalise a synergic action by the players (Bernstein and Pittman, 2004; Hardin, 2009; Dossick and Neff, 2010; Gu and London, 2010; Arayici *et al.*, 2011; CTGR, 2012; Philp, 2012). Therefore, integration of team, process, and technology is essential to extract the optimum benefits of BIM projects, which lead to a hard transition of culture in the construction industry.

Organisational culture in BIM environment and necessity of collaboration framework

Organisational culture

Notion of organisational culture is diverse to different authors; sometimes, those are controversial (Robbins, 2003; Buchanan and Huszyski, 2010). One author (Deal and Cenedy, 1982) viewed culture as ‘the way we do things around here’, while another author (Hofstede, 2001) referred as ‘the collective programming of the mind’. Becker (1982) and Schein (1988) believed that organisational culture is a system of shared meaning held by members that distinguishes the organisations from the other organisations. This definition (Becker, 1982; Schein, 1988) was refined as “culture is the commonly held and relatively stable beliefs, attitudes and values that exists within the organization”(Williams *et al.*, 1989). Hence, organisational culture is a platform of common belief held by the members, which is distinguishable and relatively stable.

Culture in BIM projects and necessity for effective collaboration

Culture in a traditional construction project-based organisation is comprised by different organisational culture (Toor and Ogunlana, 2007), where cultural conflicts often create a confrontational environment (Dossick and Neff, 2010), and ultimately lead to an adversarial culture (Abeysekara and Lata, 2002; Cain, 2003; Macmillan, 2011). This adversarial culture is reinforced by process fragmentation. As such, implementation of BIM is intended to eliminate process fragmentation and functional adversaries by overlapping construction phases and enabling effective collaboration throughout the construction project delivery process (Philp, 2012). Such a revolutionary move involves fundamental change in working style (Succar, 2009; Eastman *et al.*, 2011), which is a massive cultural shift, from an adversarial culture to a collaborative culture (Philp, 2012). However, numerous authors argued that beside applying the latest technology, it requires combined effort of all the participants throughout the process (Hardin, 2009; Gu and London, 2010; Arayici *et al.*, 2011; Philp, 2012); given that development of the model depends on the contribution of the participants (Rosenberg, 2007; Andre, 2011).

Success of an interdependent teamwork relies on the cooperation of other parties and proper direction of the organisation (Clough *et al.*, 2008; Mullins, 2010; Andre, 2011), whereas the practitioners in the construction industry are habituated with self-working process. Adoption of BIM involves massive habitual and cultural change (Yan and Demian, 2008; Philp, 2012). However, BIM embraces the parties to develop the product model in a participatory process, but does not address the initiatives to be taken by the leaders to shift the culture, which is a critical issue. If the cultural change does not happen, will BIM be able to guarantee to extract the ‘best value’ of the project? Therefore, it is crucial period to address the leadership and management issues to avoid the unpleasant experience of the failure in the Titanic adventure of BIM.

Leadership approaches within BIM projects

Leadership is a critical part of BIM adoption because leaders have to identify the agenda for essential changes for adoption of new process, motivate and lead the team during change and in future culture. Appropriate leadership is necessary to ensure proper direction of the team to achieve the goal (Cameron and Quinn, 2011). However, the term leadership is viewed diversely, ranges by behaviour, characteristics, and outcome results or end results (Kasapoğlu, 2011). To meet the necessary leadership competencies for diverse settings in modern era, different authors prescribed range of leadership approaches such as ‘situational leadership’ (Hersey and Blanchard, 1993), ‘adaptive leadership’ (Newton, 2008), and ‘creative leadership’ (Rickards and Moger, 2000). Toor and Ofori (2008) suggested that in modern globalised construction industry, it is necessary to apply different kinds of skills, knowledge and styles of leadership; which necessarily indicates a new breed of leadership style i.e. ‘authentic leadership’. Walker and Walker (2011) agreed with Toor and Ofori (2008) and addressed the essential characteristics of ‘authentic leadership’ for different situations. In a study (Grendstad and Strand, 1999) it is found that diligence in achieving goal is the primary requirement of leadership role, whereas the integration of behaviour appeared as secondary role requirement, for all different types of organisations. Many authors believe that despite leadership being a critical determinant of team effectiveness and significant importance thrived in construction management, there is a lack of completed study and discontent on achievement on leadership development in AEC industry (Newton, 2008; Walker and Walker, 2011; Back and Macdonald, 2012). Continuous attempts and frequent arguments indicate that the appropriate approach of leadership for a specific situation is an arguable issue; especially in the BIM projects, where cultural shift is one of the key requirements of effective BIM adoption (Philp, 2012), and participants need a clear aim and direction to carry on the process. This kind of deficiency necessitates further investigation to identify the appropriate leadership competencies to meet the challenges of BIM adoption.

Motivation approaches within BIM projects

Theories of motivation are abundant; which are often appearing to be compensatory, or competing. Each theory was developed by focusing on particular concern (Franken, 2002). Criticisms on each theory lead to generate other alternative findings, which sometimes contradict with the earlier ideas (Mullins, 2010). Mullins (2010) also believed that theories are partially true and help to motivate in certain situations. Fincham and Rhodes (1999) categorised theories of motivation under two broad umbrellas, i.e. Content Theories and Process Theories. Content theories attempt to demonstrate the internal forces, needs or desire that control human behaviour; whereas Process theories explain the role of cognitive process of human being, which direct human behaviour towards certain choices or behavioural systems (Schein, 1988; Fincham and Rhodes, 1999). Need theories (species of Content theories) assert that human beings are categorised by set of needs (Maslow, 1943; Alderfer, 1972; Franken, 2002). Maslow (1943) suggested that needs are organized in a hierarchical fashion, i.e. lower level of must be met to generate a desire for higher level of need; in contrast, Alderfer (1972) believed that need can be moved in either direction, for example, difficulty in fulfilling higher level of needs motivates human being to concentrate on a lower level of need (Fincham and Rhodes, 1999). Such kind of debates on different theories are ubiquitous (Franken, 2002). Therefore, to select the appropriate theory or technique for a particular situation is a critical issue; especially, in construction project, where management is focused on short

term goal (Toor and Ofori, 2008), there is a little opportunity to spend significant efforts to identify the right pattern of motivation technique for a particular project.

Each construction project is composed of people from different socio-economic background and culture (Toor and Ogunlana, 2007), where people have different understandings of self, of other, or the interdependent parties (Markus and Kitayama, 1991). Also, individuals' behaviours are directed by certain drivers in certain situations. BIM ties the parties in a shared platform and reciprocal interdependence by high-tech-driven process (Clough *et al.*, 2008; Redmond *et al.*, 2012); however, it does not necessarily stimulate the contract parties to extend the hands of cooperation for achieving enhanced value of the project. Moreover, behaviours of the contract parties in a construction project are seen as competing nature (Fleming and Koppelman, 1996). This kind of attitude affects the collaboration between the parties, which in turn hinders improvement in efficiency (Dossick and Neff, 2010). Furthermore, shifting culture requires interdependent parties' consensus to functionalise cooperative environment (Andre, 2011). Therefore, achieving success in such a complex process necessitates proper motivation within the team to enhance integration and cooperation between the parties. It may not be possible to motivate the individuals, but an attempt can be taken to create the environment where the parties will be self-motivated to undergo in an effective collaborative process. Therefore, further relevant investigation is essential to draw such a suitable motivation agenda for the effective implementation of BIM.

THE RESEARCH PLAN

Determining the cultural elements based on Competing Values Framework

The research objectives are focused on enhancing team integration among the parties of BIM project for improved project delivery practice. To meet the purpose, it is intended to develop a construction specific collaboration framework (CSCF), which will provide necessary measures to embrace, motivate, and direct all the parties towards a fully collaborative process.

The call for efficiency improvement by implementing BIM in construction industry imposes cultural change within the project-based organisations in construction supply chain (NBS, 2011); however, organisational culture is invisible but inherent within the organisations (Cameron and Quinn, 2006). Number of researchers pointed out organisational culture as a predictor of different outcomes, such as quality improvement implementation, employee and patient satisfaction, and team functioning (Helfrich *et al.*, 2007). BIM 'project culture' is a composition of diverse cultures that carried by the contract parties. Different elements of cultures in different situations predict the organisational outcomes such as effectiveness, innovation climate, and employee or customer satisfaction (Ancarani *et al.*, 2009; Alas *et al.*, 20012). Therefore, to attain the desired culture in BIM project environment, it is essential to identify the elements of project culture, i.e. the fundamental assumptions on which the project operates, and the values that characterise the individual organisations including the project-based organisation where they are unified as a team. Then the potential drivers are to be identified to initiate and manage the cultural change. However, it is difficult for anyone to identify the elements of culture and take initiatives for change; even the initiatives may be turned down by number of barriers. Organisational Culture Assessment Instrument (OACI) is one of the most frequently used instruments to assess and initiate change in organisational culture (Cameron and Quinn, 2011); which might be one way of

addressing the issue of changing culture in BIM projects, i.e. to fill the critical gap in successful implementation of BIM.

Addressing the cultural issues in BIM projects

OCAI is rooted in Competing Values Framework (CVF) and it has been widely accepted by different disciplines to analyse diverge dimensions of the organisational culture (Helfrich *et al.*, 2007; Ancarani *et al.*, 2009; Yu and Wu, 2009; Lincon, 2010). It was developed by Quinn and Rohrbaugh (Quinn and Rohrbaugh, 1983; Cameron *et al.*, 2006). According to the authors and undertaken numerous research work, six key dimensions of the organisational culture are assessed by this instrument; those are (Cameron and Quinn, 2011):

1. Dominant Characteristics,
2. Organisational Leadership,
3. Management of Employees,
4. Organisation Glue,
5. Strategic Emphases, and
6. Criteria of Success.

Each dimension consists of four alternatives, each alternative represents a cultural orientation showed in four quadrants of CVF (see table 1, figure 1 & 2) (Cameron and Quinn, 2011). Although no framework can provide a complete solution to build the appropriate organisational culture evidently (Cameron and Quinn, 2006), exploring these six dimensions can allow better understanding about the measures of culture in terms of management action in BIM projects, as it has a proven track of being used widely.

The core proposition of BIM is to establish collaborative project delivery process to earn the best value (NBS, 2011). However, the term ‘value’ in construction project is crucial and bears diverse meanings (Barima, 2010). Different authors (Barima, 2010; Wiewiora *et al.*, 2010) suggested that further investigation is required to understand and identify the key elements of value that are driven by diverse cultural elements of modern construction projects. BIM enabled project is the most modernised paradigm of project delivery process and bear unique characteristic underpinned by cutting-edge technology. However, adoption of BIM in project delivery process is challenging, as it involves cultural change (Eastman *et al.*, 2011; Philp, 2012). Successful implementation of BIM demands effective project management, suitable leadership, optimum team cohesion, proper direction, and precise value proposition (Andre, 2011; NBS, 2011; Porwal and Hewage, 2013). The content and potential attributes of CVF (including OCAI) appear to be one of the possible devices to uncover the fundamental elements of culture, and address the cultural issues in BIM projects.

The present stance of organisational culture in BIM projects will be assessed by established method of using OCAI and CVF analysis. Adjustments in CVF analysis procedure are to be subjected to the requirement in practical implication in projects. Simultaneously, the organisational consensus on preferred culture to be nurtured in the BIM project will be determined. The necessary initiatives to develop preferred culture will be identified thereby. The variable dimensions of the existing and preferred culture of BIM project will be figured out from CVF analysis (see figure 3).

The CVF and OCAI

The CVF consists of two major dimensions towards four major quadrants (figure 1 & 2). It works as a roadmap of developing mechanism, sense-making tool, bringing new ideas, and better understanding the system (Cameron *et al.*, 2006). The first dimension varies from flexibility, discretion, and dynamism on one end towards stability, order, and control to the other end (Cameron, 2009). For example, in some organisation, managers are evaluated as effective if they have changing, adaptable and transformation characteristics. On the other hand, in some organisations, managers are assessed as effective if they are stable, predictable and consistent.

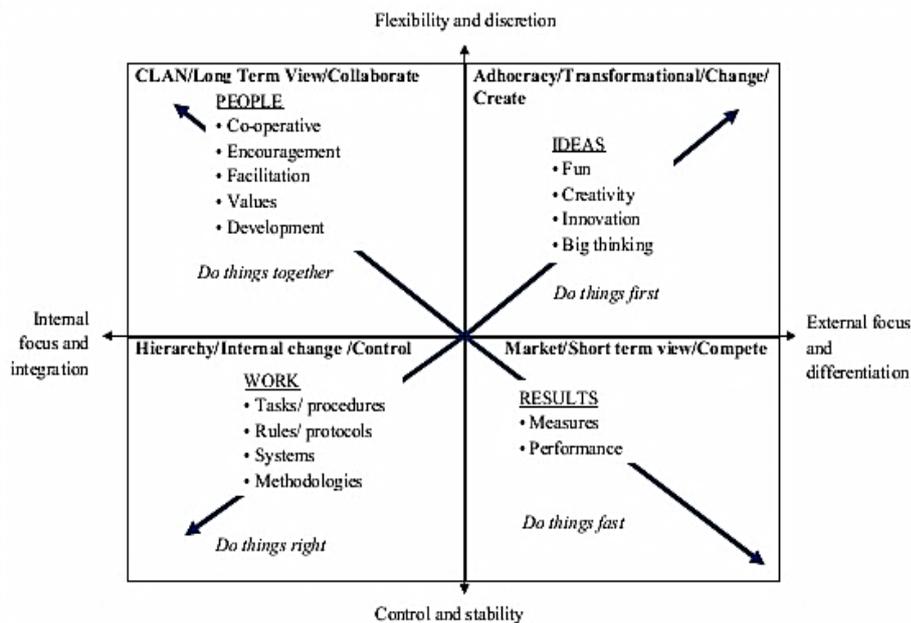


Figure 1: Four major dimensions of CVF (Cameron and Quinn, 2006; Cameron, 2009)

The second dimension emphasises internal orientation which focuses collaboration, integration and unity on one end to external orientation which focuses competition, differentiation and rivalry (Cameron, 2009). The differentiation between the managers with internal balanced relationships and the competitive to others to establish a market niche represents a good example. Each kind of manager is viewed as effective individually in different organisations. Each of the four quadrants (see figure 1 & 2) of CVF represent distinctive organisational cultural attributes, i.e. Clan, Adhocracy, Market, and Hierarchy.

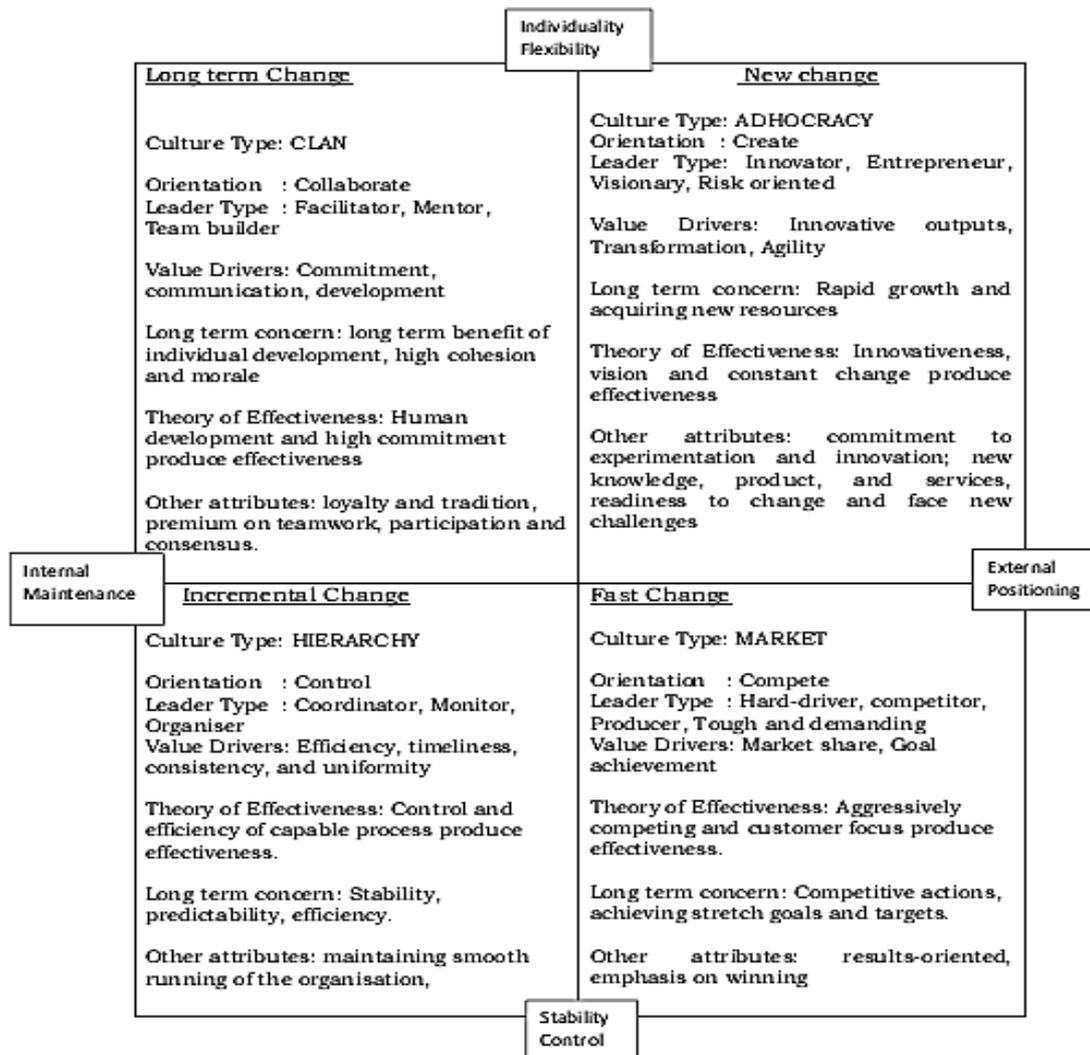


Figure 2: The brief summary of four cultures (Cameron and Quinn, 2006; Cameron *et al.*, 2006; Cameron and Quinn, 2011).

Table 1: Example of measuring the cultural stance of organisational leadership (source: Cameron and Quinn, 2011)

Organisational Leadership	Now	preferred
A The leadership in the organisation is generally considered to exemplify mentoring, facilitating or nurturing.	20	30
B The leadership in the organisation is generally considered to exemplify entrepreneurship, innovation, or risk taking.	30	20
C The leadership in the organisation is generally considered to exemplify a no-nonsense, aggressive, results-oriented focus.	35	30
D The leadership in the organisation is generally considered to exemplify coordinating, organising, or smooth running efficiency.	15	20
Total	100	100

Table 1 shows the example scoring the dimension of culture. The other five dimensions will also be scored in the similar way. Finally, scores are calculated in the suggested way

and plotted in the graph and a plot like the figure 3 will be found, which shows the existing culture (now) and preferred culture (in future).

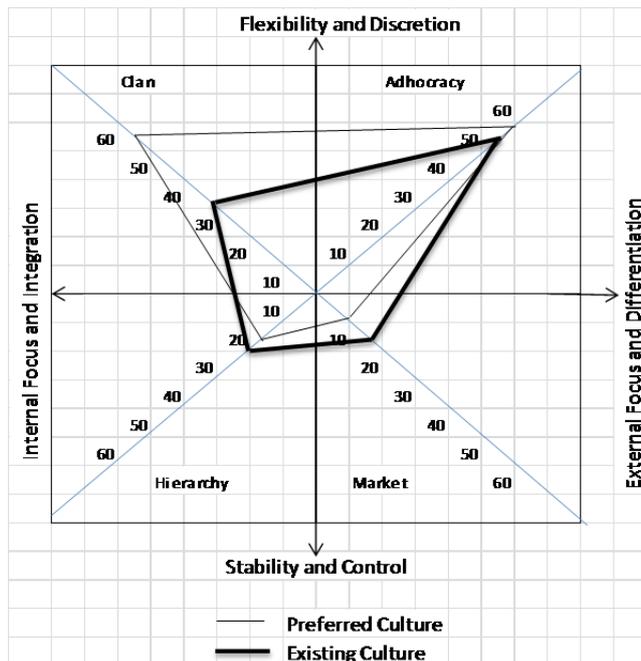


Figure 3: Plotting the (Existing) 'Now' and 'Preferred' culture (Cameron and Quinn, 2006)

CONCLUSIONS

The research plan is organised by considering the agenda of BIM adoption in the construction industry. A set of solutions will be prescribed from the investigation, which will be combined in a framework. The framework can be used to identify cultural instance of any project based organisations and to draw necessary action plan to shift the culture, i.e. to enable truly collaboration in the project delivery process, for improved efficiency, which is called for.

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