BIM and Off-Site Manufacturing: Recent Research and Opportunities

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Abstract

Evolved from the early product modelling efforts of 1980s, Building Information Modelling (BIM) concept is maturing rapidly today. Recent academic and industrial efforts indicate that the use of BIM as an information management strategy for enabling agile construction is becoming a sine-qua-non for the construction industry. In parallel with the recent advancements leading to ubiquitous information transfer and provision, the implementation of BIM spreads different domains of construction industry and this expansion introduces new needs, problems and solutions which will be particularly important for Off-Site Manufacturing (OSM). In this context, this paper aims to analyse the recent evolution of BIM concepts and the impact of BIM to OSM in light of recent literature.

Keywords: **Building Information Modelling, Literature Review, BIM, Research, Off-Site Manufacturing**

1. Introduction

Construction Industry holds its position as one of the major contributors to the economies of most of the nations. In the UK, Latham (1994) and Eagan (1998;2002) reports criticized the industry's poor performance and pointed out the importance of Information and Communication Technology (ICT) investments to efficiently establish the information management capabilities. Featuring the one-of-a-kind product/process and group of partners forming the virtual organization, characteristics of the industry brings specific needs in the information management (Turk, 2006). Building Information Modelling (BIM) is one of the recent efforts which is aiming to increase data interoperability, information quality and collaboration between the project participants within a construction project. BIM can be defined as the information management process throughout the lifecycle of a building which mainly focuses on enabling and facilitating the integrated way of project flow and delivery, by the collaborative use of semantically rich 3D digital building models in all stages of the, project and building lifecycle (Underwood and Isıkdag, 2011).

Off-Site Manufacturing (OSM) refers to production of parts of a structure at a location that is different than the location of the overall structure. Providing the benefits such as; higher speed, enhanced quality, higher tolerances, lower costs and reduced labour re-works on site, it's believed that the biggest growth in construction productivity will come from automated off-site activities that is facilitated by BIM (Goulding et al. 2012; Juhola, 2011).

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Although the start of OSM in construction industry date back far beyond the BIM concept, both face barriers that are hindering their uptake in the industry. The aim of this research was to outline the impact of BIM in facilitating Off-Site processes. The main research technique used was literature review on recent BIM research trends and the developments in OSM. This paper, commences with presenting the results of review on recent research regarding BIM and OSM. The impact of BIM in facilitating OSM later is discussed in the paper.

2. Recent Trends in BIM Research

The results of the BIM related literature review covering last 10 years period can be grouped into 3 main theme areas as Practice, Strategy and Technology. Until 2008, it is possible to say that, researchers have been concentrated on technology area as the major research focus. In the technology related research, most of the studies were concentrated on modelling and standardisation of abilities of BIMs. These works emphasize the importance of data and information exchange in BIM related research. As the research focus on data and information gathering concept shift to semi-automatic and automatic data gathering tools and techniques, their uses, benefits and integration methods with the Building Information Models are emerging topics. The use of BIM in Construction Practice has been a major focus of the BIM related research. BIM's nature as a collaboration platform for the design phase also forms a key field of research. The publications in the Practice area indicate that, there is a tendency on facilitating the pre-construction phase, especially the design phase. Despite of the rapid development in technology, the uptake of BIM remained slow and that caused the increase in the studies about BIM strategy starting from 2006. Training & Education and Internal & External Integration are found as the main areas of focus in BIM Strategy research.

3. Developments in OSM

The roots of the off-site construction stem from the end of World War One that affected the construction industry by major shortages of skilled labour and building materials and this shortage triggered a need for search of new methods of construction that would mitigate this problem. By the end of World War Two the industrial capacity wanted to be used as a supplement for the traditional building operations and these efforts stimulated the shift in the industry from traditional techniques towards off-site technologies (Taylor 2009). Various nomenclatures have been used in the industry to define this subject, such as Off-Site manufacturing, Off-Site fabrication (OSF), prefabrication (Prefab), modern methods of construction (MMC), industrialisation etc. (Gibb and Pendlebury, 2006;NHBC, 2006; BRE, 2007; Nadim and Goulding, 2011). Pan et al. (2012) defined Off-Site Production (OSP) as the manufacture and preassembly of building components, elements or modules before installation into their final locations. They grouped the terms that are used interchangeably for off-site production, by affix, under four categories. (Table 1)

Table 1: The terms that are used interchangeably for OSP (Pan et al. 2012)

off-site	**pre**	**modern**	**building**
off-site construction	preassembly	modern methods of construction	system building
off-site fabrication	prefabrication		non-traditional building
off-site manufacturing	pre-work		industrialized building

The recent research on the benefits of OSP indicate that, compared to the traditional methods, the implementation of OSP give the benefits of; reduction in (1) time, (2) defects, (3) risks, (4) costs and (5) environmental impact while consequent increase in (1) quality, (2) consistency, (3) predictability, (4) productivity, (5) performance and (6) profitability(Goodier and Gibb, 2005; Blismass and Wakefield, 2009; Pan et al. 2012). There has been various examples for the increasing interest in adopting and utilizing OSM in construction industry in many countries and regions including; Japan, Germany, Malaysia, Australia, Hong Kong, Sweden, UK and USA. (Pan et al. 2012; Goulding et al. 2012). Blismas and Wakefield (2009) argued that OSM adoption, requires fundamental structural changes to the industry and underlined that OSM changes the way people in the building industry work, both in terms of the process and product. Pan et al. (2005; 2012) highlighted the lower levels of OSM uptake despite of the demand of higher implementation by house builders. They emphasized that the main driver for off-site manufacturing is addressing the shortage of skills while the main barrier that is perceived by the industry is, higher capital costs (see. Table 2).

Table 2: The drivers and the barriers effecting the uptake of OSM (Pan et al. 2005)

Drivers	**Barriers**
Addressing the skill shortages	Higher capital cost
Ensuring time and cost certainty	Difficult to achieve economies of scale
Achieving high quality	Complex interfacing between systems
Minimizing on-site duration	Unable to freeze the design early on
	The nature of the UK planning system

Nadim and Goulding (2010) explained the reasons for the low uptake of OSP in construction industry as; (1) difficulty to ascertain the benefits, (2) the negative image regarding prefabricated/modular homes, (3) poor quality (4) poor aesthetics, (5) lower choice and (6) previous failures.

4. OSM AND BIM

The OSM and BIM both serve as valuable solutions in terms of improving performance of construction industry. The off-site technologies are improving the speed and quality of construction delivery and using BIM with these technologies will increase the amount/scale of facilities that can be modelled while decreasing the modelling time and increasing the quality (ICE, 2012). This correlation has been the subject of recent research. The research has generally been focussed on benefiting from BIM's scheduling, design and information storage and presentation abilities and the organisational, strategic and operational advantages that BIM implementation brings to OSM practices (Krawczyk, 2007; Moghadam et al. 2012; Alwisy et al. 2012; Smith, 2011; Lu and Korman, 2010; Nawari, 2012; McGraw Hill, 2012). Utilizing the principles of manufacturing industry in the construction environment, OSM is accepted as a way of streamlining construction processes with the advantage of industrialization. As a result of the different characteristics of traditional construction and the OSM processes, inconsistencies emerge between them and these act as barriers for the implementation of OSM. The recent literature in the field (i.e. Goodier and Gibb 2005; Blismass and Wakefield, 2009; Pan et al. 2012; Nadim and Goulding, 2010; Pan et al. 2005) stated the weaknesses of OSM. The following list presents the weaknesses stated in literature and then, for each item, discusses how OSM can benefit from BIM to overcome that weakness.

- *Need for high level of Information Technology(IT) integration:* High level of IT integration is required for streamlining the processes of OSM. → BIMs cover extensive amount of information regarding the attributes of the building (elements) and the processes of the construction lifecycle. They are accepted now as the sine-qua-non enablers of Architecture, Engineering and Construction (AEC) data level interoperability and integration. Today BIMs, with their enhanced capabilities, have the advantage of integrating with other information systems (Geographic Information Systems, Virtual Reality Simulations, etc.) or devices to acquire, store or share data. (Isikdag et al. 2008; Rüppel and Schatz 2011; Yanet al. 2010; Xie et al. 2011) Thus, the use of BIM during the OSM process will highly contribute to the IT integration.
- *Bad reputation because of the earlier "prefab" systems:* OSM concept has a bad reputation in the construction industry due to the massive post-war and 1960-70's social housing projects, because of the conservative characteristics of construction industry; clients, contractors or even the finance sources (banks etc.) approach this concept with suspicion→ The implementation of BIM concepts and BIM based pre-construction simulations would contribute to the acceptance of OSM as a modern method of construction, which makes the process controllable before production and component assembly. Using BIM abilities to facilitate better solutions for housing by reducing costs, optimizing schedules, generating nD models and improving design, it will provide a fundamental support for OSM (Eastman 2011; Alvarado and Lacouture, 2010, Sarno, 2012)
- *Limited experience of designers and contractors of OSM*: As the design philosophy has been built on the traditional approaches, the designers in the industry have very little expertise in OSM based designs. This is similar for the contractors who are responsible for implementing the designs on site.→The information contained in the BIMs can specially be helpful for contractors in the production and assembly process. BIM based simulations for training can be used to improve the limited experience of the parties. Utilization of 3D and 4D modelling aspects of BIM, improves interacting in a more visual way and enhances the experience in design, structural analysis, mechanical, electrical and plumbing (MEP) coordination, scheduling. (Barham et al. 2011; Korman and Simonian, 2008; Nawari et al. 2011; Peterson et al. 2011)

- Potentially difficult to modify: Once the building modules are designed it is difficult to make modifications based on on-site implementation difficulties or client demands→ BIMs' ability to generate 3D views from the base model, which involves the accurate information that is needed for fabrication of precast building components, facilitates the automated production. As the model stands on parametric rules, any update on a component, brings updates on the other objects that are related to it. Models' ability to detect inconsistencies, clashes and omissions, give users the chance to solve possible conflicts before they occur. The advanced visualization ability gives users a chance to see and predict the exact dimensions of some items that are needed to be constructed in the field. These not only reduce rework and execution time in all phases of design but also reduce the modification needs that rise during the construction phase, on site. (Eastman et al. 2011; Kim and Grobler, 2009; Goes and Santos, 2011; Leicht and Messner, 2007)
- *Transportation problems due to large components:* As the components of the building produced off-site may be large, problems on delivering them on-site and transferring them to the production area in the site may occur→The new generation of BIMs would include the state information of the building elements. The states and attributes of the elements (which can be large components or sub-components) stored in the model (states such as being on road, in site, in production facility etc.) and attributes such as(-part of-, -contains- etc) can facilitate in reassembly of smaller components into the larger components. The use of BIM based simulations and 4D schedules, provides advancements in the level of construction logistics planning. (Sarno, 2012;Harvey et al. 2009; Nummelin et al. 2011; McGraw Hill, 2008) This as a result will enable the production and transportation of smaller components.
- *Longer lead-in times:* The choice of using Off-Site Manufactured components may delay the processes in project site→ Combination of accurate scheduling with 3D model visualization abilities, results in faster production processes, better logistics and better collaboration in OSM. (Alvarado and Lacouture, 2010; Sarno, 2012;Eastman et al. 2011)
- *Higher capital costs, design fees, cranage costs:* Due to the limited skilled workforce and resources, for design and the cranage of the large components in the production facility and on site the costs of these processes are high→ BIM's technical capabilities give users the chance to not only reduce building costs but also monitor and control the costs and the cash flows related to them through all lifecycle of a construction project. According to the recent research, contractors believe that BIM can lead to cost reduction and improve budgeting and cost estimating capabilities. As an addition to its capabilities BIM has also has the potential to reduce costs by facilitating training and improving experience of the workforce. (Barlish and Sullivan, 2012; Steinkamp and Dionne, 2009; Watson et al. 2009; Chen and Gao, 2011; McGraw Hill, 2010)
- *Poor aesthetics:* Both the nature of off-site modules and the lack of art-trained people for design, limits the aesthetics→Due to their capacity to contain a rich set of information and the attributes associated with it, BIMs have the ability to generate different alternatives of design from the base information. Their ability to derive different model views respect to the needs, give users the chance of assessing different design alternatives that can be used to cover both aesthetic and

performance needs.(Schlueter and Thesseling, 2008; Lee et al. 2012; Stumpf et al. 2009; Raheem et al. 2011; Qi et al.,2011)

Table 3 provides a summary matrix that positions BIM benefits for overcoming barriers in OSM processes.

Table 3: Barriers/Benefits Matrix

BIM Benefits / OSM Barriers	Optimized Schedules	Reduced Costs	Improved Design	Better Training	Better Collaboration	Better Logistics	Reduced Design Errors	Accurate& Extensive Amount of Information	Reduced Modification
Need for high level of IT integration					●			●	
Bad reputation	●	●	●						
Limited experience				●	●				●
Modification Difficulties			●				●	●	●
Transportation problems	●		●			●			
Longer lead-in times	●		●		●	●	●	●	
Higher costs		●	●		●	●	●		●
Poor aesthetics			●					●	

The accurate and extensive amount of information that BIM presents with enabling better collaboration, provides basis for a high level of IT integration. On the other hand, the optimized schedules reduced costs and improved design provided by BIM helps in overcoming the bad reputation of OSM stemming from earlier prefab-systems. The experience gap that OSM practitioners possess would be eliminated by better training, better collaboration and reduced modification needs enabled by BIM. In order to reduce the modifications on site, BIM presents the benefits of improved design, reduced design errors, and modifications, and accurate and extensive amount of information. The transportation of big components can be facilitated by improved design / design decisions and logistics supported by optimized schedules. As an addition to this benefits reduced design errors, accurate information and improved collaboration between parties will provide the advantage to have shorter lead-in times. The design advantages, reduced costs with improved level of collaboration enabled by BIM will help in reducing the OSM costs. By the help of improved design abilities powered by accurate and extensive amount of information BIM will help in maintaining the aesthetic quality in designs.

5. CONCLUSION

BIM is one of the most apparent aspects of a deep and fundamental change that is rapidly transforming the global construction industry. As it's been stated in the recent literature, BIM research is mainly concentrated on improving models' abilities of acquiring, storing and sharing the construction related data. These improvements not only increase its information management abilities but also give BIM a role as a facilitator for new technologies and building methods. OSM, using the industrialisation principles, is an effective method of improving construction industry's poor performance. Despite of the proven benefits, OSM adoption and use in the industry is limited by some barriers which have been subject to various research this far. The recent literature highlights that new technology is a facilitator to overcome these barriers of OSM. The aim of this research was to outline the impact of BIM in facilitating Off-Site processes. The recent literature shows that; providing an improved design, facilitating collaboration and covering accurate and extensive amount of information seem to be the most useful benefits of BIM for bridging the OSP implementation gaps, avoiding longer lead-in times, high costs and modification problems. This paper, taking recent literature as the basis, demonstrates the OSM's implementation gaps and then provides suggestions on bridging these gaps by the benefits that BIM brings. In order to have broader view with the input acquired from the industry, the research can be strengthened by collecting data with surveys and face to face interviews. The integration of automatic data acquisition approaches and improved web based collaboration will provide the chance to collect, store and share the 'state' information in BIMs and will increase the reach to BIMs over the cloud. Future research will be focussed on the impacts of these developments on OSM.

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