Barriers of 5D BIM Implementation in Prefabrication Construction of Buildings

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Abstract: Building information modeling (BIM) has been proved a positive impact on architectural, engineering and construction industry recently. Especially 5D BIM which integrates 3D model, schedule, and cost information to allow automatic generation of quantities to be a quicker and more accurate data extraction procedure to facility a more efficient cost management in construction. However, there is limited research of analysing 5D BIM engaged in prefabricated buildings. This research aims at discovering significant barriers which would influence the 5D BIM implementation for prefabricated projects.

1. Introduction

BIM is a process of creating virtual models with the functional characteristics of construction projects. The concepts of 5D BIM was initially developed in 2008, which has been described as a functional feature based on 3D digital modelling of traditional architectural, engineering, and construction (AEC) projects. Reliable and accurate cost estimation is the primary goal of 5D BIM since 3D construction digital modelling has the advantages of avoiding manual estimating errors (Ustinovičius et al., 2015). The Association for the Advancement of Cost Engineering International, the American Society of Professional Estimators, the National Institute of Building Sciences, and the General Services Administration reached an agreement to accelerate the collaborative cost estimation in the entire project lifecycle (Smith, 2016).

The benefits of 5D BIM are to dynamically adjust the 'live' cost when design changes are made because these changed components can be automatically calculated. Based on this function, actual spending can be easily tracked to ensure efficiency for the project to remain within budget allowances. This 'live' cost plan helps stakeholders design to budget from the beginning to the completion of the project onsite. In comparison with a traditional approach, only a few times of update at the early phases of projects but brings a much better certainty of the project cost.

The prefabricated building is one of the most leading-edge technologies for the AEC industry (Hong et al., 2018). Research studies emphasised that the actual implementation of prefabrication not only can render 10% reduction of installation costs (Sullivan and Dye, 2015) but also is capable of dealing with compressed project schedules, unorganised site circumstances and weather conditions (Tam et al. 2006, 2007; Tam and Hao, 2014).

The current literature has found the potential to improve productivity through the implementation of 5D BIM in prefabricated projects, which can coordinate and collaborate effectively through the design stage to the construction stage instead of working in isolation and waiting for information. After accurate and reliable building elements are established within the 5D BIM system, these digital
parameters and data can be shared and disseminated over the project lifecycle to shorten the procurement schedule (Mastafa et al., 2020).

However, many barriers and challenges of 5D BIM implementation within the prefabricated projects still exist: a lack of interoperability among heterogeneous information model, the main pre-requisite for entire interoperability, and hence collaborative working in prefabrication (Stanley et al. 2014); a lack of quality on quantity automation, which would affect the accuracy in the preparation of a bill of quantities (Khosakitchalert et al., 2019).

There are many types of BIM software, such as ArchiCAD, Bentley Architecture, BIM technology, BIM 5D, Luban. However, it is constrained and challenged to transfer parametric data and models among software (Jiang, 2017). Moreover, the logistics transportation information and the location of component items are rarely connected to software, which will not be able to adjust the stacking of materials and equipment to utilise the land resources in the prefabrication project to control the cost in time effectively.

2. Literature review

Since BIM has significantly impacted on the AEC industry, plenty of literature has illustrated the implementation of integrating BIM and prefabricated building in regards to the current barriers and challenges in the prefabricated construction. The key challenges are complicated site and logistics, the poor collaborative working-level among stakeholders through the entire lifecycle of the project, limited information and data integration/exchange basis, and software to address issues (McGraw Hill Construction 2011). Meanwhile, the 5D BIM concept within prefabricated buildings is rarely researched and introduced.

Visualising the progress from the design stage through to the construction stage with actual spending over time is achievable through 5D BIM (Kehily and Underwood, 2017; Park and Cai, 2017). Primary methods in automatic estimation are to export quantities of building components to estimating software, like CostX, CostOs, or Vico. Although these spatial and geographical data provided from 3D BIM model can be read or mapped on estimating software, manual modification is still essential because of the interoperability of automatic data integration/exchange between digital models and 5D BIM-based estimating stay at an immature level in prefabrication construction.

Recent research states that design and coordination errors can be minimised through BIM solutions in prefabrication construction (Dalton et al. 2013; Ramji and Memari 2013, Wynn et al. 2013; Arashpour et al. 2015;). However, it is still lacking in adopting 5D BIM to enable accurate and timely cost management.

According to the literature, there are many concepts introduced for the "Integration of BIM and Prefabrication" like smart work packages (Isaac, 2017), smart prefabrication housing production objects (Niu, 2015), and radio-frequency identification (Torrent and Caldas, 2009; Ergen et al., 2011), etc. to augment the capability of BIM implementation in prefabrication. These related concepts or functions would be analysed and tested further under the 5D BIM framework in prefabricated construction.

The proper classification of building components in the digital model for 5D BIM quantity automation is exceptionally significant when extracting parameters from a BIM model into a costing software. Building components are usually selected either individually or as a group. However, the accuracy and quality of quantity automation in BIM data environment is a significant issue. However, Sattineni and Bradford (2011) stated that most of 3D BIM models could not be used for estimating purposes because general contractors could not receive sufficient quantities including temporary structures, architectural finishes, electrical and plumbing, mechanical, and landscaping from design teams.

Moreover, overlapping parts of compound elements, such as edges and corners, among walls and floors, resulting in excessive material quantities. If the BIM model is modified manually, the additional data will result in time-consuming and cost-intensive. Therefore, automated quantity extraction would be the core factor to achieve the 5D BIM implementation on projects. Although
many prefabrication manufacturers offer components and guidelines for designers to build up a family library which is able to contain the material and geographic data to meet the basic estimating requirements, these building components and guidelines are often limited and incomplete. Moreover, different prefabrication manufactures might use different software to create digital components which would lead to a low level of interoperability of automatic data integration/exchange (Lee et al., 2015), which may result in difficulty for construction estimators to specify requirements and integrate the pricing information to fulfil automated quantity extraction efficiently.

Research studies have been engaged to enhance the quality and accuracy of quantity automation in 5D BIM. For example, an automatic BIM modelling system specialised for building interior finishes was established by Kim et al. in 2009. A knowledge-based system for precast quantity automation was found by Aram et al. in 2014. A logical system can automatically count bill of quantities of lighting and appliances without a geographic model in the 3D BIM was established by Rajabi et al. in 2015.

An automatic calculation algorithm was established for rebar quantity takeoff by Lim et al. in 2016. A semi-automatic system for cost estimation was generated through a semantic database by Ma et al. in 2009 and 2013 to demonstrate the possibilities for adopting the BIM Industry Foundation Classes standard to the construction project estimation standard in China.

To sum up, BIM-based quantity automation can potentially replace manual measurement and estimating for a project for cost management and control for projects. However, it still has limitations that most of the proposed methods cannot be integrated together to achieve the expected automation. For prefabrication projects, the use of standard prefabricated components may include detailed material specification and pricing information from the manufacturers, which can facilitate an efficient approach for quantity automation (Dunant et al., 2018). However, the use of predefined building components may restraint innovative design and solutions. Therefore, the current limitations and barriers of 5D BIM on prefabrication projects will need to be explored and analysed to develop an integrated method to provide accurate and timely quantity automation for prefabrication construction.

3. Research methodology

The research would be using a mixed qualitative and quantitative method of literature study, questionnaire survey, interviews and multiple case studies.

3.1. Literature review
An extensive literature study in the 5D BIM and prefabrication construction will be carried out, containing articles, publications, and reports. Selected literature would contain the field of BIM-based cost estimation and cost planning and in prefabricated projects, quantity automation in BIM. The objective is to develop the breadth and depth knowledge of 5D BIM implementation in the prefabrication industry.

3.2. Questionnaire survey and interview
Questionnaire survey will be established and distributed to professionals in the construction about the 5D BIM issues identified in the literature review. This method has a simple, direct, efficient and low-cost characteristic to acquire the answers of the research question. However, the main problem would be a low response rate with ambiguous answers. Therefore, the interview would be carried out to complement these disadvantages. Semi-structured interviews will be carried out to experts in the construction industry to enable a more indepth investigation of issues, challenges and barriers of 5D BIM and how 5D BIM can be facilitate to benefit the prefabrication industry through professional insights.

3.3. ISM-ANP Methodology
The integrated interpretive structural modelling-analytic network process (ISM-ANP) is an effective method to illustrate the interrelationships among barriers in a complex system. Direct and indirect correlativelocations among several barriers would be identified with ranking (Thakkar et al., 2005; Attri et
al., 2013). In the construction management field, ISM-ANP is always applied to analyse the factors influencing the productivity of projects (Sandbhor and Botre, 2014). This research will use ISM-ANP method to generate the structural mapping of intricate interconnections of barriers to 5D BIM adoption in prefabricated construction. As below, Figure 1 indicates three necessary steps and content.

![Figure 1 ISM-ANP](image)

4. Discussion

4.1. Identification of Key Barriers
To filter these barriers, a questionnaire survey was created to send to relevant company in Architecture, Engineering and Construction (AEC) industry to acquire practicable information. Five scales are designed to test each BIM implementation barrier, i.e., severe, serious, moderate, slight, and very slight; valued as 5, 4, 3, 2, and 1, respectively.

A total of 100 online questionnaires survey were sent, and 42 respondents were collected after one month. As shown in Table 1, the respondents located in a different area, Beijing, Guangdong, Chongqing, and other areas. All of these company have over one year of experience in 5D BIM implementation in the prefabrication industry. According to the results of the questionnaire survey,
there are several barriers with the highest occurrence rate and the most profound impact on 5D BIM implementation in the prefabrication industry

| Employer               | Design company | Construction company | Real estate agent | Research institution |
|------------------------|----------------|----------------------|------------------|---------------------|
| Number                 | 22             | 13                   | 4                | 3                   |
| Location of company    | Beijing        | Guangdong            | Chongqing        | Others              |
| Number                 | 6              | 7                    | 2                | 13                  |

Based on the respondents’ working years, the figure 1 has been created to indicate the distribution of the experts in the prefabrication construction industry. The biggest proportion of the distribution is 1-3 years’ staff and least proportion is occupied by over 10 years’ professions.

4.2. Establishing Correlation Structure
After finalising literature review, questionnaire survey and interviews, experts’ suggestions about the correlations among these barriers were identified. Due to the complexity of obstacles, the collected responses were analysed to discover the contextual interrelationships among restrictions into the Structural Self-Interaction Matrix (SSIM). The Correlations among factors i and j were separated to four symbols: (1) W represents to “influencing factor i which can lead to barrier j but not vice versa”; (2) X represents to “influencing factor j which can make for barrier i but not vice versa”; (3) Y represents to “influencing factor i and j which can result in each other”; and (4) Z represents to “influencing factor i and j which are not related”.

Based on the survey and interview, initial 10 barriers were conducted and analysed below in the SSIM figure3:
Figure 3: SSIM

4.3. Reachability Matrix

SSIM is interpreted to a binary matrix for subsequent analysis through substituting symbols, i.e., W, X, Y, and Z, to 1 and 0 according to the given situation, Table 2 and 3 have displayed below to illustrate the direction of correlations between two symbol W, X, Y, and Z, the (i, j) and (j, i) of the reachability matrix. Meanwhile, they are written in as the correlated figures in Table 2. For example, if(b2.b1) in the SSIM is X, the (b2,b1) in the reachability matrix would be 0, and (b1,b2) would be 1.

Table 2 SSIM

| SSIM  | Reachability Matrix |
|-------|---------------------|
|       |                      |

| (i, j) | (i, j) |
|--------|--------|
|        |        |

| W  | 1 | 0 |
|----|---|---|
| X  | 0 | 1 |
| Y  | 1 | 1 |
| Z  | 0 | 0 |

Table 3 reachability matrix

| Barrier | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 |
|---------|----|----|----|----|----|----|----|----|----|-----|
| B1      | 1  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 1  | 10  |
| B2      | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 2   |
| B3      | 0  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 9   |
| B4      | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0   |
| B5      | 0  | 0  | 0  | 1  | 1  | 1  | 0  | 0  | 0  | 9   |
| B6      | 0  | 0  | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 9   |
| B7      | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 1  | 1  | 12  |
| B8      | 1  | 0  | 0  | 0  | 0  | 1  | 1  | 1  | 1  | 9   |
| B9      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   |
| B10     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0   |

| Dependence power | 2 | 9 | 8 | 7 | 8 | 8 | 1 | 9 | 10 | 12 |


4.4. Identification of barriers
A factor with a higher driving power represents that its elimination allows the solving of several other barriers (Attri et al., 2013). These initial ten factors filtered from the literature review and questionnaire survey are analysed to, Four obstacles with the highest dependence power have been discovered.

4.5. Negative Attitude towards Data Sharing
It is quite Reluctant for most of the stakeholders in the AEC industry to share the project information based on 5D BIM platform due to their profits and privacy protection. In the fact that effective adoption of 5D BIM needs collaborative work and integrated data, negative attitudes of data sharing would affect the 5D BIM implementation (Zhang et al., 2018).

4.6. Lack of a Well-established BIM-based Workflow
Standard 5D BIM workflow hasn’t been established for prefabricated construction in China. Stakeholders usually establish their digital model different 5D BIM software which would create separated and fragmented workflow to 5D BIM implementation (Easdifferential., 2011; Panuwatwanich and Peansupap, 2013).

4.7. Increased investment Costs
Investment cost would be increased significantly at the beginning of the 5D BIM adoption for stakeholders (Lu et al., 2014), however, the economic benefits return is not straight forward. Most of small company in Aethe C industry regarded it as a severe barrier due to tight cash flow(Azhar et al., 2011). Therefore, companies may choose not to use 5D BIM unless they can acquire related subsidies (Eastman et al., 2011).

4.8. Uncertain Economic Benefits
Most of the company indicate that the project cost saving through 5D BIM implementation is very limited, and economic benefits wouldn’t be realised until the end of the project completion. In most of the cases, the benefits of 5D BIM are intangible and difficult to calculate (Barlish and Sullivan, 2012; Jin et al., 2017; Zhao et al., 2018). Thus, it is regarded as a critical obstacle for adoption (Papadonikolaki and Aibinu, 2017).

5. Conclusion
The upgrading and the emergence of 5D BIM technology bring an unprecedented chance for traditional prefabrication industry. This research contributes to the knowledge through an in-depth illustration of interactive correlations among barriers which will influence the 5D BIM adoption in current prefabrication industry.

However, this research still has two main limitations that should be analysed further. First, this study cannot consider all barriers mentioned by previous studies in a different location due to the restriction of people and investment. Thus, obstacles with less significance were not included in the analysis. Second, the 5D BIM standards haven’t been established when this research was engaging. Therefore, primary barriers would be changed later on when the unified 5D BIM standards established. Future research is suggested to analyse these gaps proposed in this study.

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