Building Information Modelling Implementation in the Design Stage of Chinese Prefabrication Construction

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Abstract. Prefabrication construction has gained popularity in the construction industry during the last few years. Due to the complexity of prefabrication design, building information modelling (BIM) is adopted in the design stage to improve efficiency and accuracy. Many previous studies have examined the adoption of BIM in the design stage and explored the current practice of BIM adoption in prefabrication construction, however fewer first-hand investigations are made on assessing the adoption of BIM. This study aims to identify the opportunities and challenges of utilizing BIM technology in the design stage of prefabrication construction from the perspective of designers. A semi-structured interview was conducted for qualitative data collection and the data are analysed by thematic analysis. A total of eight designers from Chinese prefabrication construction projects were interviewed. The research identified 8 opportunities and 15 challenges of BIM adoption in prefabrication construction. The top four challenges are: (1) inaccurate prefabrication production drawings generated by BIM software, (2) late adoption of BIM in the design stage, (3) lack of communication platform for different designers, and (4) lack of sharing the updated design model among designers, manufacturers, and onsite engineers. These findings provide directions for improving BIM adoption in the design of prefabrication construction.

1. Introduction

In the past twenty years, prefabrication construction has gained popularity both in the construction industry and academia, which produced construction elements in a controlled factory instead of the construction site [1]. Currently, prefabrication construction is a quite common technique and has been widely used in North America, Japan, and United Kingdom, and in parts of Europe, like Sweden. It is becoming more and more popular in Australia, Germany, Netherlands, and China [2, 3]. For example, in China, 31 provinces have established incentive policies for prefabrication construction, including land use support, financial subsidies, special funds, tax credits, plot ratio, awards, credit support, examination and approval, consumption guidance, industry support. Among these policies, the use of tax credits has exceeded 90%. Moreover, financial subsidies and plot ratios all exceed 50%. Prefabrication construction is becoming mainstream in the construction industry worldwide.

The design of the prefabrication project is a complex task, which needs to consider the manufacture and assembly processes. The digital technology implementation could contribute to improving the quality and efficiency of design, such as building information modelling (BIM) technology [4, 5]. For example, BIM utilization in clash detection could reduce errors in for the designed model and improve project quality during the design for the manufacture and assembly process [6]. Based on the systematic review on digital technology adoption in prefabrication construction towards Construction 4.0 proposed by Wang et al. [7], BIM has been regarded as a mature and promising technology for prefabrication construction. Therefore, the BIM implementation is significant for the design of prefabrication construction.

However, regarding real practice in the construction industry, the technology adoption could be different from the ideal situations [8]. Previous studies on BIM implementation were conducted by literature review method, while fewer first-hand investigations were made on assessing the adoption of BIM in the prefabrication construction industry. Therefore, it is necessary to assess BIM implementation in real practice from the perspective of practitioners. This study aims to explore the current practice of BIM technology in the design stage of prefabrication construction and identify the opportunities and challenges for adoption. The semi-structured interview was conducted to obtain first-hand data of opinions from designers. The results of this study have empirical implications in promoting BIM technology for prefabrication construction industry and guide the future directions of improvement of BIM technology.

2. Literature Review

Many studies have been conducted on BIM utilization in the design stage of prefabrication construction. For example, Alfieri et al. [6] proposed a framework to integrate the Design for Manufacture and Assembly (DfMA) approach in the Italian Architecture, Engineering and Construction (AEC) context based on BIM, which could integrate DfMA solutions into the project at different stages. Liu et al. [9] adopted BIM in the design and planning of roof sheathing installation for prefabricated buildings, and it validated the BIM-based design can reduce material waste based on two case studies. Gbadamosi et al. [10] designed a BIM-based optimizer to assist designers in the selection of alternative building design elements and materials, which could improve efficiency and reduce waste. Yuan et al. [11] established a standard parametric prefabrication elements library through the re-development on family template of BIM and expanded BIM functions needed by prefabrication installation. However, these studies have only explored the effectiveness of BIM utilization in improving the design efficiency and waste reduction for prefabrication construction, while they didn’t investigate the needs and barriers for BIM technology adoption from the designers’ perspective.

In terms of BIM implementation in the prefabrication construction industry, some studies have identified the main barriers of practical adoption. For example, previous research identified some most important barriers of implementing BIM in construction industry, including “lack of flexibility” and “lack of supply chain buy-in” [12-14]. Ozorhon and Karahan [15] identified three critical factors of BIM implementation, which were the availability of qualified staff, effective leadership, and availability of information and technology. Tan et al. [16] identified 12 key barriers of BIM implementation based on literature review and proposed that the biggest barriers to the practical application of BIM for prefabrication construction are the lack of research about BIM in China and the absence of standards and domestic-oriented tools. Zhao and Wang [17] and Mostafa et al. [18] explored the barriers of integrating BIM in the Australian prefabrication industry based on previous studies, and it identified the seamless and timely information exchange among major project stakeholders through a BIM system is the most critical factor to adopt BIM successfully. However, the identification of barriers on BIM implementation in previous studies is more based on literature review and lacks first-hand data from construction industry.

Therefore, to address the research limitation in previous studies, this study interviewed the designers from the Chinese prefabrication construction industry to collect the opinions on using the BIM in the design stage. This study could identify the opportunities and challenges of utilizing BIM from a practical adoption perspective for prefabrication construction.

3. Research Methodology

The semi-structured interview is recognized as an effective approach to gain deep knowledge of the construction industry [19], so it is selected in this study. The research design is seen in Figure 1.

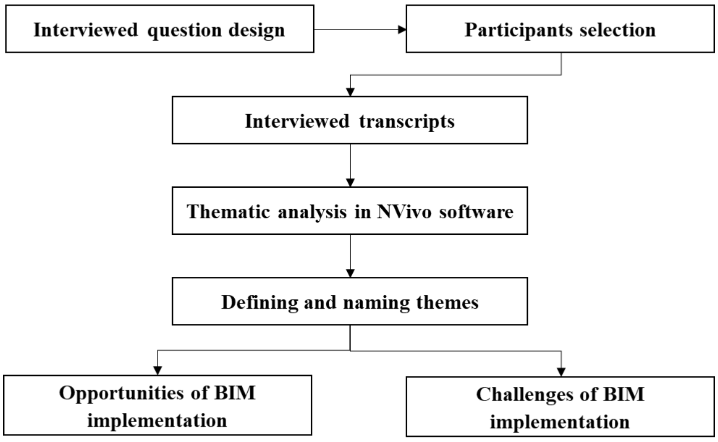

Figure 1. Research design.

The first step is data collection. Face-to-face individual interviews were conducted to obtain the detailed opinions from designers on BIM implementation in Chinese prefabrication construction projects. Each interview took around 1 hour to 1.5 hours. The interview questions were compiled based on a literature review on recent and related publications, including digital technologies [20, 21], technology implementation [22-24], waste management [25, 26], construction management [8, 27], technology adoption in prefabrication construction [28]. Interview with open questions makes it possible that participants can openly explain their attitudes about BIM implementation. For example, the questions include "Do you aware BIM could improve your current practice?" and "what do you think are the difficulties of using BIM?". The adequate sample size is usually reached at saturation point when themes start to repeat themselves [29]. Therefore, the completion of the interview is based on that there is no more new information after a certain number of interviews.

To get reliable data, the selection of interviewees considers working experience in prefabrication construction. The background information of the interviewees can be seen in Table 1. These selected designers come from the design sectors which are the earliest to adopt prefabrication in China, so they had enough experience in prefabrication construction. More than 3 years' work experience in the prefabrication construction industry demonstrates the interviewees have a deep understanding of the current practice. The job titles are determined as they indicated to the author, including structure designer, architecture, and BIM engineer. Among them, six interviewees have more than 5 years of working experience in construction industry. In addition, five interviewees have been involved more than 10 prefabrication construction projects. In conclusion, the selected interviewees are eligible to provide opinions for this interview, and the interview transcripts data presented in this study are available.

After data collection, the next step is data analysis. The interview manuscripts are qualitative data, which are non-numerical and unstructured [30]. Thematic analysis is the most suitable method for analyzing interview data, as it focuses on themes and patterns to understand people's experience, views, opinions, knowledge of things [31]. The NVivo software is used to reduce manual tasks during thematic analysis. The themes can be created under the research purpose to guide themes generation [32]. In the eight interview transcripts, the phrases and sentences related to BIM were selected as initial themes. Then the initial themes that mentioned the same opportunity or issue will be grouped as new themes. Defining themes involves formulating exactly what is the meaning of each theme and figuring out how it helps to understand the data. Naming themes involves coming up with a succinct and easily understandable name. Finally, after grouping and naming themes, the opportunities and challenges of BIM implementation were identified.

Table 1. Background information of interviewees in Chinese prefabrication construction industry

ID	Job title	Experience in prefabrication construction	Experience in construction industry	Number of PBPs completed or in progress
1	Structure designer	5-10 years	11-20 years	> 10
2	Structure designer	5-10 years	11-20 years	> 10
3	Structure designer	5-10 years	5-10 years	> 10
4	Structure designer	3-5 years	5-10 years	> 10
5	Structure designer	3-5 years	5-10 years	>10
6	Architecture	3-5 years	3-5 years	4-6
7	BIM engineer	3-5 years	3-5 years	4-6
8	BIM engineer	3-5 years	11-20 years	7-9

4. Findings and Discussion

After thematic analysis, the interview data were analyzed into structured themes. The opportunities and challenges of utilizing BIM for design are presented in this section. As proposed by Abedi et al. [33], the number of quotes represents the importance of the theme. Accordingly, the significance of each technology can be obtained from the analysis of themes. 8 opportunities for BIM implementation in the design stage of prefabrication construction were identified, as seen in Figure 2.

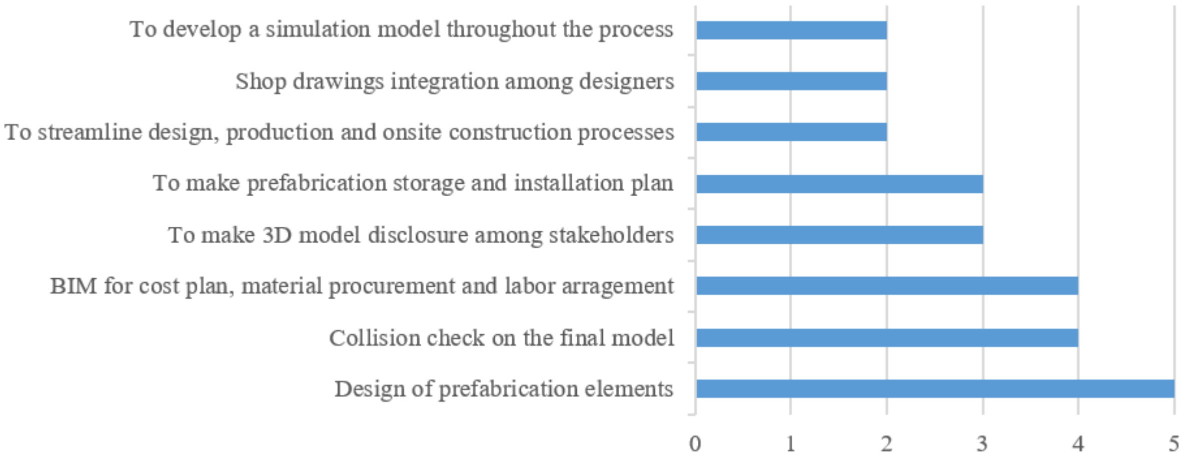

Figure 2. Opportunities of BIM implementation in the design stage of prefabrication construction.

The most mentioned advantage of BIM is the design of prefabrication elements based on BIM software, which is the critical process of prefabrication project design. Interview ID 6 mentioned that

"We still use some software that is used in traditional construction to design 3D model of prefabrication elements, like Autodesk Revit, AutoCAD, which are helpful."

The second and third mentioned benefits are the collision check of the final model, and making plans of cost, materials procurement, and labor arrangement, which are the most common functions of using BIM software. The fourth and fifth factors are both mentioned with 3 quotes, which are the 3D model disclosure among stakeholders and making storage and installation plan of prefabrications. Interview ID 2 stated that

"The current practice of the installation process is that the structure designers need to make the technical disclosure with the onsite contractors, such as techniques of the onsite installation and connection joints with onsite structures. Now we do these mainly by using PPT presentations or videos. BIM can make this process more efficient."

The other three opportunities are mentioned by two interviewees, while they are also significant in the design stage. BIM can be used to streamline the design, manufacture, and onsite construction processes. Interviewee ID 1 mentioned that

"The whole life cycle management can be achieved by streamlining all tasks and personnel in the BIM platform."

BIM can also be used to integrate the models designed by different professionals. Interviewee ID 3 mentioned that

"Currently if BIM can be applied, it can solve the integration problems of design drawings from various designers."

BIM can also be used for 3D model simulation and to guide the manufacturing process. Interviewee ID 6 mentioned that

"We design the 3D shop drawings based on BIM software and do some virtual simulations of the manufacturing process for the factory."

In conclusion, BIM technology is regarded as a beneficial technology for prefabrication construction design. The practical implementation of BIM is significant for designers. However, although BIM has many advantages for prefabrication design, it is still less utilized in real practice. 15 major challenges for adopting BIM in the design stage are identified, as seen in Figure 3. These challenges also represent the future directions of improving BIM for promotion in prefabrication construction. Different from the previous studies using BIM technology in relatively simulated or ideal situations [6, 34, 35], this study pointed out more practical issues of BIM adoption for the prefabrication construction industry. The top four challenges are detailed discussed in the following section.

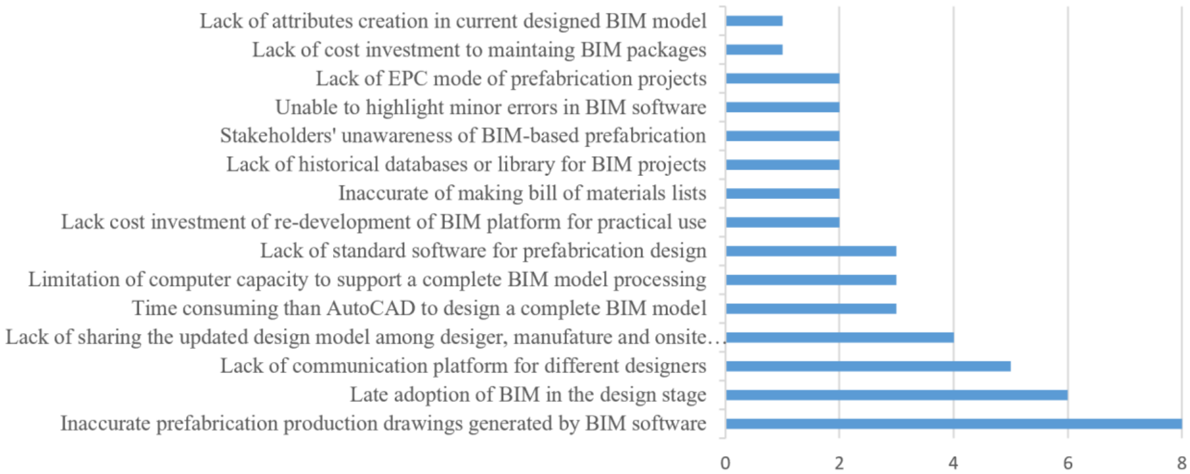

Figure 3. Major challenges of BIM implementation in design stage of prefabrication construction.

Among the identified challenges, the top issue is the inaccurate prefabrication production drawings generated by BIM software, which is mentioned by all interviewees. This issue could influence both design and manufacture stages. The current design of prefabrication projects is still based on AutoCAD software. Revit or Navisworks is still less adopted. All interviewees claimed that models created by the BIM software have errors of information loss and disordered layout, which is not able to guide the manufacturing process directly. Many manual adjustments are still required for generating shop drawings. In this case, using BIM software for designing is not efficient.

The second issue is the late adoption of BIM in the design stage, which is mentioned by 6 interviewees. Interview ID 1 mentioned that

"We used BIM to design, but it involved after the completion of prefabrication design rather than starting from the scheme design stage."

Interview ID 6 stated that

"All these designers, manufacturers, and onsite workers need to work together at the very early design stage, which is different from traditional construction."

The third issue is the lack of communication platform for different designers and is discussed by 5 interviewees. Interviewee ID 4 stated that

"How to keep the design model consistent during architecture design, detailed design, and MEP design is the main problem. Once the design model is not updated to each other in a real-time manner, it may result in design information loss or design errors. And this is a common issue in the current practice".

The current BIM is not able to exchange model in real-time among different designers efficiently. As mentioned by interviewee 6

"The platform of Revit could realize some information communication among designers, we had used it for a while, but it is not such efficient and effective."

The fourth issue is the lack of sharing the updated design model among designers, manufacturers, and construction sectors, which is concerned by 4 interviewees. After the model is designed, the designed model needs to be shared with the manufacturing and construction sectors. Due to the inevitable changes, any updates on the design model need to be informed to every sector. Interviewee ID 5 claimed that

"The current BIM is not able to connect stakeholders, which causes the loss of information and difficulties in tasks delivery among stakeholders. A complete BIM platform that can be used throughout whole stages to communicate with each other is urgently needed."

Other issues, such as the lack of computer capacity to support the processing of a complete BIM model and lack of standard BIM software are also common issues in the construction industry [18]. The cost-related issues, such as the cost for the re-development of the BIM platform and maintaining BIM till facility management phase also have been identified in previous studies [16, 36].

To be concluded, although BIM is regarded as a mature technology in previous studies [7], there are still many issues for practical adoption. The major issues are caused by the BIM software. From the perspective of designers, the current BIM software is not mature enough for their design. The produced drawings for prefabrication production are not standard, so the format rules of shop drawings generated by Revit or Navisworks need to be optimized. In addition, the design of prefabrication construction requires more communication functions among designers and stakeholders from other stages, especially the communication among designers. In real practice, there is a lack of design sectors that could do all the design tasks for a prefabrication project. So, it is common that different designers need to work with the same model. However, previous studies have only emphasized the importance of communication among different stakeholders [16, 37].

Compared with previous studies on barriers of BIM adoption in prefabrication construction, this study has identified more empirical challenges in the design stage for Chinese prefabrication construction. The identified challenges are the most concerned issues by the designers. Some challenges need to be addressed by the measures taken by the government and design companies, such as increasing the investment in BIM software and platform development, database establishment of historical prefabrication projects, and standardization of the software utilization in the design stage. These solutions need to take a long time to complete. Other challenges could be solved by adjusting the current organization structure or management mode, such as implementing BIM from the scheme design stage and using EPC mode for prefabrication projects. These solutions are more possible to be achieved within a short time. Therefore, the outcomes in this study have more practical implications to guide BIM technology adoption.

5. Conclusions

This study provides empirical understanding and knowledge to both academics and industry practitioners in prefabrication construction. To get a deeper understanding of the current practice of BIM implementation, semi-structured interviews are conducted with 8 experienced designers in the Chinese prefabrication construction industry. The thematic analysis is used for identifying the opportunities and challenges of utilizing BIM for prefabrication construction design. From the perspective of designers, 8 opportunities and 15 challenges of practical BIM technology adoption in the design stage of prefabrication construction are identified.

Based on the analysis of 8 opportunities, this study identified that BIM could improve the current design practice for designers. To achieve the success of BIM adoption, the challenges of utilizing BIM are identified. The uniqueness of this study is that it focused on the real practice in the industry, which is closely related to efficiency and quality improvement of the design process. The top four identified challenges are (1) inaccurate prefabrication production drawings generated by BIM software, (2) late adoption of BIM in the design stage, (3) lack of communication platform for different designers, and (4) lack of sharing the updated design model among designer, manufacturer, and onsite engineer. These identified challenges are unlikely to be identified from previous studies and only can be derived from empirical data from industry. The identified issues are the major obstacles of the BIM to be more accepted by designers. Therefore, the addressing of these issues could not only improve the efficiency of prefabrication design but also promote the BIM adoption in the prefabrication construction industry towards Construction 4.0. The findings are new to the current studies and can contribute to guiding and facilitating digital technologies in real practice.

In the future, more attention should be paid to addressing the identified challenges, such as improving the format accuracy of drawings produced by BIM software and making them more suitable for guiding prefabrication production in factories. Moreover, in addition to the improvement of BIM software, it is recommended that other factors that could influence the BIM implementation should also be explored, such as the type of prefabrication projects and promotion of BIM in prefabrication design. Even though this research is limited to designers from prefabrication projects in China, it could be regarded as a pilot study of promoting practical BIM implementation and provide some directions for BIM development in different countries and areas.

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