Application of BIM in the Refined Management of Prefabricated Building Design Phase

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Abstract. This thesis will explore the application mechanism of BIM technology in the design phase of prefabricated buildings, focusing on the construction of standardized prefabricated component libraries, efficient multidisciplinary collaborative design, intelligent clash detection, professional detailed design and accurate engineering quantity calculation. By integrating theoretical analysis with typical engineering case studies, this paper analyzes the core advantages of BIM applied in prefabricated building design, including shortened project cycles, enhanced design refinement and remarkable cost reduction. The research demonstrates that compared with conventional design modes, BIM can effectively address major pain points in prefabricated building design. It provides reliable technical support for improving design efficiency and engineering quality, and presents great potential for accelerating the sustainable and standardized development of prefabricated architecture in China's construction industry.

Keywords: BIM technology, prefabricated buildings, collaborative design, prefabricated component library, engineering quantity calculation.

1. Introduction

Under the requirements of industrialized construction, green, low-carbon, and environmentally friendly development in China, prefabricated buildings have become the mainstream direction for the current transformation of the construction industry due to their advantages of fast construction speed, assured quality, and environmental friendliness [1]. The first part of refined management throughout the entire lifecycle is the design phase. As the fundamental stage of refined management, design not only determines the building's form but also guides subsequent component production, construction, operation, and maintenance, making it the core of the entire refined management process. In this point of view, the traditional drawings cannot meet the construction requirements of modern industrialized buildings. Problems such as the information is fragmented, the transmission distortions happened frequently, so that the coordination problems during later construction happens, it is difficult to achieve the standard of component precision, and the problem of difficulty to fully realize the advantages of the prefabricated buildings.

The emergence of Building Information Modeling (BIM) gives a brand new way to solve the above problems. Based on visual 3D modeling and combined with a lot of information such as the information of material parameters and cost, it has the core ability like visual collaboration and parametric design, which provides the technical support for the design stage in the refined management. For the prefabricated buildings, the application of BIM has also been extended to platform construction, earthwork calculation, quantity estimation, etc. So, the design information can be pre-integrated with the production and the construction processes and achieve the transformation of design into information.

This thesis reviews the application of BIM in the design phase of prefabricated buildings, discusses the difficulties met when BIM is applied, and looks at the future development of this technology. However, with the in-depth application of BIM in the refined management of the prefabricated buildings, a number of technical problems have appeared, such as the lack of information integration.

2. Overview of BIM technology and prefabricated buildings

2.1. Principles and characteristics of BIM technology

BIM technology is a technical tool that digitally represents the physical and functional characteristics of building projects. It uses three-dimensional digital models as the carrier, parametric data as the core, and uses a collaborative sharing mechanism to integrate various information in the entire life cycle of building design, construction, and operation. The main features of this technology are reflected in the following aspects: First, BIM is three-dimensional model visualization, that is to say, it is used to convert the two-dimensional lines on the plane of the drawing into three-dimensional model. Thus, the construction model and the small structural details in the drawing can be clearly presented to the designer. This saves the time that the designer would spend on cross checking the drawing many times, while also is able to quickly find out the problems. Second, BIM has a high capacity for information integration. By making different disciplines collaborate on one model platform, the information like cost data, equipment selection, material property, is integrated. This kind of integration method does not have such problems as information silos. Once the designers completed the whole process from preliminary design to final design on this model platform, the error is reduced while also the cost is saved. In addition, BIM technology has powerful simulation and analysis functions, such as predicting the future weather conditions on the construction site, simulation the construction energy consumption, and performing the fluid dynamics simulation. This function can provide the science support for the decision in the design phase. In summary, BIM technology with the features of information integration, visualization, and simulation analysis has become an indispensable and important tool in the modern building design. Formatting author names and author affiliations.

2.2. Overview of prefabricated buildings

The prefabricated buildings refer to the structures in which some or all components are pre-manufactured in a factory and then transported to the construction site to be assembled according to a designed method. The main difference from the traditional construction is that the prefabricated buildings transfer a large amount of on-site work to the controlled factory, thus it will reduce on-site labor while ensuring the controllable quality in the production of component [2]. At the same time, the prefabricated buildings also take the key step in the energy saving and environmental protection; producing the components in factories can effectively reduce the dust, noise and wastewater emission. Under the current low-carbon emission requirement, combined with the green building material and energy efficient design, the carbon emission is reduced [3]. In addition, most of the task such as component connections can be done in the factory, which will reduce the labor cost, and reduce the high-altitude work, scaffold assemble, and welding operation which carry high risks and thus lower the risk of on site accident. This provides the migrant worker with the reliable industrial transition environment from the exposed outdoor work to the regulated factory, which is safer and healthier.

Although prefabricated buildings have so many advantages, there are still many issues and many problems. The pre-fabricated components produced in factories are various, the standards are difficult to be unified, and the large scale mass production is not often happened. Then the cost is increased inadvertently [4]. For the standardization issues with components, it is also affect the future assembly process. For example, the dimensions of connection node are not consistent, then the assembly will be failed. The waterproofing at crack junctions is also difficult, which have various safety risks. At first, the design cannot fully take into account the site condition, so most of the problems in the transportation and lifting processes often happened. The subsequent modification often occurred frequently, that prevent the full of use of the advantage of prefabricated integration. The coming of BIM can solve these issues. So, BIM is a strong tool in the design of prefabricated buildings.

3. Key applications of BIM in the design phase

3.1. Construction of standardized prefabricated component library

The refined design in prefabricated building is in the first place the standardized control of prefabricated component. The construction of prefabricated component library supported by BIM technology is not the traditional 3D modeling, it is to defined component according to the known information, to complete the information encoding, and to do the parametric design. When standardizing the components, because the different prefabricated building structural system is not general used in the design, we need to classify the component types of reasonableness according to different discipline and should select the very versatile component that abide by the principle of standardization and modularization for the library. For example, components such as the composite slab, the prefabricated stairs and the prefabricated exterior walls should be designed in the series of dimensions to set standard component family library for industrial production. In the information integration, each component must have its code as the special identification mark; then the standard information such as positioning and dimensions should be completed to make sure the accuracy before the code data can be stored in the library. The dynamic management of the component library is also very important. The design units need to make out the clear permission mechanism and the version control process. So that the operation of adding, changing or stopping the component can be traced and managed. The standardized component library not only will enhance the effect of efficiency and the quality in the design phase but also will lay a consistent data foundation for the after automatic quantity calculation, manufacturing and on the site assembly.

3.2. Integrated multi-disciplinary design based on a collaborative platform

The biggest difference between the design of prefabricated buildings and the design of traditional buildings is that the issues such as the component production and transportation have to take in advance in the design process of [5]. It means that the design cannot be done with simple "series" management, but must adopt "parallel" management, that is to say, the collaboration from many perspectives, from different disciplines, from all participants. BIM can realize the integrated standard design among different disciplines and design units on the collaborative management platform, and it makes sure the various design information can be shared and transmitted in real time in the platform. By building such a cloud based collaborative environment, units like architectural design, structural design, MEP design, prefabricated component factory, general contractor can be worked in parallel on the unified model. When the design institute has done on the architectural drawing and other design plan, the component manufacturing factory can do the product production feasibility analysis in advance based on the data received, do the simulation construction, and the MEP specialties can do the pipeline hole position when the component reservation and embedding stage. This mechanism can make the issues which normally can only be found in the construction phase to be solved in the design phase.

Clash detection also reflects collaborative design. Clash detection is one of the core applications of BIM in the design phase of the prefabricated buildings. In the traditional design, since the drawing from different discipline are independent of each other, we can hardly detect the spatial overlaps, e.g. the overlap between the ventilation duct and the structure beam [6]. These issues are only found in the on-site installation, which causes rework, demolition, project delay, and more cost. In the BIM technology, through the three-dimensional modeling, the all the models from different discipline, including architecture, structure, MEP and interior decoration are integrated into one three-dimensional model. Algorithms are used to automatically scan the spatial coordinates of all the components of the model to identify the interference between the geometry **entity and** generate the clash detection report. It can save a lot of the time which is wasted on the rework in the later construction stage.

3.3. Refined quantification of project work

Table 1. Comparison between BIM Technology with Traditional method.

In terms of comparison	BIM Technology	Traditional method
Computational Accuracy	The quantities of work are based on a three-dimensional model and calculated by computer, with errors controllable within 1%, ensuring extremely high accuracy.	Calculations based on drawings have low accuracy and are prone to errors and omissions, as well as inconsistencies in dimension annotations.
Computational Efficiency	Once the model is completed, quantities can be extracted, and when the model changes later, the quantity calculation can be updated in real time, reducing the time spent on repeated measurements.	The calculation process is time-consuming and labor-intensive, and for some large-scale engineering projects, it requires several weeks of measurement. Moreover, when there are changes in the design, the quantities cannot be updated synchronously and need to be recalculated.
Cost Control	Cost control is implemented in advance, with precise calculation of project quantities during the design phase to carry out accurate budgeting and estimation, ensuring that costs remain within the budgeted range.	Costs cannot be fully controlled during the design phase, and subsequent changes often lead to cost variations.

Due to the numerous types of components in prefabricated buildings, using traditional design methods to calculate project quantities in terms of human, material, and financial resources consumes a significant amount of cost, and accuracy is difficult to guarantee [7], making errors and omissions in calculations prone to occur, which can have a non-negligible impact on subsequent projects. After adopting BIM, the automatic quantity calculation function of BIM technology can effectively solve the above problems. BIM models contain all types and material data of prefabricated components, and with the assistance of professional software, automatic extraction and classification summary of project quantities can be achieved. Designers can directly export quantity calculation tables, such as detailed rebar schedules specifying the quantity and type of rebar, and concrete usage tables. These serve as the main data support during bidding and cost control. Moreover, BIM models not only allow for precise quantity calculations but also enable real-time updates of quantities for design changes, significantly reducing time and labor costs and overcoming the difficulty faced in traditional design methods where quantity calculations cannot be updated in a timely manner after drawing modifications. This "model-data" dynamic linkage mechanism allows the design team to quickly conduct economic and feasibility evaluations during the scheme selection phase, achieving coordinated design optimization and cost control [8]. Compared to traditional methods, the advantages of BIM are evident in multiple aspects, as shown in Table 1.

3.4. Optimized design plan

The technology of BIM, with powerful simulation and analysis, is an excellent way for design scheme optimization. For example, it is used for simulating the meteorological condition. After the model is completed, it can be imported into professional solar analysis software (such as Ecotect) [9]. Once the relevant parameters are entered, it can do calculation and make the visual solar report. According to the solar report, the doors and windows of the buildings have changed, and the living experience of the residents has improved. The energy consumption has made some achievements, for example, with the exterior maintenance component, the designer can choose and give combinations for the component of the label component library with BIM and make a standard prefabricated building component system by combination of the standard structural component, the envelope component, interior component and the equipment piping component. Set with the carbon emission

standard, carbon emission does not exceed the limit in the whole lifecycle and make the energy saving and environmental protection objective [10].

4. Conclusion

4.1. Research conclusions

Through the above review, we can see that BIM with the advantage of visual 3D modeling, multi-platform collaborative integrated design, clash detection, and energy consumption simulation, has strong technical support for the refined management of the prefabricated design phase. After use BIM, the efficiency of design phase is improved greatly, which is reflected in the detailed quantity calculation; The design accuracy is visibly increased, with data result got through rigorous algorithmic calculation controlled in the error margin of less than 1%; the design cycle is greatly shortened, by replacing manual drawing with 3D modeling, it is contribute to the refined development of the industry. In energy consumption and lighting simulation, BIM technology provides the reliable support for the design decision by the data method, it marks the sustainability performance of building imroved greatly. In summary, the application of BIM technology in the refined management of prefabricated building design phase has achieved preliminary results. Its value is not only reflected in the design optimization of specific project but also gives the new idea and methods for the development of industrialized construction. With technology maturing, BIM will play more and more important role in the field of prefabricated building, it will promote the industry to be more intelligence and efficient.

4.2. Existing challenges and future prospects

Although the application of BIM has brought many conveniences to the design of prefabricated buildings, there are still some issues in practice that should be settled. Because of the lack of uniformity in the data formats among different BIM software, information loss and format mismatches can happen for the data conversion, which will affect the accuracy of refined management. Since the rendering of relatively complex BIM models of prefabricated buildings needs support of the high performance central processing units, it indirectly brings much cost burden to the design firms. Therefore, in the future trend is going to be the integration of the technology of BIM with artificial intelligence, big data and other technologies. Not only can it expand the application boundaries of the technology of BIM, but also it can provide new solutions for intelligent design and intelligent construction. The future work can combine these two aspects, to provide more efficient, cost saving and intuitive technical support for the refined management in the design phase of the prefabricated buildings.

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