The Application of BIM Technology in Prefabricated Buildings

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Abstract. With the rapid advancement of digital technology, Building Information Modeling (BIM) has shown exceptional potential in the field of prefabricated construction. This study deeply integrates BIM technology with various stages of prefabricated building, including design, manufacturing, construction, and operation, to achieve information management throughout the entire lifecycle of construction projects. Based on an extensive literature review of the current development of BIM technology and analysis of practical cases both domestically and internationally, this research explores the application strategies of BIM in prefabricated construction. The findings indicate that using BIM technology for architectural design optimization helps ensure standardization and modularization of designs, thereby accelerating the production and construction processes of components. This paper aims to establish a lifecycle cost management model that leverages BIM to effectively control the overall budget, monitor project progress in real time, and reduce the risk of cost overruns. Promoting the standardized application of BIM technology in prefabricated construction and enhancing the modernization of the construction industry holds significant theoretical and practical value.

Keywords: Application of BIM; Prefabricated Buildings; Lifecycle Management; RFID Technology.

1. Introduction

Since the beginning of the 21st century, with the continuous deepening of construction industrialization, prefabricated buildings have become an important direction for the future development of the construction industry, attracting widespread attention from various sectors of society. According to the “13th Five-Year Plan for Prefabricated Building Action” issued by the Ministry of Housing and Urban-Rural Development, prefabricated buildings refer to buildings assembled on-site using prefabricated components [1]. The classification of these prefabricated components is illustrated in Figure 1. Prefabricated buildings are renowned for being green, efficient, and open for sharing, playing an increasingly significant role in energy conservation, emission reduction, and improving construction efficiency [2]. They are widely used in residential construction, office and commercial buildings, industrial construction, and the construction of educational and medical institutions. With continuous technological advancements and robust government support, the application scenarios for prefabricated buildings will further expand, progressing towards intelligence, informatization, and digitization [3].

Building Information Modeling (BIM) technology is a digital representation of the physical and functional characteristics of a building. Its fundamental principle is to integrate all relevant information of a construction project into a three-dimensional model, enabling the sharing and collaboration of information across the entire lifecycle, from planning and design to construction and operation [3]. As one of the core technologies in the construction field during the information age, BIM can play a crucial role in the design, manufacturing, construction, and operation of prefabricated buildings. It effectively improves project quality and efficiency and facilitates optimal allocation of costs and resources [4]. BIM technology originated in the 1970s and was initially used only in the design phase of buildings. With the advancement of computer technology and three-dimensional modeling, BIM has gradually extended to the construction and operation stages, continuously enhancing the degree of building informatization [5]. In the 21st century, BIM technology began to be widely adopted internationally. In 2002, Autodesk introduced Revit software, which supports BIM, marking a significant step towards the practical application of BIM technology[6].

In recent years, governments and enterprises across China have placed a high emphasis on the application of BIM technology in prefabricated buildings, introducing relevant policies and standards to promote the deep integration of BIM technology with prefabricated construction. For example, in 2015, the Ministry of Housing and Urban-Rural Development issued the “Guidance on Promoting the Application of Building Information Modeling”, explicitly advocating for the extensive application of BIM technology in prefabricated buildings and accelerating the establishment of BIM technology standards. This initiative marked the rapid development phase of BIM technology application in China [7]. Undoubtedly, BIM technology plays a crucial role in optimizing the construction process of prefabricated buildings. It reduces cumbersome procedures, liberates a significant amount of labor, and provides convenience and efficiency without sacrificing precision [8].

This paper is structured around the BIM lifecycle and is presented in four chapters. The first chapter provides an overview of BIM technology and prefabricated buildings. The second chapter discusses the integration of BIM technology with prefabricated construction. The third chapter analyzes BIM technology through case studies from both domestic and international examples. The fourth chapter offers a future outlook and a summary of BIM technology.

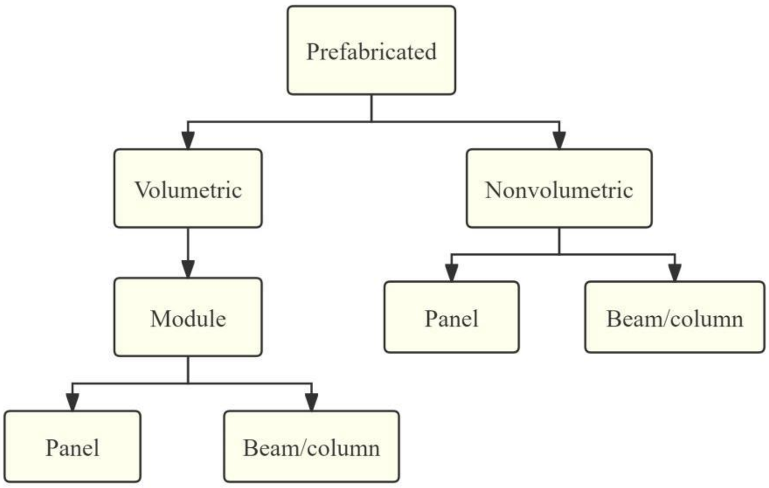

Figure 1. Classification of prefabricated construction

2. The Combination of BIM Technology and Prefabricated Buildings

As a future development trend in the construction industry, prefabricated buildings also face many challenges, with lifecycle management being the most prominent. Applying BIM technology to the lifecycle management of prefabricated buildings is highly beneficial in addressing these issues (the combination of BIM technology and prefabricated construction is illustrated in Figure 2). The following sections describe the application of BIM technology in the design, manufacturing, construction, and operation phases, highlighting the crucial role of BIM technology throughout the entire lifecycle of prefabricated buildings.

2.1. The Application of BIM Technology in the Design Phase of Prefabricated Buildings

The application of BIM technology in the design phase is extensive. It helps architectural design teams collaborate more effectively, improve design efficiency, and reduce design errors and costs. Its applications include, but are not limited to, 3D modeling and visualization, data management, model collaboration, visual analysis, and automated design [10]. Compared to traditional architectural design processes, BIM not only provides more efficient and intuitive advantages during the design phase but also offers comprehensive support for subsequent construction management and operations [11]. BIM technology integrates professional information from architectural, structural, and MEP engineering fields. Through 3D models, design clashes can be identified visually, which enhances overall efficiency and the capability for pipeline design. Additionally, it reduces construction complexity, costs, and time wastage [12].

The design team must first establish the basic requirements and standards of the project and set the design objectives. Utilizing BIM technology's real-time data processing and visualization capabilities, the design solutions can be intuitively displayed and tested to verify whether they meet the predetermined specifications and performance requirements. If the design simulation results do not meet the standards or have room for optimization, the team will initiate an iterative process to revise the design parameters.

The advantages of BIM technology highlight its applicability and necessity in the field of architectural design. The design phase is the most critical stage of a construction project, as it determines the future building structure [9][14]. BIM technology can significantly enhance knowledge management and project management capabilities, assisting reconnaissance and design units in providing consultation or participation during the construction phase, thereby expanding service areas and boundaries. This enables the integration of reconnaissance and design information throughout the entire project lifecycle [15]. BIM technology is poised to become a requisite for future modernization, promoting rapid upgrades and creating greater technical and economic value [9][16].

2.2. The Application of BIM Technology in the Manufacturing Phase of Prefabricated Buildings

Prefabricated panel production is the most critical and central step in the construction process. PC component factories utilize horizontal fully automated production lines. During this phase, the application of BIM technology significantly enhances the timeliness and accuracy of information transmission. Manufacturers can use the BIM information platform to conduct real-time analysis of product dimensions, colors, materials, and styles, allowing them to quickly formulate corresponding production plans. Additionally, the BIM information platform enables real-time feedback to owners, facilitating efficient exchange of production information. This process helps develop a more scientific construction plan at the site, ensuring smooth connections between different stages and guaranteeing the quality and successful completion of the project. BIM technology enables comprehensive control over all stages of component production and transportation [7].

The integration of BIM and radio frequency identification (RFID) can provide a powerful means for construction projects, including information such as material types, geographical locations, installation locations, etc., and embed them in different types of prefabricated components. Due to its unique coding method, RFID technology can be accurate and reliable in all aspects of production, storage, transportation and lifting. The function of BIM in the production process is not only limited to the production and management of parts, but also provides relevant information for product storage, quality control and production. The integration of BIM technology and RFID technology can improve construction efficiency, improve quality control, and improve construction safety [17]. By combining BIM's powerful data management capabilities with RFID's real-time tracking abilities, construction professionals can enhance project efficiency, improve quality control, and increase safety. In the design phase, the integration of BIM technology with VR, AI, and RFID not only boosts operational efficiency and safety but is also crucial for enhancing these aspects throughout the project's lifecycle [14][18].

2.3. The Application of BIM Technology in the Construction Phase of Prefabricated Buildings

In the construction phase, BIM technology can use three-dimensional visualization models to simulate and optimize the construction of prefabricated buildings [5]. By utilizing the detailed component information contained in the BIM model, the precise installation positions of prefabricated components can be accurately located, guiding on-site construction and ensuring the construction quality of prefabricated buildings. Additionally, BIM-based virtual construction technology can optimize site layout, reasonably plan the temporary facility arrangements on the construction site, and improve site utilization [19].

In the assembly construction phase, BIM technology provides several key application benefits. Firstly, it improves inventory and site management of prefabricated components. On actual construction sites, it can be challenging to accurately locate components or identify incorrect placements. Strict site management is essential to prevent such issues. The effective combination of BIM technology with RFID technology at this stage enables real-time tracking and monitoring. The advantages of this combination lie in the accuracy of information and the speed of transmission, reducing human errors. Secondly, BIM technology optimizes construction and cost planning through five-dimensional construction simulation to control project progress. By incorporating time and resource dimensions into the 3D-BIM model, a 5D-BIM model is formed. This allows for dynamic construction planning by simulating various resources and the entire construction process. During the simulation, existing construction plans can be optimized to avoid delays and cost increases [18][19][20].

After completing the iterative design process, the design plan enters the detailed design phase, resulting in comprehensive design drawings and the proactive planning of construction materials and equipment preparation. When the construction phase begins, the construction team uses precise 3D models and project information to accurately guide the manufacturing and transportation of prefabricated components and optimize on-site construction processes. The ultimate goal of the project is to realize the design concept through the final inspection and acceptance. BIM technology provides solid information support throughout the entire lifecycle of prefabricated buildings, from the initial visual design phase to the detailed operations during construction, and ultimately to the final project delivery. This integration covers key processes such as design simulation, optimization, detailed design, and construction [9][13].

2.4. The Application of BIM Technology in the Operation Phase of Prefabricated Buildings

As a digital tool, BIM technology can play a crucial role throughout the entire lifecycle of prefabricated buildings, especially during the operation phase where its advantages are most evident [5]. Through the BIM model, the entire lifecycle information management of prefabricated buildings can be achieved, providing comprehensive data support for subsequent operations and maintenance. The BIM model, once the project is completed, can serve as a database for property operations and maintenance, helping property managers quickly retrieve necessary information and enhancing property management efficiency [9][21].

In the operation phase, BIM technology is primarily applied in the following areas: equipment management, maintenance management, energy consumption management, space management, and safety management. Additionally, the BIM operation model facilitates construction units in maintaining and repairing building defects during the defect liability period by formulating feasible maintenance plans, thereby better serving the owners [6]. The rich data information transferred from the design and construction phases can be used to establish a new BIM operation and maintenance management model, enabling the routine management of equipment and facilities. Furthermore, the integration of BIM technology with GIS, sensors, the Internet of Things (IoT), and cloud applications allows for dynamic, intelligent, and visualized management of project operations and maintenance [5][22].

Intelligent operation is a significant application direction of BIM technology in the operational phase. Utilizing equipment parameter information within BIM models enables intelligent diagnosis and predictive maintenance of equipment. By embedding various sensors into BIM models, real-time collection of building environment and equipment operational data is achievable. When data anomalies occur, automatic alerts are triggered, generating work orders to guide maintenance personnel in prompt problem resolution, thereby avoiding escalation [23]. Simultaneously, accumulated historical operational data can be utilized to optimize building energy consumption, achieving energy savings and efficiency gains. The development of BIM technology, starting from design, manufacturing, construction, and operation phases, analyzes the actual situation of prefabricated buildings and the application of BIM technology in the entire lifecycle management of assembly buildings. It is evident that BIM has a significant impact on every stage of the lifecycle of new and ongoing construction projects, thereby brightening the prospects of assembly buildings under the integration of BIM [9][24].

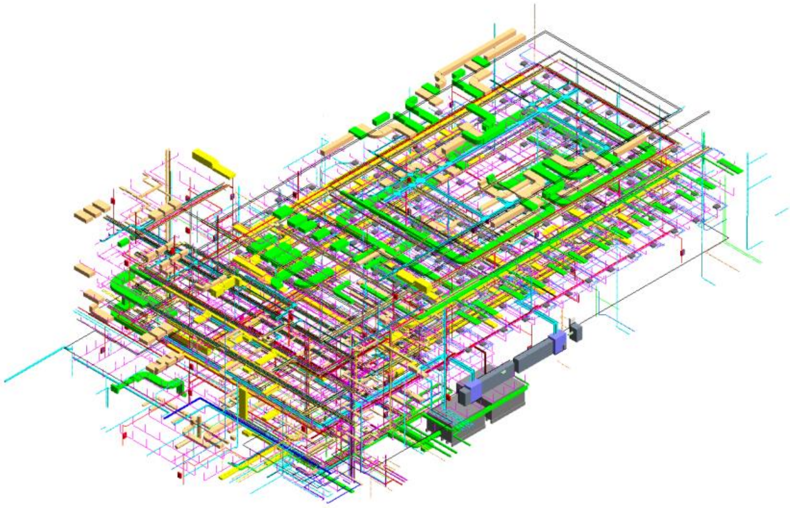

Figure 2. The combination of BIM technology and prefabricated buildings

3. Example Analysis of BIM Technology in Prefabricated Buildings

The Beijing Metro Line 16 is the first successful application of BIM technology in prefabricated subway station projects in China. This project adopted fully prefabricated construction, where various professional sections such as station hall, platform, equipment, and decoration were assembled using prefabricated components. Utilizing BIM technology for collaborative design, the installation of prefabricated components was simulated in the model, optimizing the production of prefabricated components and on-site installation schemes, thus guiding and standardizing factory prefabrication production and on-site assembly construction. Through the application of BIM technology, 138 design issues across 10 categories were avoided, including discrepancies in design drawings and problems with reserved embedment, saving approximately 1200 hours of coordination time for various professional designs [30].

During the project implementation, BIM models were utilized to analyze and simulate the assembly processes and construction procedures of typical nodes. These analyses were then converted into QR codes and posted at the construction site. Construction personnel could easily scan these QR codes with their smartphones to view the corresponding three-dimensional models and technical disclosure animations, significantly enhancing the efficiency and accuracy of prefabricated construction. Furthermore, BIM was employed for construction site layout and logistics management, facilitating rational planning of site roads, material stacking, mechanical equipment, and temporary facilities. The visual characteristics of BIM provided intuitive grounds for scientifically organizing construction, thereby enhancing on-site management precision [30].

The Metropolis apartment building project in Los Angeles, USA, adopted a highly integrated prefabricated construction solution and extensively utilized BIM technology for comprehensive process management [25]. During the design phase, a high-precision three-dimensional model was established to facilitate the detailed design and multidisciplinary collaboration of architecture, structure, mechanical, and electrical systems. The project embraced a standardized, modular design concept, with over 2000 types of prefabricated components. Through the BIM model, parametric design of components and factory production were realized, leading to a significant increase in production efficiency and quality control standards.

During the construction phase, the project team utilized the BIM model for 4D construction simulation and progress management, enabling dynamic simulation of the construction process, optimizing construction sequences, and developing detailed construction plans. Simultaneously, the BIM platform was used to track the entire process of component processing, transportation, and installation, facilitating precise positioning of components and seamless assembly. Digital technologies such as laser scanning were employed at the construction site to compare and analyze actual construction data with the BIM model, enabling timely identification and resolution of construction issues, thereby ensuring project quality [26].

The successful case of the Metropolis project demonstrates that the deep integration of BIM technology with prefabricated construction can significantly enhance project efficiency and quality, achieving digital integrated management throughout the design, production, construction, and operation phases. This novel construction approach not only shortens construction schedules and reduces costs but also ensures high-quality, sustainable building delivery. BIM technology is emerging as a crucial driving force for the transformation and upgrading of prefabricated construction, promoting the development of the construction industry towards industrialization, informatization, and intelligence [27].

4. Prospects and Conclusion

In response to the concept of green and sustainable development in China, prefabricated construction is gradually becoming a benchmark for the development of the construction industry in the 21st century. The integration of BIM technology addresses the deficiencies in collecting information and processing assembly in construction. The application of BIM technology in the lifecycle management of prefabricated buildings indicates promising prospects for the development of prefabricated construction. Within BIM technology, the combination with RFID technology can further enhance the efficiency of managing the design, production, construction, and maintenance of prefabricated buildings. Therefore, deeper research into the application of BIM technology in prefabricated construction will be our future main research direction [28].

Despite the achievements of BIM technology in the field of prefabricated construction, there are still some challenges and limitations. Firstly, the application of BIM in prefabricated construction is still in its infancy, with related standards and implementation guidelines being incomplete, and the interoperability between different software platforms and data formats needing improvement. Secondly, the accuracy and precision of BIM models directly affect their application effectiveness. Addressing production and construction requirements adequately during the design phase to construct high-quality BIM models poses a significant challenge. Additionally, the comprehensive application of BIM technology places higher demands on the knowledge and skills of practitioners, necessitating enhanced training and education to transform traditional work methods and processes. Lastly, as BIM technology continues to develop and mature, and with the widespread adoption of prefabricated construction, the integration of BIM and prefabricated construction will deepen, providing strong support for the informationization, digitalization, and intelligence development of the construction industry [9][29].

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