Intelligent Analysis and Construction Coordination of Prefabricated Building Structure Design

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Abstract: As a new construction mode, prefabricated buildings are a key path to promote the development of building industrialization, with significant advantages such as improving production efficiency, ensuring engineering quality, reducing environmental pollution, and saving labor costs. With its rapid growth, higher requirements have been put forward for the efficiency and precision of the design and construction process. In this context, the introduction of Building Information Modeling (BIM) technology provides strong technical support for the industrialization process of prefabricated buildings. BIM technology significantly enhances the overall digitalization and intelligence level of projects by achieving information integration and collaborative management in various stages such as design, production, and construction. At the same time, the application of intelligent mechanical construction equipment in the installation process of prefabricated components has further improved construction efficiency and automation, promoting the transformation and upgrading of construction methods. This article focuses on the intelligent analysis methods and multi-disciplinary collaboration mechanisms in the design of prefabricated building structures, and studies how to deeply integrate BIM technology into the entire process of structural design, thereby improving design precision and construction feasibility.

1. Introduction

In the contemporary construction industry, with the continuous advancement of technology and the increasing demand for building quality, construction efficiency, and sustainable development, prefabricated buildings, as a new type of intensive, industrialized, and intelligent construction method, are gradually becoming an important direction for the transformation and upgrading of the construction industry [1]. Compared to traditional cast-in-place concrete structures, prefabricated buildings achieve standardization, modularization, and refinement of the construction process through an integrated process of "design factory prefabrication logistics transportation on-site assembly", significantly improving construction efficiency, engineering quality, and resource utilization level [2]. Against the backdrop of the "dual carbon" goal and the construction of new urbanization, the development of prefabricated buildings has become a key path to promote high-quality development of the construction industry [3]. The design and manufacturing processes are particularly critical throughout the entire lifecycle of prefabricated buildings. Currently, the widespread application of digital technology provides strong support for the design optimization and intelligent manufacturing of prefabricated buildings [4].

By introducing advanced technologies such as BIM, parametric design, and intelligent algorithms, precise modeling of components, intelligent analysis of structural performance, and automatic output of production data can be achieved, significantly improving design efficiency and manufacturing precision [5]. At the same time, the application of intelligent manufacturing equipment in the production of prefabricated components has further promoted the process of building industrialization [6]. However, prefabricated buildings are essentially a construction model that separates design production assembly in time and space, with significant temporal and spatial spans between each stage. Changes during the design phase are difficult to timely transmit to the production and construction stages, resulting in frequent occurrences of component mismatches, installation conflicts, and project delays [7]. Despite the deepening application of BIM technology in the field of architecture in recent years, most research still focuses on basic modeling and visual display, lacking systematic exploration of multi-stage and multi-disciplinary collaboration mechanisms [8]. Existing research mostly stays at the level of data integration in depth, and although it has gradually extended to fields such as construction management and schedule simulation in breadth, research on optimization of construction site layout and visualization collaboration of assembly processes is still insufficient.

BIM technology, with its powerful 3D modeling capabilities, information integration characteristics, and multi-dimensional simulation functions, provides an effective way to solve the above problems. By constructing a parameterized model of the entire lifecycle data, BIM can not only achieve refined expression and node optimization of structural design, but also support collision detection, assembly simulation, and resource scheduling before construction, thereby improving design rationality and construction feasibility. More importantly, BIM platforms can achieve information sharing and efficient collaboration among multiple stakeholders such as design, production, and construction, breaking the "information island" and promoting the development of project management towards intelligence and integration. Based on this, this article proposes a visual design method for prefabricated building structure construction site layout based on BIM technology, aiming to scientifically plan and dynamically simulate the construction site through digital twin and 3D simulation technology, and improve the intelligence and refinement level of site management.

2. Construction Process and Application Points of Prefabricated Buildings Based on BIM

2.1 Construction Process

In the digital design and construction process of prefabricated buildings, BIM technology plays a crucial role as the core supporting means, and is a key technical guarantee for improving the integration level of building design, production, and construction [9]. In the scheme design stage, the design unit needs to communicate fully with the construction unit, clarify the functional requirements, assembly rate requirements, and technical standards of the project, and carry out preliminary scheme design based on this [10]. With the help of BIM technology, the design team can construct a three-dimensional information model of prefabricated buildings, achieving visual expression of building structure, component layout, and spatial relationships. This model not only provides a data foundation for subsequent deepening design, component splitting, and production processing, but also becomes the core information platform for collaborative work among all participating parties. To ensure high precision and efficiency in the construction process, BIM technology is integrated into the full lifecycle management of prefabricated components. During the model creation and optimization phase, designers refine the structural system based on the preliminary plan, extract and supplement standardized prefabricated component information, and construct a complete prefabricated building BIM model.

In the design process, it is also necessary to fully consider external factors such as the geographical environment, transportation conditions, infrastructure support, and power supply of the project location to ensure that the design scheme has good feasibility. In graphic layout design, the principles of regular layout and reasonable column grid should be followed to optimize the efficiency of functional space utilization and streamline organization, and enhance the practicality and humanization level of the building. During the construction phase, BIM models are used to guide the production, transportation, and on-site lifting of prefabricated components. Through precise size control and installation positioning, the compatibility and construction quality of the components are ensured. By utilizing the 4D (time) and 5D (cost) simulation functions of BIM, dynamic management of construction progress and resource scheduling can be achieved, real-time monitoring of construction status can be carried out, promoting information sharing and efficient collaboration among design, production, and construction parties, significantly improving the safety and construction efficiency of lifting operations. The construction process of prefabricated buildings based on BIM is shown in Figure 1.

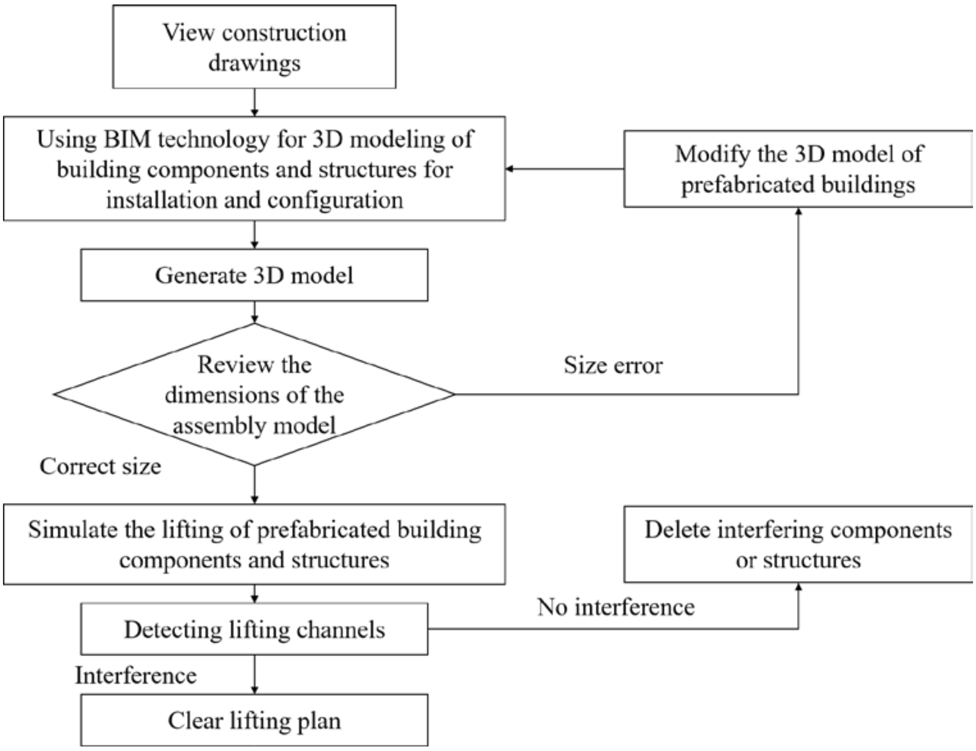

Figure 1 Construction process

2.2 Application Points

In the construction process of prefabricated buildings, the application of BIM technology has significantly improved the level of refinement and intelligence in construction management. Through BIM modeling software such as Revit, 3D visualization modeling and spatial simulation of construction sites can be carried out to achieve scientific planning and dynamic management of the construction site, optimize the layout of component stacking areas, transportation channels, and lifting equipment, effectively improve space utilization, reduce work conflicts, and ensure the orderly progress of the construction process. The BIM model constructed based on construction drawings can be used for digital pre assembly and deviation detection of prefabricated components, accurately identifying differences in size, position, and connection nodes between actual components and design models, timely discovering and correcting potential problems, thereby improving the precision and traceability of construction information. This process strengthens the data collaboration between the design model and on-site components, ensuring high consistency from design to construction and improving overall collaboration efficiency.

In addition, BIM technology plays a key role in the simulation of lifting construction. By establishing a 4D construction simulation (3D model+time), the lifting sequence, lifting angle, running path, and working space of prefabricated components can be dynamically simulated throughout the entire process. By combining the comparison and collision detection of multiple lifting schemes, BIM can detect spatial conflicts between equipment, structures, and components in advance, evaluate the feasibility and safety of each scheme, optimize construction organization design, screen the optimal lifting strategy, and significantly improve lifting efficiency and work safety. At the same time, BIM technology also supports the implementation of green building concepts. By utilizing its energy consumption analysis, sunlight simulation, ventilation evaluation, and other functions, the building envelope structure, material selection, and energy system configuration can be optimized during the design phase, reducing energy consumption and carbon emissions throughout the entire life cycle of the building, and helping the project meet green building evaluation standards.

3. Design of Visual Layout Method

3.1 Basic Framework Establishment

A visual design method for the layout of prefabricated building structures based on BIM technology has been developed, which integrates design, production, and construction into a digital collaborative work framework. The aim is to achieve efficient management and visual control of the entire construction process. The core of this method is to use BIM technology to create a 3D digital model that integrates information from multiple disciplines such as architecture, structure, equipment pipelines, etc., to achieve collaborative work among various disciplines in the design phase. Through 3D visualization techniques, potential spatial conflicts, structural defects, and installation difficulties can be identified before construction, effectively reducing design changes and on-site rework, and improving the constructability and implementation efficiency of the design. This method emphasizes the collaborative management of the entire process of "design production assembly", which includes three levels: first, the collaboration between design and production manufacturing, directly outputting component processing drawings and CNC instructions through BIM models, achieving seamless transmission of design data to the production line. The second is the coordination between design and construction assembly, using BIM for construction simulation and process optimization to ensure that the design scheme has good assembly feasibility.

The third is the collaboration between production manufacturing and construction assembly, using model information to achieve precise matching of component production schedule, transportation plan, and on-site lifting rhythm, improving overall construction organization efficiency. In the construction of fabricated steel structures, BIM technology further integrates the Internet of Things (IoT) and the network information sharing platform, integrates the component information, construction progress, quality data, etc. in the whole life cycle of the building into a unified model, and realizes the dynamic visual display of the construction site layout. Management personnel can use the model to real-time grasp key node information such as component entry status, lifting progress, and distribution of work surfaces, scientifically plan site layout, transportation routes, and mechanical equipment locations, and optimize resource allocation. In addition, robot technology is introduced in the component manufacturing process, combined with precise geometric data output by BIM, to achieve intelligent control of processes such as laser cutting and automatic welding. Through advanced robot control systems and algorithms, precise control of motion parameters is achieved, improving machining precision and production efficiency, and reducing manual errors and manufacturing costs. The basic framework of construction visualization layout based on BIM technology is shown in Figure 2.

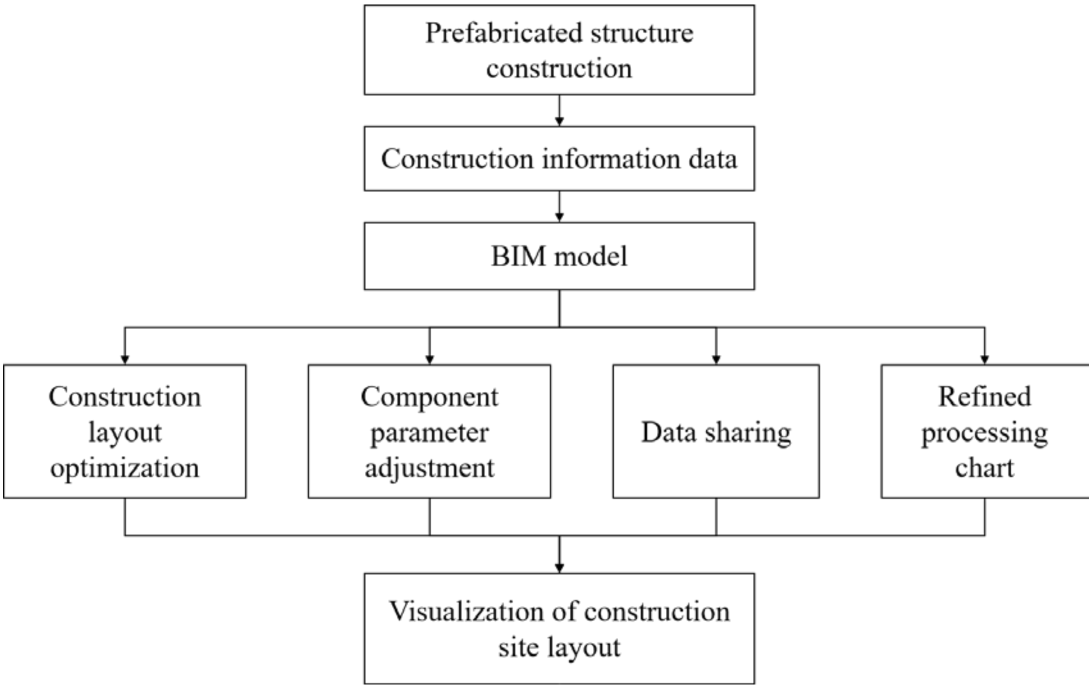

Figure 2 Basic framework

3.2 Collaborative Sharing and Visual Design

Collaborative sharing and visual design are key means to improve the efficiency and quality of prefabricated construction management. With the help of BIM technology's 3D modeling, visualization display, and dynamic roaming functions, complex construction site layouts can be transformed into intuitive virtual models, achieving immersive simulation and comprehensive presentation of prefabricated steel structure construction scenes. Through visual expression, designers can clearly grasp key elements such as component layout, construction channels, and the scope of lifting equipment operations, thereby optimizing space utilization, identifying and avoiding potential conflicts in advance, and improving the feasibility of construction plans. The introduction of digital twin technology further enhances design precision, enabling high fidelity mapping of actual design schemes to virtual environments, fully presenting the geometric features and construction details of building structures. This high-precision virtual model enables the design team to predict construction difficulties in the early stages, such as node connections, lifting path interference, etc., effectively reducing later design changes and lowering rework costs.

At the same time, combined with virtual reality (VR) technology, designers can conduct immersive simulations of component assembly, production processes, and construction techniques, carry out virtual scenario roaming, optimize material configuration, spatial organization, and component layout. Prefabricated buildings involve multiple professions and departments such as design, production, transportation, and construction, and collaborative management is crucial. A 4D construction schedule management system based on BIM combines 3D models with time dimensions (schedule plan), and integrates with project management software such as Project to achieve dynamic simulation and visual deduction of construction schedule. The construction plan can be intelligently generated and visually displayed in the form of graphics, data reports, etc., facilitating unified understanding and coordination among all participating parties. At the same time, combined with IoT monitoring devices, the system can real-time collect key parameters such as on-site temperature, displacement, stress, etc., timely warn of abnormal situations, and ensure controllable construction quality. Through the information sharing mechanism of the BIM platform, all parties involved can synchronously view the construction progress and optimization plans, jointly participate in key node decision-making, and achieve efficient collaboration across departments.

4 Conclusions

This article proposes a visualization design method for prefabricated building structure construction site layout based on BIM technology. By integrating digital twin and 3D simulation technology, it achieves scientific planning, dynamic simulation, and full process visualization management of the construction site. This method can not only optimize component stacking, transportation routes, and mechanical equipment layout, but also effectively identify spatial conflicts and organizational bottlenecks during the construction process, significantly improving the intelligence and refinement level of on-site management. Research has shown that introducing intelligent construction equipment in prefabricated building construction not only improves construction efficiency and precision, but also enhances the safety and controllability of the construction process, which is of great significance for improving the overall construction quality. With the continuous innovation of digital technology and the continuous improvement of industry standard systems, BIM, IoT, technologies such as intelligent construction will play a more profound role in prefabricated buildings. In the future, through the integration of multiple technologies and full process collaboration, it is expected to achieve higher levels of engineering quality, construction efficiency, and cost control, further promoting the industrialization process of construction and injecting strong impetus into the sustainable development of prefabricated buildings.

References

[1] Wang Xiaogang, Han Xueying, Liu Zhao, et al. Research on the Evaluation of Coordination between Prefabricated Building Design, Production, and Construction[J]. Railway Standard Design, 2023, 67 (10): 208-213.

[2] Mei Hao. Analysis of Key Points in the Design of Prefabricated Building Structures[J]. Engineering Technology Research, 2024, 9 (04): 200-202.

[3] Xu Dong, Han Hongxiang. Application analysis of digital technology in the design and construction process of prefabricated buildings[J]. China Building Metal Structures, 2025, 24 (02): 144-146.

[4] Sun Runyu, Chen Sheng, Gan Jingyang, et al. Application of BIM technology in the construction of prefabricated building structures[J]. Sichuan Building Materials, 2024, 50 (12): 142-143+146.

[5] Xu Bin, Li Jiahao, Zhang Guoxing, et al. Research on Fine Construction Management of Prefabricated Buildings under Digital Construction Technology[J]. Journal of Hebei University of Architecture and Technology, 2023, 41 (01): 163-169.

[6] Li Qingzhong. Thoughts and Applications on Digital Design and Intelligent Manufacturing of Prefabricated Buildings[J]. Development Direction of Building Materials, 2024, 22 (20): 43-45.

[7] Wang Guolin, Wu Yunlong, Gong Lizhi, et al. Research on the Application of BIM Technology in the Design Practice of a Prefabricated Energy saving Building[J]. Adhesive, 2023, 50 (02): 180-183.

[8] Ge Hongliang. The Application of BIM Technology in the Design of Prefabricated Building Structures[J]. China Building Metal Structures, 2023, 22 (07): 123-125.

[9] Hu Xiujun, Fang Lubing, Wei, Jinjin. Application analysis of BIM technology in the deepening design and construction of a high-rise prefabricated building[J]. Engineering and Construction, 2022, 36 (05): 1450-1453.

[10] Chen Guang, Ma Yunfei, Liu Jichao, et al. Thoughts and Applications on Digital Design and Intelligent Manufacturing of Prefabricated Buildings[J]. Civil and Architectural Engineering Information Technology, 2022, 14 (04): 121-127.