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BIM-driven prefabricated building components: key technologies for information integration through biomechanical innovation

Dong Yan[1,*]
[1] School of Economics and Management, Bengbu University, Bengbu, Anhui, 233000, China
Corresponding authors: (e-mail: yandong930504@163.com).

Abstract At present, the construction industry is facing the dual challenges of labor shortage and energy conservation and environmental protection needs, and prefabricated buildings, as a new form of building industrialization, have attracted much attention because of their advantages of shortening the construction period and reducing energy consumption. However, there are obvious problems in the construction of prefabricated building projects. The project involves many parties involved in design, production, construction, etc., and the amount of information generated is huge and complex. In addition, there is a lack of uniform standards for information at all stages, from design to construction. For example, when the information of design drawings is transmitted to the component production link, misunderstandings often occur due to differences in expression forms, resulting in inconsistency between component production and design; During construction, it is also difficult to match the on-site progress and component supply information, resulting in construction stagnation or component backlog, forming information faults and islands, and seriously restricting the development speed of prefabricated buildings. Solving the problem of information sharing and transmission has become the key to promoting the development of prefabricated buildings. BIM technology provides a solution with the advantages of systematic and efficient information integration management. It integrates the whole life cycle information of the building with a 3D digital model, accurately reflects the information of prefabricated components from the design stage, helps manufacturers to produce accurately, and helps construction personnel clarify the installation process and avoid construction conflicts during the construction stage. The "14th Five-Year Plan" for the development of the construction industry clearly requires enterprises to build a BIM cloud service platform to realize the cloud transmission and sharing of BIM data, and promote the seamless connection of design, production and construction. Designers can update their plans in real time in the cloud, and all parties can access information in a timely manner. Therefore, it is of great significance to explore the use of BIM and Internet technology to realize the integrated management of prefabricated building component information, which can assist decision-making, improve efficiency, and provide reference for the industry, so as to effectively promote the development of prefabricated buildings and the sustainable progress of the construction industry.

Index Terms prefabricated building components, BIM, Information integration

I. Introduction

In the development process of the construction industry, policy guidance plays a crucial role. In 2016, the "Guiding Opinions on Vigorously Developing Prefabricated Buildings" promulgated by the State Council is like a beacon, pointing out the direction for the development of prefabricated buildings. The opinion designates the three major urban agglomerations of Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta as key promotion areas. For cities with a permanent population of more than 3 million, it is clearly required to actively participate in the development of prefabricated buildings; Other cities need to be flexible and encourage the development of various types of buildings, while vigorously promoting the development of prefabricated concrete structures, steel structures and modern wood structures. Its ambitious goal is to increase the proportion of prefabricated buildings in new buildings to more than 30% in the next ten years, which undoubtedly injects a strong impetus into the development of prefabricated buildings.

With the passage of time, prefabricated buildings have achieved remarkable results under the promotion of policies. In 2020, the "13th Five-Year Plan" for Prefabricated Buildings issued by the Ministry of Housing and Urban-Rural Development showed remarkable results. At that time, 31 provinces, autonomous regions, municipalities directly under the central government and the Xinjiang Production and Construction Corps started construction of

630 million square meters of prefabricated construction area, an increase of 50% compared with 2019, and the proportion of the total area of new buildings jumped to 20.5%, successfully exceeding the target of more than 15% stipulated in the "13th Five-Year Plan", demonstrating the vigorous development of prefabricated buildings [1]. In January 2022, the Ministry of Housing and Urban-Rural Development announced the "14th Five-Year Plan" for the development of the construction industry, which opened a new chapter in the development of the construction industry. The plan highlights the importance and urgency of standardization and digitalization in the construction and engineering industry. In terms of standardization, we are committed to improving the unified standards for modulus coordination and component selection, building a complete library of parts and components, implementing standardized management of building planes, facades, parts and components, interfaces, etc., and actively promoting the design mode of less specifications and more combinations, so as to achieve the harmony and unity of standardization and diversification, so as to comprehensively improve the overall level of the construction industry.

In the field of digitalization, BIM technology is a central focus. In order to realize the all-round high-quality application of BIM technology, on the one hand, it is necessary to increase efforts to improve the data exchange operation mechanism and formulate strict safety standards and standards; On the other hand, strengthen the digital collaboration and cooperation of design, manufacturing, construction and other links to ensure that the digital achievements of the whole process of engineering construction can be transmitted and used in a timely and effective manner. In order to achieve the rapid promotion and application of BIM technology, it is necessary to accelerate the construction of the BIM standard system, formulate unified standards covering data interfaces, various information exchanges, etc., and promote the deep integration of BIM technology with production management systems, engineering management information systems and construction industry Internet platforms, so as to form a closer and more efficient linkage system and lay a solid foundation for the digital transformation and high-quality development of the construction industry.

II. BIM related theories

BIM technology is a technology proposed by Chuck Estma that can optimize the structure and function of buildings for visual description [2]. In his BIM manual, he elaborates on the extraordinary features of BIM: it automatically updates all drawings in a single operation and automatically maintains a consistent layout of all elements. Not only that, BIM also builds a complete and unified database to provide strong support for visual analysis and quantitative analysis. With the passage of time and the iteration of technology, the application of BIM technology has become more and more extensive, its concept has been deepened, and the scope of application has also continued to expand. Through BIM technology, the digital collaboration of the design, construction, and operation processes of prefabricated buildings can be realized [3].

As early as 1986, Roben Aish published an article on the use of BIM technology in a number of key areas, including 3D modeling, automatic terrain mapping, database building, and real-time forecasting of construction progress. This article is like a guiding star, guiding the direction for the further development of BIM technology in these fields in the future.

The Institution of Surveyors has a unique definition of BIM as a new way of working. Essentially, BIM is a digital engineering technology that acts as a bridge to enable architects and other stakeholders to collaborate throughout the lifecycle of a facility. With the help of BIM technology, it is possible to improve the operational efficiency and safety of buildings.

Further, BIM is based on open industry standards to transform various information such as the physical characteristics, functional settings, structural structure, installation details, and operation status of facilities into intuitive and visual data. During the decision-making phase of a project, this visual data plays a huge role in making the decision-making process more accurate and reliable, and thus maximizing the value of the project.

From the early days as a simple modeling tool, BIM software has undergone continuous innovation and has evolved into a comprehensive software with highly integrated functions, and its functions have been expanded to many aspects such as scheme design, model detection, collision detection, and visual presentation. These new features are widely used in all aspects of the construction project and are constantly being optimized and upgraded as technology advances.

The core modeling software forms the cornerstone of the BIM concept. They support the achievement of project objectives and can be adapted to the unique needs of different phases of the project. In the field of civil construction, the Autodesk Revit series of software has become the first choice due to its excellent performance, and is widely used in the design and construction of various civil construction projects. In areas such as municipal engineering, the Bentley family of software dominates with its professional adaptability to meet the complex and diverse needs of municipal projects.

During the decision-making phase of a project, BIM software such as Autodesk Design Review and Onuma Planning System come into play. By providing comprehensive and intuitive data display and analysis, they help decision-makers make accurate and scientific judgments at the beginning of the project, laying a solid foundation for the subsequent design and implementation of BIM solutions.

When it comes to the design phase, different types of BIM software have their own roles to play. Functional design software such as Solibri Model Checker focuses on model checking to ensure the accuracy and compliance of models. Autodesk Navisworks focuses on clash detection to identify and resolve possible conflicts in the design in advance. Professional design software such as PKPM and ETABS assume the important task of structural design and provide guarantee for the stability of the building structure; Software such as OesignM ASTE brings its expertise to the field of M&E design to the careful planning of a building's M&E systems. The application of BIM technology in the construction of prefabricated buildings has many values, including optimizing design, controlling costs, improving efficiency, saving manpower, and optimizing management [4].

When the project enters the operation and maintenance phase, software such as Archibus and Navisworks are also indispensable. They help managers to efficiently manage the operation and maintenance of building facilities, identify and deal with potential problems in a timely manner, and ensure the stable operation of the building throughout its life cycle.

III. Information integration management

Integrated management focuses on the skillful integration of two or more system components, striving to achieve the optimal state of system function, and at the same time bringing together the various scattered parts of the project into a closely connected and organically unified whole. Integration naturally has the remarkable characteristics of aggregation, aggregation and synthesis. At every stage of the project, the benefits can be maximized with the power of integration. Moreover, thanks to the different phases and the complementarity of the various parties involved, the overall objectives of the project were achieved smoothly and efficiently.

The core goal of integrated management is to create a complete and sophisticated system. Not only does this system make the elements more connected and collaborative, but it also maximizes the overall effectiveness of the project. It is systematic, complex, collaborative and innovative. In the face of changing project needs, integrated management can scientifically organize and efficiently manage projects through the deep integration of integrated thinking and practical operation, thereby significantly improving the operational efficiency of projects. Practice shows that optimizing the enterprise management mode has a very significant role in promoting the improvement of work efficiency.

From the theoretical perspective, integrated management covers a number of key levels, including the overall control of the project, the fine sorting of the process, the coordination of various components, and the efficient flow of information. Based on the functions played by integration, it can be further subdivided into three levels: target integration, process integration and information integration, which are explained as follows:

Target integration aims to build a comprehensive and perfect target system with the help of advanced technology. In this system, many key factors such as project schedule, cost input, and quality assurance can be fully considered, and work together in an organic way to achieve optimal management results. In this way, the objectives of all aspects of the project can be interrelated and mutually reinforcing, and jointly serve the achievement of the overall goal of the project.

Process integration, the use of integrated integration technology, can effectively overcome the common problems of process intersection and overlapping work in construction projects. In this way, all aspects of project planning, design conception, construction, operation and maintenance can be efficiently and collaboratively managed. Tighter connection between phases and smoother information transfer avoids wasted resources and time delays due to poor processes, ensuring that the project can stay on track as planned.

Information integration is a crucial task. The information involved in construction projects is huge, diverse and comes from a wide range of sources. In order to achieve effective control of this information, it is necessary to fully integrate it into the whole life cycle management of the project, and build an efficient communication and exchange mechanism between all parties involved in the project and between the project and the external environment. In this way, all kinds of information in the project can be transmitted and shared in a timely and accurate manner, providing strong support for project decision-making and ensuring the smooth development of the project in a smooth information environment.

The core essence of BIM is to build an intuitive visualization system based on digital models at the initial stage of design. In this system, multi-dimensional information such as the shape, location, quantity details and various attributes of the building can be organically gathered and integrated. At the same time, the concept of integrated management of information resources also plays a key role in various fields. With the help of advanced computer technology and network technology, it integrates all kinds of information resources, information technology and user groups involved in the process of information resource management, so as to enhance the competitiveness and adaptability of information, and the concept has been widely used in enterprises and various organizations.

In-depth exploration will find that there is an inextricable and extremely close theoretical connection between BIM and information integration management, which is mainly reflected in the following key aspects:

First, BIM can be regarded as a concrete practice path for information integration management. Information integration management is abstract in nature, and BIM, as an important information management tool in the construction field, can undertake core tasks such as information integration and coordination excellently. Therefore, from a practical point of view, BIM is undoubtedly one of the specific forms of information integration management.

Second, BIM has a strong ability to integrate information, which can bring together all kinds of information in the construction industry in an orderly manner. Before the concept of BIM, it was difficult to manage the massive amount of data in the construction industry. Today, BIM has successfully achieved the organic integration of this information with a digital model that integrates building, structural, electromechanical and other information. Similarly, in the field of information integration management, in order to achieve better information management results, it is also necessary to effectively integrate various forms of information, and there is a high degree of consistency between the two.

Third, both BIM and information integration management regard information sharing and collaboration as key points. In practical application, whether it is the use of BIM or the implementation of information integration management, theoretically it is focused on the circulation and sharing of data and collaborative operation. In the BIM environment, the various participants of the project can easily obtain information about specific building objects, so as to realize the integration and collaboration of different dimensions of information. Information integration management promotes the sharing and collaboration of information between different systems through visualization, so as to improve the operational performance within the enterprise.

Fourth, the effective implementation of BIM and information integration management is highly dependent on technical support. The construction of BIM system and the management of information integration are inseparable from the strong support of computer technology and network technology. BIM, for example, requires the digitization of building information with the help of professional design software such as CAD. Information integration management needs to rely on ERP, CRM and other application software to achieve efficient management and in-depth analysis of information.

IV. Component data source analysis

Through the research and analysis of prefabricated building prefabricated components, on the basis of a full understanding of the building structure design specifications, the parametric design of shear wall walls, edge members, laminated plates and superimposed beams common in practical engineering is carried out. According to the geometric characteristics of the component, the corresponding parametric model is established, and the coordinate position of the geometric shape is designed, so as to determine the positioning point of the model [5]. In the process of information integration of prefabricated building components, clarifying the information content to be integrated is the primary key to opening the door to success. In view of the clear phased characteristics of prefabricated building construction, we can accurately divide the data source of component information into four stages: design, production, transportation and construction. Combined with the ideas and principles of classification and coding design of prefabricated building prefabricated components, the coding needs to meet the requirements of automatic classification of components, high flexibility, and the ability to meet the requirements of the whole industry chain (design, production, transportation, warehousing, construction, operation and maintenance, etc.) [6].

The design phase is where the information about the prefabricated building components originates, and the information produced at this stage is extremely rich and diverse. It covers the details of the component project, such as the unique name of the component, the unique code, the person responsible for the design, and the specific time when the design was carried out, which is like the identity label of the component, which provides an indispensable basic support for the smooth progress of the subsequent process. The length, width, height of the component, the volume size, the cross-sectional area and the perimeter and other accurate dimensional specifications are also crucial, which play a decisive role in the adaptation of the component to other components in the actual installation, as well as whether the overall building structure can be accurately built. According to the size and shape of the façade of the project, the size of the hanging board was preliminarily designed

, and the façade where the hanging board was located was preliminarily divided according to the design, production, and construction conditions, and the relevant information of the materials was also determined in detail at this stage [7]., involving the material used in the component, such as the strength grade of concrete, the amount of material, the proportion of steel bar, the use of additives, the durability and corrosion resistance of the material, the setting of the external insulation layer, the details of the embedded material, as well as the volume, quantity and weight of the component, etc., this information is directly related to the quality and performance of the component. In addition, mechanical properties such as compressive strength, expansion coefficient and flexural strength are also clarified in the design stage, which determine the specific performance of the component under different stress conditions. The various data sources generated in the above-mentioned design stage together form the cornerstone of component information integration, and can be accurately extracted with the help of BIM modeling software, and then imported into the component information integration platform, providing key support for the subsequent component production and collaborative operation of each link.

The core task of the production stage is to transform the component information in the design stage into real products, so as to achieve digital production and collaborative optimization of information. At this stage, multiple layers of information are generated. Production plan arrangement information such as production batch planning, component production quantity and specific production time, reasonable production plan can ensure that the production work is carried out in an orderly manner and avoid chaos and waste of resources. The material name, specification model, unit, quantity, and material supplier or source and other material list details are an important basis for the preparation of production resources, which can ensure the timely and sufficient supply of materials required for production. Detailed process records such as the time nodes, processes, operators, and machinery and equipment used in the production process help to trace the production process, so as to optimize the production process and improve production efficiency and product quality. The inspection results, testing time and quality control records of inspectors for each component strictly ensure that the product quality meets the standards. Warehouse management information such as the storage location, quantity and current status of components in the warehouse is convenient for efficient allocation of component resources and improvement of construction efficiency. Cost accounting information such as production cost, labor cost, and material cost provides data support for cost control and helps enterprises reasonably control costs. Equipment maintenance records such as maintenance time, maintenance personnel, and maintenance content of production equipment ensure the stable operation of production equipment and reduce production stagnation caused by equipment failure. Production personnel can manually enter this information and upload it to the component information integration platform, which provides an important reference for the subsequent transportation and construction of components.

The data source is a key component of component information integration, which is responsible for transporting components from the production site to the construction site safely and on time. This includes the transportation route planning, transportation time arrangement and transportation mode selection of the components, and other transportation plan details, and a reasonable transportation plan is the key to ensure the safe and on-time delivery of the components. The type, quantity, and real-time location of transport vehicles are helpful for transportation scheduling and management, and improve transportation efficiency. The name, job number, position and other information of the transport personnel are convenient for clarifying responsibilities and implementing management. The transportation monitoring information obtained through GPS positioning, camera monitoring and other means realizes the real-time control of the transportation process of components. With the help of advanced technologies such as GPS positioning and RFID, the component transportation process can be monitored in real time, and the data can be imported into the component information integration platform to achieve digital management and collaboration.

During the construction phase, it is necessary to integrate all kinds of construction information and data into the BIM model to achieve effective management and monitoring of construction progress, quality and safety. Construction record data such as construction process logs, quality checklists, materials and equipment entry registration, and employment record information comprehensively and truly reflect the construction process. Construction personnel management data such as construction personnel's working hours, work areas, and construction progress can help managers accurately control the construction progress and quality. Construction equipment management data such as the location, use time, and maintenance records of a large number of equipment such as cranes and elevators required for construction ensure the rational use and maintenance of equipment and ensure the smooth progress of construction work.

V. Key technologies for the integration of prefabricated building components driven by BIM

In the process of information integration of prefabricated building components, key technologies based on BIM play a vital role, covering multiple core fields such as data storage, BIM model information extraction, and web-based model visualization.

Data storage is the foundation of information integration. According to the classification of prefabricated component information, the data can be divided into structured and unstructured data, and different storage strategies are required. Structured data is stored in MySQL because of its standardized format and clear logic. When building the database, a component table, a design information table, a production information table, a transportation information table, and a construction information table are created to store the specific information of the component at different stages, and each table uses the component code as the primary key to ensure the consistency and relevance of the data. Unstructured data, such as documents and images, is stored in MongoDB, a NoSQL database, due to its flexible format and irregular structure. MongoDB's document-based storage method, combined with the GridFS mechanism, can efficiently process large-size unstructured data, such as videos and images, and provides strong support for the management of unstructured data. In addition, in order to solve the problem that it is difficult for the platform to cover all the information fields, two methods of dynamic expansion fields and EAV mode are proposed. Dynamically Extended FieldsBy setting extensible fields in the data table, users are allowed to customize and fill in information, and dynamically parse JSON data during queries. The EAV mode stores entities, attributes, and values in different tables, effectively solving the problems of unstable data structure and uncertain number of attributes, and greatly enhancing the flexibility and scalability of the database.

BIM component model information extraction is a key step to achieve information integration. At present, all kinds of BIM software are blooming everywhere in domestic BIM applications, but from the perspective of design, the most widely used in the industry should be Autodesk's Revit series software [8]. Revit modeling software has become an important tool for BIM model construction due to its advantages of parameterization and visualization, and its element structure is composed of model elements, visual elements and other auxiliary elements (Figure 1 and Table 1). In order to realize the 3D model reconstruction, information association and interactive operation on the web side, it is necessary to extract key information such as category, geometry, material, appearance and floor. Using Visual Studio and Revit as the development environment, using the C# programming language for secondary development, and creating data extraction plug-ins. Due to the large number of commercial promotion of Autodesk, and CAD as the only standard in China's construction industry, it has also accelerated the promotion of Revit software to become the most widely used BIM design software in the domestic construction industry. The information can be extracted from the 3D model and stored as an XML file, laying the foundation for subsequent display on the web [9].

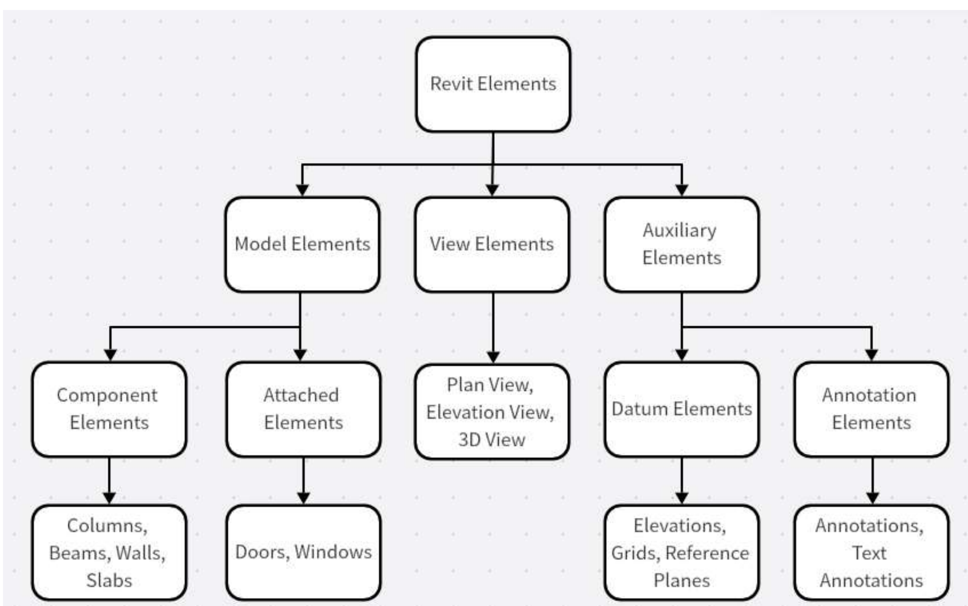

Figure 1: Revit modeling software

Table 1: Extract information of Revit modeling software

serial number	Extract information	Details:
1	Category Information	Structure, component name, component ID, and so on
2	Geometry information	Length, width, volume, vertex coordinate values, and so on
3	Material information	Material Name, Material ID, Material Category, Transparency, and so on
4	Appearance information	Appearance name, appearance ID, bump, and so on

The visualization of the web-based model is an important means to improve the user experience of the information integration platform (Figure 2). WebGL technology, as the core technology to achieve high-performance and high-fidelity data visualization on the web side, can transmit 3D images to the browser through hardware acceleration without the need for users to install additional software. It has a variety of features, including the use of the GLSL shading language to acquire vertex and color data, and the generation of graphics in web pages < canvas > canvases, which are supported by all major browsers. When displaying the BIM 3D model on the web side, the XML format file extracted from Revit is first converted into a JavaScript object, and then the component model is created and rendered in the scene using a WebGL framework (such as Three.js), and finally the BIM model is displayed in 3D on the web side, so that users can intuitively view the model information.

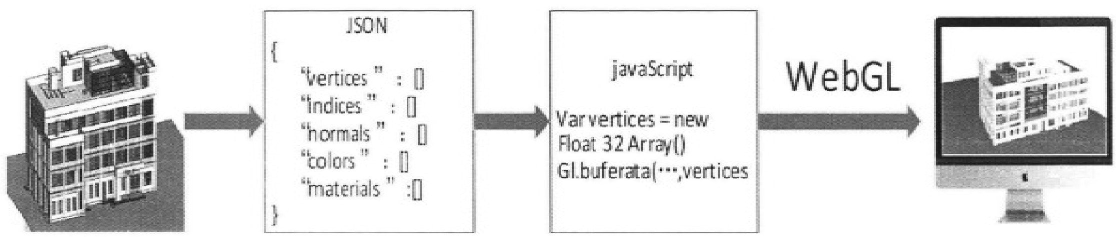

Figure 2: The visualization of the web-based model

VI. Design and application of BIM-driven prefabricated building component information integration platform

Design and application of BIM-based prefabricated building component information integration platform

Under the trend of vigorous development of the prefabricated building industry, it is very important to build an efficient and comprehensive component information integration platform to improve the efficiency of project management and promote the coordinated development of the industry. This chapter focuses on the BIM-based prefabricated building component information integration platform, from coding system design, system architecture and module planning, user authority setting, to actual case analysis and application effect evaluation, and conducts all-round and in-depth research and discussion. A cloud-based BIM-based information integration system for prefabricated building prefabricated components was designed to meet the information needs of prefabricated building users for prefabricated components and ensure the quality of prefabricated buildings [10].

As the key foundation of the information integration platform, the coding system plays a decisive role in the efficient management of component information. Its design needs to follow a series of important principles: the principle of uniformity ensures that the component coding conforms to the relevant national standards and specifications, and ensures the consistency of the coding meaning in different construction projects; The principle of simplicity requires that the code be concise, easy to remember and operate, and usually use a combination of numbers and letters to shorten the length of the number; The principle of functional practicability emphasizes that coding has the ability to quickly query, locate and track component information in the information system, so as to improve the efficiency of construction project management; The principle of scalability enables the coding to encode new components according to certain rules, which facilitates the upgrade and maintenance of the system.

Internationally, the omniClass standard is an important reference for the classification and coding of building information. It was jointly developed by the American Building Standards Institute (CSI) and the Canadian Building Standards Institute (CSC), and refers to the ISO12006.2 classification standard system, through 15 classification tables to accurately classify and describe building information, each data item has an independent and clear numbering scheme. In China, the Zhejiang Provincial Department of Housing and Urban-Rural Development has issued the "Coding Standard for Prefabricated Building Structural Components" in order to standardize the coding of prefabricated building structural components, which stipulates that the coding is composed of eight parts, including category code, project code and building number code. In this study, the coding system of prefabricated building prefabricated components suitable for the platform was carefully designed by fully combining the classification characteristics of prefabricated components and the actual functional requirements of the platform, and referring to the above-mentioned domestic and foreign standards.

There are many types of prefabricated components, such as prefabricated concrete frame structures, which mainly include prefabricated columns, beams, slabs, walls, stairs, and balconies [11]. The overall design of the coding adopts a flexible code structure with high flexibility, and the coding of a single component is composed of rigid code segments, flexible code segments and serial code segments. The rigid code segment includes the building number, the floor number and the component classification number, in which the building number and the floor number are encoded with two digits, and if there are less than two digits, "0" is added in front. The component classification number is indicated in capital letters, as shown in the following Table 2~ Table 3:

Table 2: Reference of the omniClass standard

Component classification	**post**	**beam**	**board**	**wall**	**staircase**	**balcony**
encode	With	L	B	Q	T	And

Table 3: A flexible code structure with high flexibility

The name of the widget	**encode**
Prefabricated columns	01
Prestressed superimposed beams	02
Ordinary superimposed beams	03
Prestressed laminated plates	04
Ordinary laminated board	05
Reinforced truss laminated plates	06
Prefabricated non-load-bearing façade panels	07
Prefabricated façade cladding	08
Prefabricated non-load-bearing interior wall panels	09
Prefabricated integrated wall panels for doors and windows	10
Prefabricated slab staircase	11
Precast beam staircase	12
Fully prefabricated prefabricated balconies	13
Prefabricated balcony slabs	14

The overall coding rules stipulate that the standardized coding of BIM components of prefabricated timber buildings is determined by the "component type code" [12], and the flow code segment is used to distinguish different individuals of the same type of component. For example, the code "07 - 11.B - 01 - 06" clearly indicates the 6th prestressed laminated plate on the 11th floor of Building 7, accurately and intuitively identifying the specific information of the components.

The prefabricated building component information integration platform adopts the advanced Browser/Server (B/S) network application architecture, and users can easily access the platform through the browser. The architecture consists of a data layer, a service layer, an application layer, and a user layer.

The data layer is responsible for the storage and management of data, integrating storage components such as databases and file systems. Based on the Revit API, the material statistics function is provided, and the scope of engineering quantity statistics is selected by the program by default and cannot be dynamically changed [13]. Among them, the database is used to store the structured and unstructured data of the components, the structured data is stored in the MySQL database, and the unstructured data is managed by the MongoDB database to ensure the security, stability and efficiency of the data storage. As the core hub of information processing and distribution, the service layer includes data services, business services, and interface services. The data service realizes the access and query functions of component information; Business services are responsible for connecting different business processes and interacting with the application layer through interfaces. The interface service provides data interfaces for design management systems, production management systems, transportation management systems, and construction management systems, facilitating the smooth flow and sharing of data. In the actual inspection, in addition to monitoring the geometric dimensions of the components, the appearance defects of the components are detected, and when the components do not meet the standard specifications, the positioning management of the component numbers is carried out in the BIM 3D model [14].

The application layer displays the functional modules of the platform in a centralized manner, covering data collection, processing, sharing, and system management. The data acquisition module supports a variety of data collection methods such as table import and sensor reading to ensure the integrity and accuracy of the data. The data processing module standardizes the collected data according to the data dictionary, and adopts manual processing for abnormal data to improve the data quality. The data sharing module provides a unified information sharing environment for all participants in the project; The system administration module is responsible for managing user and role information. The user layer clarifies the users of the platform, including designers, producers, transporters, builders and owners, to meet the diverse needs of different users.

The functional modules of the platform are closely built around the actual needs of all participants in the project, mainly including four modules: data collection, processing, sharing and system management. The data acquisition module is responsible for comprehensively collecting data at all stages in the construction process of prefabricated buildings, supporting multiple methods such as table import and sensor reading to ensure the integrity and accuracy of data. The data processing module standardizes the collected data according to the data dictionary, and adopts manual processing for abnormal data that does not conform to the format specified in the data dictionary to effectively improve the data quality. The data sharing module provides a unified information sharing environment for all participants in the project, which is convenient for all parties to view the model information and attribute information of components, break down information barriers, and promote collaborative work. The system management module is responsible for managing user and role information, realizing user classification and hierarchical management and role authorization, and ensuring the security and reliability of the system. In the construction preparation stage, BIM technology is used to simulate the construction of on-site components, as well as on-site resource and process planning. BIM technology was used to simulate the lifting and crane parts and placement range of prefabricated components, so as to discover and improve the problems that are likely to occur in the construction process in advance, and effectively optimize the process [15].

In order to ensure the security of the system and the confidentiality of data, the platform adopts a role-based permission control mechanism. According to the different roles of users in the project, users are divided into design roles, production roles, transportation roles, construction roles, and system administrator roles (Table 4).

Table 4: A role-based permission control mechanism

user roles	Permission description
Design the character	Upload information such as design drawings and component parameters, view and modify your own uploaded data, view the data uploaded by production, transportation, and construction parties, and related statistics
Production roles	Upload information such as component production plan, materials required for production and processing, quality inspection report and finished product acceptance report, view and modify the uploaded data, view the data uploaded by the design, transportation and construction parties, and related statistical information
Transportation roles	Upload information such as transportation plans, component loading information, and delivery acceptance records, view and modify the data uploaded by yourself, and view the data uploaded by the design, production, and construction parties, as well as related statistics
Construction roles	Upload information such as construction progress reports, on-site safety supervision records, and construction quality inspection reports, view and modify your own uploaded data, and view data uploaded by design, production, and transportation parties, as well as related statistical information
System administrator	Edit users on the platform and assign user permissions to manage

The prefabricated building component information integration platform adopts the network application architecture based on Browser/Server (referred to as B/S). The server uses the Web Server to process structured and unstructured data to achieve data interaction. The specific tiers are as Table 5.

Table 5: Network application architecture

Level	Specifics
User layer	Designer, producer, transporter, constructor, owner
Application layer	Data acquisition, data processing, data sharing, system management
Service layer	Data services, business services, and interface services
Data layer	Structured data, unstructured data

The first phase of a rental housing project is located in Nanjing High-tech Biomedical Valley R&D Zone, with a total investment of about 1.3 billion yuan, and the planned land is a single employee apartment land, with a total construction area of 1000.02 square meters. The project includes 4 18-storey policy-based rental buildings and other supporting buildings, with a prefabricated building ratio of 100% and a single prefabricated assembly rate of ⩾50%, which puts forward higher requirements for component information management.

Project information filling is the basic link of the platform to realize project information management. Users fill in the relevant information of the project in detail on the platform, such as the construction unit, production unit, construction area, etc., to realize the sharing of project information, provide decision-making basis for all participants in the project, and ensure the smooth progress of the project.

After the user clicks on the model to view the function, the platform uses WebGL technology, Three.js graphics engine and JavaScript language to parse the JSON model file, obtain the model parameters and render them, and realize the three-dimensional display of the web-based model. Users can intuitively view the location, shape and other information of components, providing strong support for construction and management decisions.

The data acquisition function supports the import of data from other management system platforms. Users only need to download the Excel template, fill in the content according to the prescribed format, and then import the completed Excel sheet to the platform. Taking the collection of production plan information as an example, users fill in the relevant information in the downloaded template and upload it to the platform to ensure accurate data entry and improve the efficiency and accuracy of data collection.

The platform's BIM technology is used to simulate the hoisting, positioning and joining of prefabricated building components. In the simulated hoisting process, the influence of different lifting point positions and hoisting angles and other parameters on the force of the components was analyzed. For example, when the position of the lifting point deviates from the center of gravity of the component, it will cause the component to be stressed unevenly during the hoisting process, increasing the risk of component damage; And the inappropriate hoisting angle may make the component produce excessive bending moment and shear force in the process of lifting and in place, and affect the structural safety of the component. Through simulation, the position of the lifting point and the lifting angle can be optimized in advance to ensure the safety and stability of the lifting process.

In the process of simulating the positioning and connection, the platform can show the precise docking and connection effect between the components, help the construction personnel to familiarize themselves with the construction process in advance, find possible problems, such as the size deviation of the connection part, the mismatch of the bolt holes, etc., and make timely adjustments to improve the construction efficiency and quality.

In the prefabricated building project, with the help of the BIM technology of the BIM-based prefabricated building component information integration platform, the hoisting, positioning and connection process of the components are simulated, which provides important support and guarantee for the project construction.

Taking a large-scale prefabricated residential community project as an example, the platform's BIM technology plays a key role in simulating the hoisting process. The precast concrete columns used in the project, 6 meters long and weighing about 8 tons, are designed to support the main structure of the building. In traditional construction, determining the position of the lifting point and the hoisting angle often depends on the experience of the construction personnel, which has certain risks. Through the BIM simulation function of the platform, the construction team can accurately input parameters such as different lifting point positions and hoisting angles, and intuitively analyze their influence on the force of the components.

When the position of the lifting point deviates from the center of gravity of the component, the consequences are very obvious. For example, the lifting point is set 2 meters away from one end of the component (0.5 meters away from the center of gravity) for simulated lifting. In the simulated scene, it can be clearly seen that the component has an obvious sinking trend at the end away from the lifting point at the moment of lifting. From the analysis of mechanical principles, this is because the center of gravity does not coincide with the lifting point, so that the component is unevenly stressed during the hoisting process. This uneven force can lead to additional stresses inside the component, increasing the risk of damage to the component. Just like when picking up the flat burden, if the weight of the weight at both ends of the flat arm is inconsistent and deviates from the shoulder position, the flat arm is easy to break due to uneven force, and the precast concrete column may also crack or even break in this case, which seriously affects the quality of the component and the safety of construction.

An unsuitable hoisting angle can also have a detrimental effect on the component. When the hoisting angle is set to 30° to the horizontal direction (the normal recommended angle is 45° - 60°) for simulation, the member generates large bending moments and shear forces during lifting and positioning. It is clear from the stress contour diagram simulated by BIM that some parts of the component are significantly concentrated and the color is dark red, indicating that these areas are subjected to high stresses. Excessive bending moment and shear force will threaten the structural safety of the component, and in this state of stress for a long time, the component may have problems such as deformation and damage to the internal reinforcement, reducing the overall stability of the building.

Through the simulation of BIM technology, the construction team can optimize the position of the lifting point and the lifting angle in advance. After several simulations of the precast concrete columns, it was finally determined that the lifting point was set at a distance of 2.5 meters from both ends (i.e., the center of gravity position), and the lifting angle was adjusted to 45°. Such parameter setting makes the component evenly stressed and the stress distribution reasonable during the hoisting process, which effectively avoids the risk of component damage caused by the force problem and ensures the safety and stability of the hoisting process.

When it comes to simulating the positioning and connection process, the platform's BIM technology also excels. Or take the residential community project as an example, in which the connection between the precast beams and the precast columns is the key link in the construction. In the simulation, the platform is able to demonstrate the precise docking and connection between the components with high accuracy. Through the platform, the construction personnel can observe the coordination of the precast beams and precast columns in the process of being in place from all angles.

In one simulation, the constructor found that there was a 2 cm dimensional deviation between the connection of the precast beam and the reserved interface of the precast column. If this problem is not detected in advance during the actual construction, it will lead to connection difficulties and need to be repaired on site, which will not only delay the construction progress, but also may affect the connection quality. In addition, during the simulation, it was also found that some bolt holes were not matched, which would make the bolts unable to be installed smoothly and affect the connection strength of the structure.

With the help of the platform's simulation function, the construction team discovered these problems in advance and notified the designers and producers in time to make adjustments. The designer optimized the design drawings of the components, and the producer adjusted the production process according to the revised drawings to ensure that the actual production components could be connected accurately. In the actual construction, because the construction process is familiar through simulation in advance, the construction personnel can operate quickly and accurately, which greatly improves the construction efficiency and quality. The connection, which was expected to take a week to complete, was completed two days ahead of schedule, and the quality of the connection was significantly improved, and it was tested to be fully compliant with the design standards.

To sum up, the BIM-based prefabricated building component information integration platform simulates the hoisting, positioning and connection of prefabricated building components, and effectively helps the construction team find problems in advance and optimize the construction plan through accurate parameter analysis and intuitive display, which plays an irreplaceable role in ensuring construction safety, improving construction efficiency and quality, and provides solid technical support for the smooth progress of prefabricated building projects.

The administrator can view the basic information, production information, transportation information and construction information of the component through the component information query function module, so as to realize the integrated management of component information. This provides comprehensive data support for the collaborative work of all participants in the project and promotes the efficient progress of the project.

By building a prefabricated building component information integration platform, the project realizes the centralized storage and transmission sharing of component information from the early stage of design to the later stage of construction. On the one hand, costs are significantly reduced. Data consolidation avoids data redundancy and duplicate entry caused by the use of multiple systems, while reducing the cost of data management and maintenance. On the other hand, the ability to collaborate among the various participants has been enhanced. Data sharing enables all parties to collaboratively manage prefabricated building components, realize the timely and accurate transmission of resources and information, and provide effective support for enterprise decision-making, thereby improving work efficiency and promoting the refined management of prefabricated building projects.

VII. Discussion

The National Informatization Development Outline calls for enhancing the ability to integrate and apply emerging informatization technologies such as cloud computing, BIM, and the Internet of Things, and comprehensively improving the level of informatization construction in China's construction industry [16]. From a technical point of view, the optimization of data storage is key. Although the relational database MySQL is used to store structured data, the NoSQL database MongoDB is used to store unstructured data, and the storage problem of user-scale data is solved by dynamically expanding fields and EAV mode, the performance and scalability of the storage system are challenged by the continuous growth of data volume and the increasing complexity of data types. For example, in large-scale projects, massive amounts of structured data may cause MySQL query efficiency to deteriorate. For ultra-large-scale unstructured data, MongoDB's storage and processing capabilities need to be further improved. In addition, the data interaction and collaboration between different databases are not smooth enough, and how to achieve more efficient data fusion and sharing is the direction that needs to be broken through in the future technology development.

There is also room for improvement in BIM model information extraction and web-based model visualization technology, and the database has the ability to connect with BIM, which can read the quantity schedule information of different depths exported from the BIM model into the software [17]. Although Revit software is widely used in BIM modeling, compatibility problems between different versions often occur, which may lead to incomplete or incorrect extraction of model information. WebGL technology still needs to be improved in terms of loading speed and performance optimization when dealing with complex models, especially in the face of refined models for large-scale construction projects, which may freeze or even crash, affecting user experience and work efficiency.

In terms of practical application, the promotion and use of the platform faces certain obstacles. Although BIM technology has many advantages in theory, some enterprises and practitioners have limited acceptance of it, mainly due to the high learning cost and the difficulty of integrating existing workflows with BIM technology. For example, some small construction enterprises lack professional BIM technical personnel, and it is difficult to give full play to the functions of the platform; However, large enterprises need to invest a lot of manpower, material resources and time to adjust and adapt when integrating BIM technology into existing complex business processes. In addition, the data sharing and collaboration mechanism between different participants is not perfect enough, and there are data security and privacy concerns, which leads some enterprises to have reservations when sharing information, which affects the overall benefits of the platform.

From the point of view of simulating the hoisting, positioning and connection process of prefabricated building components, although certain results have been achieved, there are still improvements. At present, the simulation mainly focuses on mechanical analysis and simple construction process demonstration, and does not consider the coupling effect of multiple factors in complex construction environments. For example, the influence of natural factors such as wind and topography on the construction site, as well as the dynamic changes of construction equipment on the forces of components and the construction process, has not been fully simulated. In addition, the accurate matching of the simulation results with the actual construction situation needs to be improved to ensure that the simulation can guide the actual construction more accurately.

From the perspective of industry development, the integration of BIM technology and prefabricated buildings has brought new development opportunities to the construction industry, in terms of construction means, the cross-section method is often used for small devices or local components, if applied to a larger scale, it needs to be combined with other methods, and the cross-section method is often used in combination with the mosaic method when building high-rise skins. With the development of numerical control equipment, the design method and construction technology have been relatively mature, which can create a rich skin shape, but also puts forward higher requirements for industry standards and specifications [18]. At present, the relevant standards and norms are not perfect, and there are differences in the implementation standards between different regions and different enterprises, which not only affects the sharing and collaboration of information, but also restricts the overall development of the industry. The establishment of unified and perfect industry standards and specifications is a necessary condition to promote the wide application and in-depth development of BIM technology in prefabricated buildings.

In view of the above problems, in the future, it is necessary to strengthen technology research and development, improve data storage and processing capabilities, optimize BIM model information extraction and visualization technology, reduce software compatibility problems and improve web performance. At the same time, increase the training of enterprises and practitioners, formulate reasonable training programs, lower the learning threshold of BIM technology, and help enterprises better integrate BIM technology into the existing work process. In addition, improve the data sharing and collaboration mechanism, strengthen data security and privacy protection, and eliminate concerns among enterprises. In terms of simulated construction, the breadth and depth of simulation are further expanded, and more practical factors are comprehensively considered to improve the accuracy and practicability of simulation results. In the formulation of industry standards, the government, industry associations and enterprises should participate together to accelerate the formulation of unified and scientific standards and specifications, and promote the deep integration and coordinated development of BIM technology and prefabricated buildings.

In general, the information integration technology of prefabricated building components based on BIM has broad prospects, but in order to achieve its wide application and sustainable development, it is necessary to solve many problems such as technology, application, and standards. Through the joint efforts of all parties, we will continuously optimize and improve relevant technologies and mechanisms, which will inject strong impetus into the digital transformation and high-quality development of the construction industry.

References

[1] Yan Jianjun. Research on BIM Technology Application and Component Information Integration Platform in Prefabricated Buildings[J]. Engineering Construction and Design,2024(9):158-160. DOI:10.13616/j.cnki.gcjsysj.2024.05.046.

[2] Du Songyang. Research on information integration of prefabricated building components based on BIM[D]. Shandong:Shandong Jianzhu University,2023(in Chinese).

[3] Hao Yun. Application of BIM technology in prefabricated building components[J]. Architecture & Decoration,2023(2):190-192.

[4] Zhu Yingzi. Research on parametric design and application of prefabricated components of a prefabricated building based on BIM[D]. Jilin:Northeast Electric Power University,2023. DOI:10.7666/d.D03053545.

[5] Yang Zepan, Ye Yufei, Chen Leixing. Research on Intelligent Coding of Prefabricated Building Prefabricated Components Based on BIM[J]. Chongqing Architecture,2022,21(Z1):180-182. DOI:10.3969/j.issn.1671-9107.2022.S1.180.

[6] Wang Shengnan, Huang Longfei, Wang Junfei. Application of BIM Technology in the Design of Prefabricated Components of Prefabricated Buildings[J]. Mold Manufacturing,2024,24(6):193-195,198. DOI:10.13596/j.cnki.44-1542/th.2024.06.062.
[7] Zhu Hongkun. Research on Structured Coding Technology of BIM Components for Building Operation and Maintenance[J]. Shanghai Construction Science & Technology,2024(3):106-110. DOI:10.3969/j.issn.1005-6637.2024.03.023.
[8] Tian Dong, Li Xinwei, Ma Tao. Design analysis and research of prefabricated concrete building component system based on BIM[J]. Building Structure,2016,46(17):58-62.
[9] Liao Junfeng, Cao Zheng, Hu Peng. Application of BIM-based process design of prefabricated building slab components (reinforcements)[C]//Proceedings of the Fifth National Conference on BIM. 2019:218-221.
[10] Yang Jin. Information Integration System of Prefabricated Building Prefabricated Components Based on Cloud BIM[J]. System Simulation Technology,2021,17(2):123-127. DOI:10.3969/j.issn.1673-1964.2021.02.012.
[11] Wang Mingqi. Research on Componentized Design of Rural Prefabricated Composite Wall Building System Based on BIM--A Case Study of Peixian Party and Mass Service Center Project in Northern Jiangsu[D]. Jiangsu:Southeast University,2022.
[12] Tan Hantao. Research on the design and development of standardized BIM component library for prefabricated timber buildings[D]. Hunan:Changsha University of Science and Technology,2022(in Chinese).
[13] Luo Zhiqiang. Research on parametric implementation of prefabricated concrete building components based on BIM[D]. Shandong:Liaocheng University,2018(in Chinese). DOI:10.7666/d.D01435665.
[14] Jiang Meng, Liu Jianxing. Research on Quality Inspection Method of Prefabricated Building Components Based on BIM[J]. Smart City,2021,7(9):17-18.
[15] Lin Jiaoqing. Research on Engineering Application of Prefabricated Building Prefabricated Components Based on BIM Technology[J]. Sino-Foreign Exchange,2021,28(9):533.
[16] Ma Xiaofei. Research on integrated management of prefabricated building prefabricated components based on cloud BIM[D]. Hubei:Wuhan University of Technology,2017(in Chinese).
[17] Zeng Yu Shu. Research and development of LCA database management system for building components based on BIM[D]. Tianjin:Tianjin University,2017(in Chinese). DOI:10.7666/d.D01650031.
[18] Ba Jing. Application of BIM technology in building component design[D]. Tianjin:Tianjin University,2016(in Chinese). DOI:10.7666/d.D01392324.