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Application of BIM Technology in Prefabricated Concrete

Liming Wang, Bo Liu*, Juannong Chen

1 North China University of Science and Technology, Tangshan 063000, China

Abstract

With the rapid development of China's economy, the construction industry has also received high attention in seeking more environmentally friendly and green types of buildings. The application scope of prefabricated concrete structures in China has been expanding due to its advantages such as low construction cost, high production efficiency, and energy-saving and environmental protection. BIM, as an indispensable new architectural information technology, is also widely used. Applying BIM technology to prefabricated concrete buildings can not only increase production efficiency and save time but also coordinate and regulate the construction schedule and process. The combination of prefabricated concrete buildings and BIM technology has become the mainstream of China's development in the future.

Keywords

Construction; BIM; PC Structure; Engineering Applications.

1. Introduction

China's development in prefabricated construction started relatively late. It was only in the last century that prefabricated construction entered our field of vision. Foreign countries have been using prefabricated construction earlier. In Europe and America, prefabricated wood and steel structures are mainly used as daily residential frame structures. In Japan, prefabricated wood and reinforced concrete structures are the main types of frame structures for housing. In China, concrete is widely used, mainly as a shear wall structure in prefabricated concrete. The full name of BIM in English is Building Information Modeling, also known as Building Information Model. It was first proposed by Dr. Chuck Eastman of Georgia Tech College. Dr. Eastman believes that "Building Information Modeling integrates not only the model information of all component parts, their functions, and performance, but also integrates all the information of the entire life cycle of the building project into an independent building model, including construction, construction, and maintenance management process information"[1]. By combining BIM technology with prefabricated concrete construction, the entire building tends to be more transparent and information-oriented, enabling better management of the entire construction process.

2. Development of Prefabricated Buildings

2.1 Domestic Development of Prefabricated Buildings

As early as the 1950s, prefabricated buildings began to emerge in China. However, due to the lack of advanced technology, the development of prefabricated buildings in China has been slow and even stagnant. In comparison with European and American countries, China's development in this area is far behind. The rate of prefabricated residential component utilization in the United States is about 80%, while in China, it is only about 1/4[2]. In May 1956, the State Council issued the "Decision on Strengthening and Developing Building Industrialization," which stated the need to fundamentally improve China's traditional construction methods and gradually transition to building industrialization[3]. It wasn't until after 1999 that the State Council reissued the "Opinions on

Promoting the Modernization and Quality Improvement of the Residential Industry," which set out the development goals, tasks, and measures for the modernization of housing in China, marking a new stage in the development of prefabricated buildings[4]. However, at that time, the overall development of prefabricated buildings in China was still slow.

It was only in recent years that prefabricated buildings in China have gained more attention. During the period of 2015, the total area of newly built prefabricated buildings in the country reached 35 to 45 million square meters, and the number of new prefabricated component factories reached about 100 in the past three years[5]. On September 30, 2016, the State Council issued the "Guiding Opinions of the General Office of the State Council on Vigorously Developing Prefabricated Buildings," which clearly stated that the country should vigorously develop prefabricated concrete, steel structure, and wood structure buildings. In future construction, the proportion of prefabricated buildings should be continuously expanded, and efforts should be made to promote and encourage the development of prefabricated buildings in various regions. The goal is to achieve a proportion of about 30% of prefabricated buildings in the total newly built area in about ten years[6]. From 2017 to 2021, the number of prefabricated concrete component enterprises in China showed a gradual increase (Fig. 1). Due to the severe impact of the epidemic in 2022, the construction industry has also been greatly affected, resulting in slow development of prefabricated buildings. The number of PC component manufacturers remained the same as in 2021. By the end of 2022, there were 328 national-level prefabricated building industrial bases, 908 provincial-level industrial bases, 1,261 PC component manufacturers, 1,122 prefabricated steel structure component enterprises, and 110 prefabricated wood structure component enterprises in the country. Currently, prefabricated concrete structures are still the main focus in China[7].

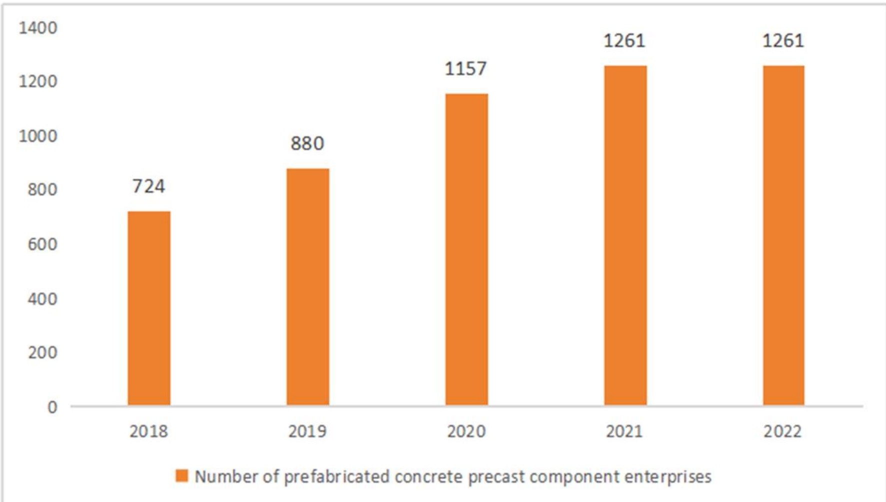

Fig. 1 Number of prefabricated concrete precast component enterprises

2.2 Features of Prefabricated Concrete

Due to the predominant use of concrete materials in our country's construction industry, the importance of prefabricated concrete is increasing. Traditional concrete construction requires continuous operation of concrete mixer trucks on the road, and the components are made on-site when they arrive at the construction site. This not only increases costs but also generates a large amount of pollution and noise, which contradicts our country's "dual carbon" plan. Prefabricated concrete involves transporting factory-produced precast (PC) components to the construction site. During the construction process, certain voids are left, and after the connections are completed, grouting or anchoring methods are used to enhance the overall seismic resistance and stiffness of the building by integrating the precast components into a cohesive structure. Compared to traditional concrete construction, prefabricated concrete buildings can save about 40% of building materials, and the generation of construction waste can be reduced by about 70% compared to traditional building

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materials[8]. Prefabricated concrete components mainly refer to the PC components required for factory production. There are six main types of precast components: precast floor slabs, precast beams, precast walls, precast columns, precast stairs, and other complex-shaped precast components (Fig. 2).

The basic prefabricated components of prefabricated concrete structure buildings are divided according to the component characteristics and performance of the constituent buildings, including:

A. Prefabricated floor slabs (including prefabricated solid slabs, prefabricated hollow slabs, prefabricated laminates, prefabricated balconies)

B. Precast beams (including precast solid beams, precast laminated beams, precast U-beams)

C. Prefabricated walls (including prefabricated solid shear walls, prefabricated hollow walls, prefabricated laminated shear walls, prefabricated non-load-bearing walls)

D. Precast columns (including prefabricated solid columns, prefabricated hollow columns)

E. Prefabricated stairs (prefabricated staircase sections, prefabricated rest platforms)

F. Other complex special-shaped components (prefabricated bay windows, prefabricated exterior walls with bay windows, prefabricated corner exterior walls, prefabricated integrated kitchen bathrooms, air conditioning panels, etc.)

Fig. 2 Common prefabricated components

In order to reduce the production cost of precast components, manufacturers often limit the specifications of commonly used precast components to two or less, which increases the reuse rate of templates and achieves cost savings. According to the structural system, prefabricated concrete residential buildings using prefabricated concrete in recent years can be divided into five categories, with the most commonly used being the prefabricated frame system (Figure 3), precast shear wall system, precast composite shear wall system, etc[9].

Prefabricated concrete residential structure system and pictures		
Prefabricated frames	Prefabricated shear walls	Prefabricated laminated shear walls
		

Fig. 3 Common prefabricated concrete housing structure system

Prefabricated concrete buildings have the following characteristics: (1) High standardization: PC components are generally produced in factories and then transported to the construction site for on-site assembly, ensuring construction standardization and quality. (2) Convenient on-site construction: Concrete components are prefabricated in factories instead of being cast on-site, which ensures both the quality of the components and the efficiency of construction. (3) Environmentally friendly: Prefabricated concrete components reduce air pollution and noise on construction sites to some extent, as they are not constructed on-site. (4) Large demand for lifting equipment: The focus of prefabricated buildings is on assembly, so there is a high demand for transportation and lifting equipment during construction. At the same time, reasonable protective measures need to be taken to ensure the integrity of the components during transportation[10]. (5) Suitable for low-rise buildings: Prefabricated concrete buildings require the assembly of columns, beams, slabs, and other components, integrating them into the building structure. This requires strict control over the entire connection process, and it becomes more challenging to meet construction standards for high-rise or super high-rise buildings.

3. BIM Technology

3.1 Development of BIM Technology

The concept of Building Information Modeling (BIM) was first proposed by Dr. Chuck Eastman and published in the AIA Journal[1]. In the late 1970s to early 1980s, similar BIM development and research was also gradually happening in Europe, particularly in the United Kingdom. At that time, the United States referred to it as "Building Product Model," while Europe referred to it as "Product Information Model." The term "Building Information Modeling" was originally introduced by Robert Aish as "Building Modeling."[11].

Before the 21st century, BIM technology faced challenges from AutoCAD software and its own limitations, which hindered its progress and limited its application in engineering. It was not until the 21st century, with the rapid development of computer hardware and a deeper understanding of the building lifecycle, that BIM technology became well-known and widely applied. In 2002, the concept and methods of BIM were introduced and promoted by Autodesk, leading to a global wave of BIM technology. China also began to embrace the concept and technology of BIM around that time[12].

Around 2003, some construction industries in China started adopting BIM technology. Currently, BIM is primarily used by design firms in China. The government, BIM consulting companies, specialized BIM training institutions, and some universities have also started to recognize the value and significance of BIM application. The Ministry of Housing and Urban-Rural Development in China has also implemented some policies related to BIM (Figure 4).

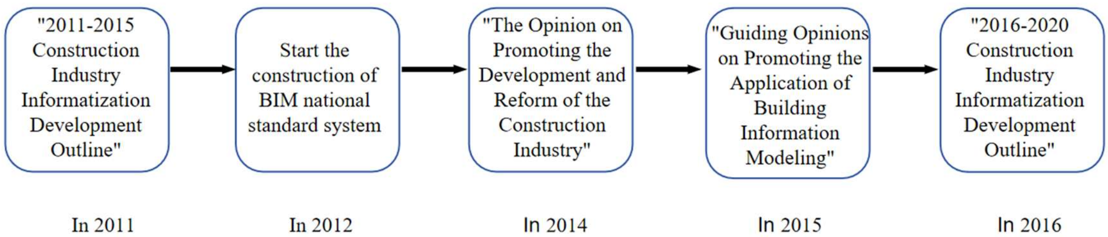

Fig. 4 Relevant policies issued by the Ministry of Housing and Urban-Rural Development

As the birthplace of BIM technology, the United States is relatively advanced in its application. The percentage of BIM application in the United States increased from 28% in 2007 to approximately 71% in 2012[13].

3.2 Technical Concepts of BIM

Geraldine Rayner, a senior BIM consultant at SummitAEC, stated that BIM is not just a technology or software tool, but it is more about the relationships between people. BIM is 10% technology and 90% about "relationships." In other words, simply using BIM-related software tools without

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following the principles of BIM does not constitute true BIM application. Many non-BIM modeling software can also achieve basic modeling functions[14].

Building Information Modeling (BIM) is defined by the International Organization for Standardization (ISO) as "the use of a shared digital representation of a built object (buildings, roads, bridges, etc.) to facilitate the design, construction, and operation processes, forming a reliable basis for decision-making.[15]" BIM can also be defined as "the ability to represent any physical and functional characteristics of a building process using shared digital information." The International Facility Management Association (IFMA) provides a definition of BIM as the digital representation of the physical and functional characteristics of a facility, using open industry standards to support the project's lifecycle, and allowing access and modification of the model when permitted[16]. Dr. Eastman, known as the "father of BIM," also stated that BIM is used to store the geometric characteristics and other relevant precise data of a project. It allows access to all entity information of the 3D model throughout the project's lifecycle, enabling visualization and simulation of the project's future conditions for better construction outcomes[17].

3.3 Technical Characteristics of BIM

According to the definition of BIM, we have summarized five characteristics of BIM technology: visualization, coordination, simulation, optimization, and the ability to generate drawings [18]. BIM can be seen as an information repository that displays various information about the entire construction process through software, including geometric and physical information during the design phase, construction simulation during the construction phase, and equipment management information during the maintenance phase. BIM software can better manage the entire construction process, and BIM technology can unify and exchange information between the stages of architectural modeling, architectural design, construction, and building operation and management[19]. Unlike CAD software, which can only draw simple 2D lines and geometric shapes, it cannot simulate the physical performance and collision detection of buildings, and personnel from project owners, design units, construction units, and management stages cannot exchange files and share data. Unlike traditional CAD software, BIM's architectural design is a new concept that not only has powerful information storage and retrieval capabilities but also allows collision detection to be conducted during construction, saving construction costs and time, and avoiding repetitive work and design flaws caused by lack of communication. Therefore, the proper use of BIM technology in engineering projects can facilitate communication and collaboration among all parties involved, thereby improving efficiency and cost savings.

4. Application of BIM Technology in Prefabricated Concrete

There are many different BIM software available (Figure 5), but currently the most widely used software in China is Autodesk's Revit. It allows architects, structural engineers, and MEP designers to create models on the same platform, making information exchange more convenient. In the entire construction process of prefabricated concrete buildings, the design phase is particularly important. It is crucial to determine the locations of reserved openings so that they can be well integrated with the prefabricated concrete components. Therefore, BIM technology can be effectively combined with prefabricated concrete construction, greatly reducing costs, shortening construction time, and improving construction schedule management.

1) Planning phase: In this phase, it is mainly about effectively combining BIM technology with GIS technology. By importing maps into the model during site planning and modeling, it can better facilitate scientific planning [20].

2) Design phase: In the early stages of construction, it is necessary to determine the dimensions of the components in advance. In order to meet the requirements of component and reserved location matching, as well as the requirements for assembly, design units, construction units, and component manufacturers need to collaborate to create and refine the required component dimensions. In Revit software, it is possible to establish a library of prefabricated families, applying the design and

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processing of prefabricated components in prefabricated assembly structure design. The created family library has parametric features, so there is no need for commands such as cutting or stretching when making modifications in later stages. Instead, modifications and management of the family's parameters can be done uniformly through the project, saving time and improving project efficiency.

3) Optimization phase: Due to the strict accuracy requirements of prefabricated concrete structures, using Revit software to establish a visual 3D model can optimize the position of reinforcement and reasonably optimize the layout of components, enabling coordination and collaboration between architecture, structure, and equipment on the same software [21].

4) Clash detection: During the construction process, the installation of pipelines becomes complex due to the involvement of multiple specialties and large amounts of information. It is necessary to not only meet the reasonable layout of pipelines for each specialty, but also arrange the positions of pipelines with respect to structures, buildings, and other pipelines within limited space and avoid clashes [22]. BIM technology can effectively avoid this issue. By creating architectural, structural, and MEP models in Revit software, and then importing the created models into Navisworks software, clash detection can be performed using the Clash Detective feature [23]. The clashes can be identified and modified, reducing rework and improving construction schedules.

Use features	BIM software and series
Scheme design	Onuma Planning System
	Affinity
Structural analysis	STAAD
	ETABS
	Robot
	PKPM
	Lizheng series
Basic modeling	Autodesk series
	Benlty series
	Nemtschek series
	Dassault series
visualization	3DS Max
	Artlantis
	AccuRender
	Lightcape
Collision checking	Luban
	Autodesk Navisworks
	Bentley Projectwise Navigator
	Solibri Model Checker
Cost management	Innovaya
	Solibri Model Checker
	Luban
	Guanglianda

Fig. 5 Commonly used BIM software

5. Summary

The use of prefabricated concrete in construction is different from traditional construction methods and is a key technology for achieving industrialization in the construction industry. Building

Information Modeling (BIM) is a new architectural concept that utilizes building information models to improve project efficiency. This article first discusses the development of prefabricated construction and the characteristics of prefabricated concrete. It then analyzes the development, concept, and characteristics of BIM technology. Finally, it summarizes the advantages of applying BIM technology to prefabricated concrete construction. BIM technology can be utilized by planning and design personnel as well as construction management personnel to facilitate information exchange and sharing. It can be used for analysis and processing from the early stages of building site planning to the final stages of project management and operation. Therefore, the proper use of BIM technology can improve project efficiency and save construction costs. However, due to the current lack of sufficient awareness and industry standards for BIM in China, as well as a shortage of specialized personnel, the application of BIM technology still has significant limitations. In the future, it is necessary to combine the national conditions of China to increase the understanding and use of BIM among professionals in the construction industry, making the application of BIM technology in prefabricated construction more comprehensive and truly beneficial.

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