8. Ni, Na. Research on Traffic Characteristics and Security Assurance Technologies of Tunnel Intensive Section in Mountainous Expressway / Chang'an University. –2017.
9. Du,Zhigang. Pan, Xiaodong. Yang, zhen. et al. Research on Visual Turbulence and Driving Safety of Freeway Tunnel Entrance and Exit / China Journal of Highway and Transport. –2007. – No. 20(5). – p. 101-105.

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STANDARDIZATION SYSTEM INTEGRATION OF ARCHITECTURAL DESIGN BASED ON DIGITAL METHODS

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This paper analyzes the standardization development path of prefabricated buildings in China and summarizes the new theories in the standardization development of prefabricated buildings in the new era—the definition and characteristics of the standardization system integration of architectural design based on digital methods. Through systematic digital design, industrial digital processing, on-site assembly construction, and intelligent informatization operation and maintenance, a technical path of high efficiency, high quality, low consumption, and low emission is formed throughout the entire lifecycle of the building. Finally, this paper introduces the system integration standardization strategy of prefabricated buildings adopted in the design and construction process of an actual case—the Asia Financial Tower project, which the author presided over. The application of full lifecycle BIM digital design, synchronized docking with factory processing, assembly construction, and intelligent operation and maintenance, has realized high-quality construction and efficient operation and management of the project. It is an innovative application of the integrated assembly building system, aiming to provide a Chinese case for enhancing the connotation of architectural standardization in the digital economy era.

Keywords: System integration standardization of architectural design, prefabricated building system, digital methods, upgrading of the construction industry

1. Technical Path of Prefabricated Building Development

1.1 Modular Standardized Prefabricated Building System

In the 1950s, the Chinese construction industry once learned from the Soviet Union and embarked on a path of construction industrialization. By standardizing and modularizing the construction of building types such as offices, factories, and residences, a industrialized building system based on the prefabrication of building components was established.

This system addressed the urgent need for large-scale construction at the beginning of the founding of the People's Republic of China. Just as the Khrushchyovkas in the Soviet Union solved the housing difficulties of a large number of urban new residents in a short time, its limitations were also obvious: the excessive dependence on standardization severely constrained the space for architectural design creativity, and the individualized needs and diverse expressions of buildings were restricted. With the continuous improvement of standards for seismic resistance, sound insulation, and thermal insulation performance of buildings, the original standardized prefabricated building system was unable to adapt to diversified high-quality building requirements due to its own technical limitations. After the era of large-scale diversified construction in the construction industry arrived, this purely modular standardized prefabricated building system gradually exited the stage.

1.2 Component Standardized Prefabricated Building System

The component standardized prefabricated building adopts an industrialized method to standardize and normalize the structural, maintenance, and decorative components of the building. It realizes efficient construction through factory production and on-site assembly, reducing on-site engineering pollution and energy consumption.

This approach is the core technical strategy adopted by most of the current standardized prefabricated buildings. By decomposing the entire building into assembly standard components with different functions, and centering on the standard components, design, processing, and installation are carried out. Various supporting technical systems are also developed around the components, such as the design, processing, and connection of standard and non-standard parts, as well as supporting construction, material, and process technology systems for insulation and waterproofing. This model is currently the mainstream form of prefabricated buildings internationally, and has greatly developed on the basis of modular standardization. However, this approach is still limited by the current assembly construction methods, materials, and node methods, and there are still limitations in responding to the demand for building diversity.

1.3 System Integrated Prefabricated Building System (SIPBS)

With the digital upgrade of industrial industries, mere modular standardization and component standardization are no longer sufficient to meet the industrialization needs of the construction industry in the digital era. Utilizing the thinking of system integration, system standardization, performance standardization, and technical standardization are embedded into the digital design collaborative platform (BIM). This integration paves the way for a seamless connection throughout the entire lifecycle of design, processing, construction, and operation and maintenance, bringing a technological leap to the assembly of buildings. The System Integrated Prefabricated Building System (SIPBS) liberates prefabricated buildings from the narrow constraints of standardized technology through the interconnected application of novel digital design and processing technologies. It opens up possibilities for personalized creation based on industrial production, injecting new connotations into the architectural standardization system of the digital era. Simultaneously, the introduction of advanced manufacturing methods transforms prefabricated building components into integrated modules that consolidate various architectural functions. This transformation challenges traditional professional boundaries and divisions of labor in architecture, aligning the construction industry with the technical characteristics of contemporary advanced manufacturing industries. It also revolutionizes traditional building construction, usage, and operation and maintenance management methods, significantly enhancing the quality and performance of buildings.

2. Characteristics of High-Quality System Integrated Prefabricated Building System

Under the goal of high-quality development in the construction industry, enhancing building efficiency, reducing environmental burden, and pursuing high-quality construction have made industrialization, integration, and standardization of buildings a rational choice. The System Integrated Prefabricated Building System (SIPBS) outlines a technical path for the construction industry to integrate innovative developments from cutting-edge fields, achieve industrial upgrading, and maintain high-efficiency construction, high-quality use, low energy and material consumption, and low carbon emissions throughout the building's entire lifecycle.

The System Integrated Prefabricated Building System (SIPBS) emphasizes starting from the inception of the building's entire lifecycle—the planning stage. By sorting out the functional requirements of the building and utilizing digital design methods, various components of the building are systematically integrated to form integrated modules with composite functions. Subsequently, these modules undergo industrialized and unitized production and processing. On-site, the unit modules are assembled to realize efficient and complex integrated construction. The above digital standardized design, production, and construction facilitate efficient and precise docking with later operation and maintenance, realizing an intelligent operation platform for the building (Figure 1).

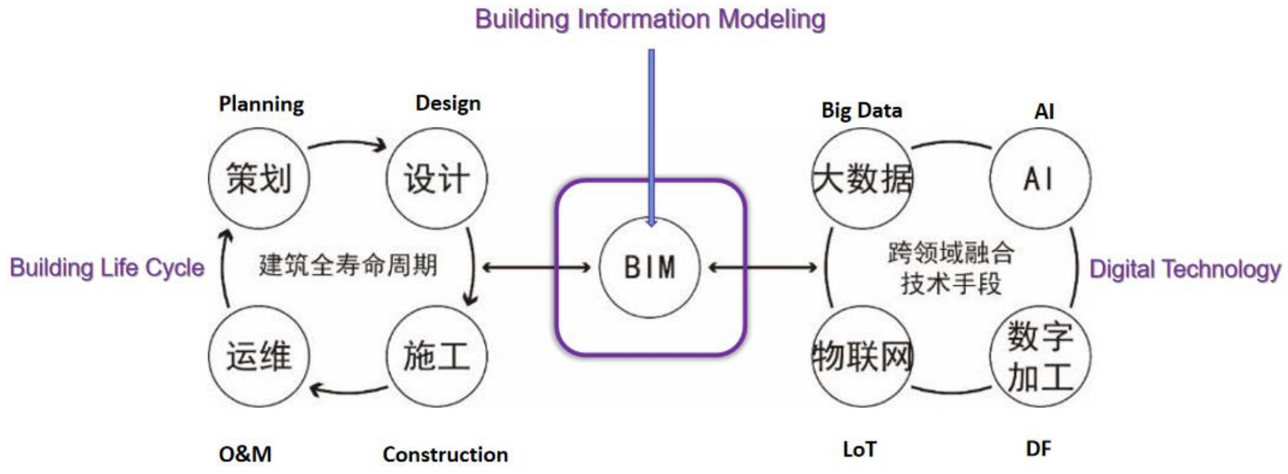

Figure 1 - System Integrated Prefabricated Building System

Diverging from prefabricated construction based on traditional standardization, the architectural design system integration standardization system based on digital methods encompasses the following four characteristics:

(1) System Digital Design: Unlike traditional architectural design, system digital design is grounded in the digital collaborative design platform BIM (Building Information Modeling), achieving the informatization and datafication of design elements. This approach enables integrated design from various dimensions and aspects, making it possible for multi-disciplinary standardized collaboration. In the architectural design process, the traditional vertical model of architectural design and multi-disciplinary collaboration is transformed. Design tasks are divided into various system-integrated prefabricated module units. Each module unit encompasses the professional content required for industrial processing, such as architecture, structure, and mechanical and electrical equipment, as well as various special control principles and operating mechanisms to meet the building's green energy-saving and intelligent operation and maintenance requirements. This transforms architectural design from traditional vertical professional division of labor to a systematic design facing integrated unit modules realizing the main structure of the building, enclosure system, interior decoration, and professional system functions. Thus, achieving dynamic standardized collaborative design.

(2) Industrial Digital Processing: The industrial processing of architectural products and components is based on standardized production methods, utilizing modern digital production modes. Aligning with digital architectural design information and using digital decomposition and processing technology, complex architectural processes are broken down into simple processing components. These components are then directly connected to product processing through digital commands, achieving the alignment of design and processing of building components. Digital processing technology breaks free from the narrow confines of standardization, achieving the coexistence of standardization and personalization through digital control, and aligning with the high efficiency and high-quality production of industrialization. This represents a fundamental shift in the production mode of the construction industry from extensive to technologically integrated and intensively customized production.

(3) On-site Assembly Construction: Assembly construction draws on the successful experience of the advanced manufacturing industry, resembling the assembly of a product line during the construction process. A significant amount of on-site work traditionally involved in construction is transferred to factories. Here, building system components and accessories are processed and manufactured, then transported to the construction site for assembly and installation through reliable connection methods. Assembly construction includes prefabricated assembled concrete structures, steel structures, and modern wooden structure buildings. By adopting digital design, factory production, and integrated finished products, and connecting to the information management and intelligent applications after the building is put into use, the uncertainty in quality due to on-site manual operations is minimized. This is a robust guarantee for the standardization of the building system.

(4) Intelligent Information-based Operation and Maintenance: Smart buildings integrate new-generation network technology and Internet of Things technology. Their overall solutions are based on the principles of systems engineering and aim to meet the management and usage needs of different users. They integrate modern computer technology, communication technology, automatic control technology, multimedia image display technology, and other modern information technologies. They are the products of the organic integration of emerging technical means such as blockchain, IoT, cloud computing, and big data with building technology. The foundation of their application lies in the collection, monitoring, management, and control of information on equipment, environment, and users within the building, achieving an optimized combination of the building environment and providing users with the functionalities required by the building's design as well as modern information technology applications.

3. Practical Exploration of System Integrated Prefabricated Architecture

The Beijing Olympic Park B27-2 project serves as a high-standard international financial institution headquarters office space (Figure 2). The design of the project prioritizes creating a high-quality usage environment and architectural space, striving to cultivate a harmonious and integrative architectural spatial environment among "people, architecture, and the environment." The goal is to achieve precision craftsmanship, intelligent manufacturing, and smart operation and maintenance. The design expresses the integration with the environment through urban space and architectural form, creating a people-oriented, multi-level communicative architectural space at its core. It endows the building with a new public space experience, integrating green, social, and shared internal and external spatial environments.

Figure 2 - The Beijing Olympic Park B27-2 project

The project is located at the northern end of Beijing's central axis, with a total floor area of 389,972 m², comprising 16 above-ground floors and 3 underground levels. From the inception of the project design to its completion and occupancy, there is a stringent construction period of only three years. At the same time, the project is benchmarked against world-leading construction technology standards, necessitating breakthroughs in systems and methods right from the design stage. A series of innovative technical systems were employed in the design, among which the application of the System Integrated Prefabricated Building System (SIPBS) is a particularly important technical implementation.

3.1 System Construction of the System Integrated Prefabricated System

The project incorporates complex technical integration and advanced technologies, bringing together a series of engineering technologies such as steel structure digital processing technology, eco-friendly green energy-saving technology, BIM design and platform technology, and high-quality indoor environmental control technology. BIM technology is utilized as a foundational tool for architectural design, construction, and operation and maintenance, realizing efficient management and control of the entire process of design and construction through digital means. Through the innovative application of BIM technology, the links between digital design, digital construction, and intelligent operation and maintenance are seamlessly connected. This forms a systematized construction system for smart buildings based on BIM, realizing an integrated system of on-site intelligent construction and subsequent intelligent operation and maintenance.

The building adopts a full steel structure system and applies integrated "design-processing" technology for steel structures based on digital design, resulting in a high degree of assembly in the design and construction. Different system-integrated prefabricated facade modules are used for different external appearances of the building. The interior utilizes a fully assembled partition wall system, an integrated ceiling system, modular assembled flooring, and a separated equipment electromechanical pipeline network system. The overall assembly rate of the project reaches 91%.

3.2 Three-dimensional Space Construction Based on the Large-span Assembled Full Steel Structure System

The overall spatial design of the project aims to create a richly layered indoor communication space. Through the mega-structure approach, structural layers interweave and crisscross, forming a tall and penetrating atrium space, which accommodates the architectural functional needs for large-volume spaces, flexible office spaces, and communication spaces.

The vertical support core of the entire building consists of 16 core tubes, with only four columns set between every two core tubes, achieving a maximum column span of 27m. Every three floors of office space are treated as a three-dimensional unit, interweaving and enclosing between the core tubes. The main structural system of the building adopts steel plate shear wall core tubes + steel tube concrete columns/steel composite beam frames. The core tubes utilize 30mm thick steel plate shear walls to replace reinforced concrete walls, significantly enhancing the efficiency of the building’s spatial usage.

The structural design of the all-steel structure system throughout the project was conducted using Building Information Modeling (BIM) technology. This ensured precise integration between digital processing at the steel structure factory and on-site assembly construction. The steel structure BIM model was strictly aligned with the BIM and production control data software of the manufacturers. Design drawings corresponded directly to factory processing, ensuring an efficient decomposition process. Even non-standard designs achieved standardized factory processing, resulting in almost zero errors during implementation. Precise reservations were made for equipment pipeline openings, securing vertical space for electromechanical pipelines (Figure 3).

The project's overall envelope structure employs a composite integrated curtain wall system, integrating an intelligent detection and control system to achieve insulation, heat insulation, decoration, and control integration. This system is capable of intelligent monitoring and active regulation under complex meteorological and environmental conditions such as wind, rain, snow, and pollution. An integrated intelligent electric shading system and a passive ventilation system are installed, significantly reducing the air conditioning load. BIM technology was utilized to design integrated complex functional modular units, which were then produced in factories to achieve integrated processing. On-site assembly was used for efficient construction.

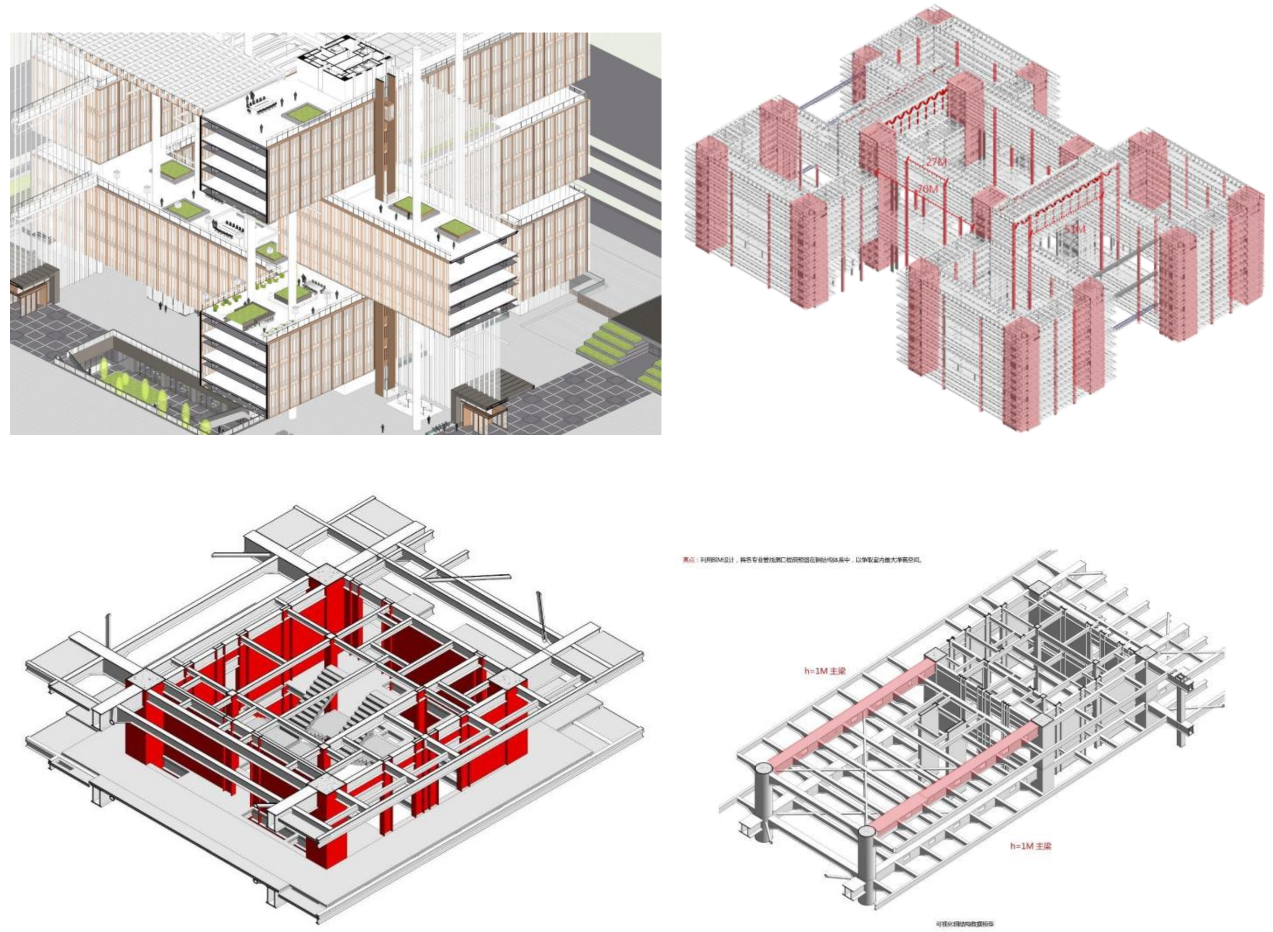

Figure 3 - Digital Design of Complex Structures

3.3 High-Performance Integrated Composite Functional Envelope System

The curtain wall of the standard office space facing outdoors employs a double-layer breathable unit curtain wall system, efficiently integrating numerous energy-saving application technologies. These include a double-layer breathable curtain wall maintenance and openable structural system, an internal electric hard shading system, an intelligent adjustment system that automatically senses light and temperature, a curtain wall internal ventilation circulation system, and a night scene lighting system, among others. Unit modules integrate architectural, structural, curtain wall, electromechanical, HVAC, mechanical, lighting, and intelligent control content through system-integrated design. System integration, factory processing and manufacturing of curtain wall units, and on-site assembly construction not only ensure rapid construction of the project but also provide ample technical support for complex systems.

This system leaves a certain width of air layer between the outer glass and the inner openable glass doors, with electric folding blinds in the shape of window flowers set between the layers, capable of automatic adjustment based on lighting conditions. The interlayer cavity and the indoor ventilation, as well as the opening and closing of the electric folding blinds, increase the thermal comfort and adjustability of the indoor space. The comprehensive K-value of the maintenance structure system is 1.4, effectively achieving passive energy saving for the building as well as active breathing and ventilation capabilities.

The large atrium skylight curtain wall system of the building's interior integrates seven subsystems, addressing multiple system functions such as structure, drainage, lighting, electric opening, smoke exhaust, shading, and photovoltaic panel fixing for the large skylight. A large-span lower chord steel structure system is used for the structure. These functions are all systematically integrated into the roof skylight curtain wall system, with integrated design, factory processing and integration, assembly construction, and intelligent operation and maintenance (Figure 4).

Figure 4 - High-Performance Integrated Composite Functional Envelope System

3.4 Integrated Indoor Decoration Engineering System

The above-ground part of the project employs modular spliced overhead flooring, with walls using integrated curtain walls for decoration and assembled finished partition systems. The ceiling employs an integrated equipment ceiling system. The inner curtain wall facing the atrium employs a full-framed unit curtain wall system, also adopting an integrated intelligent detection and control system, as well as integrated design for insulation, heat insulation, fire protection, and decoration. A steel frame curtain wall is set on the inner side of the unit plate, with a steel glass inspection door set in the visible area, and electric shading roller blinds between the two layers of glass panels (Figure 5).

A large number of prefabricated autoclaved lightweight aerated concrete wall panels are used for internal partition walls, mainly used in bathrooms, above-ground equipment rooms, staircases, elevator shafts, anterooms, pipe shafts, and restrooms. Considering the flexibility, sustainability, and expandability of the internal space in the office area, deformable partition walls are used for spatial division, all of which are prefabricated in factories and assembled on-site.

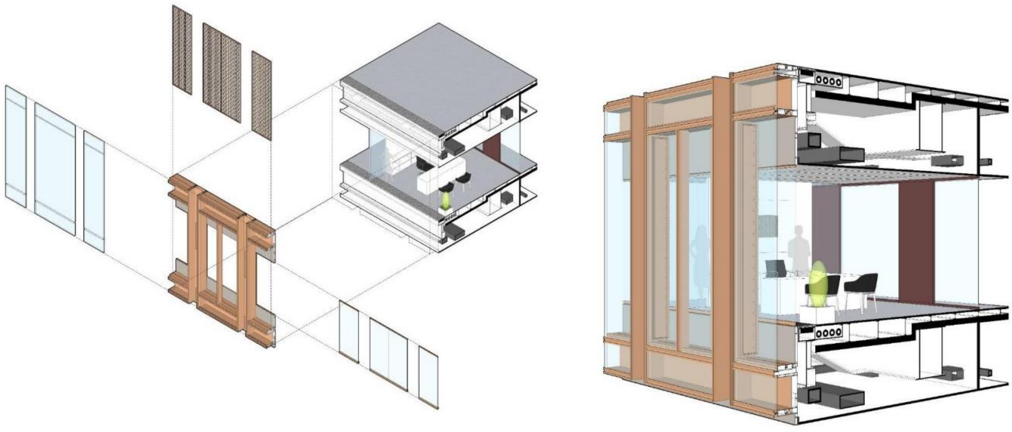

Figure 5 - Unitized Curtain Wall Component Decomposition

3.5 Integrated Equipment Modules and Separated Pipeline System

In this project, the equipment and pipeline systems adopt an assembly method. From the beginning of the project design, relying on BIM technology, the detailed design of the integrated three-dimensional model of the pipeline was carried out in advance to determine the direction, location, and elevation of the equipment pipelines, and to precisely dock with the building component factory, reserving holes for the equipment pipelines in advance. At the same time, the main parts and components such as ventilation ducts, water pipes, cable trays, trough boxes, and supports and hangers are all produced in batches in the factory, achieving a high degree of assembly construction on site. The equipment room achieves a highly efficient use of space through the three-dimensional pipeline optimization layout in the BIM system (Figure 6).

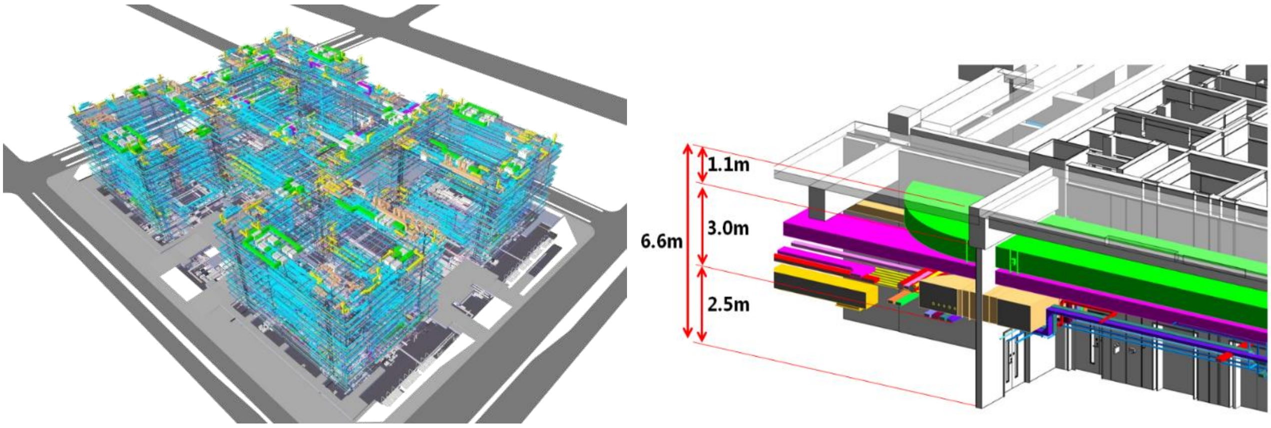

Figure 6 - Pipeline Integrated Design

3.6 Operation and Maintenance Management System Based on the Integrated BIM System

The smart management platform in the operation and maintenance phase of this project continues to use the key BIM design models and data from the design and construction phases. After lightweight processing, it is imported and completed, forming a common result of all stages of the building design life cycle. At the same time, based on the "digital twin" information of design and construction, a smart operation and maintenance management platform has been established. In the operation and maintenance process, the system-integrated assembly unit system becomes a series of unit modules that play independent functions and are closely connected to the entire system, laying a solid foundation for the lightweight data structure of the operation and maintenance platform and the high efficiency of operational implementation.

Conclusion

The project has a construction area of nearly 390,000 square meters, and the construction period from design to commissioning is only 3 years, delivered on time and with high quality. In 2019, the project became a national assembly-type demonstration AAA-level project under China's Ministry of Housing and Urban-Rural Development, and in 2020, it became the only public building demonstration and promotion project for assembly-type construction in Beijing. The improvement in quality and efficiency of the project is attributed to the system-integrated architectural design technology based on digital methods established in the early stages of the project, representing a theoretical exploration and practical application of the standardized system of assembly-type construction in the digital era.

REFERENCES:

1. Ding Lieyun. Introduction to Digital Construction. China Architecture & Building Press, 2020.
2. Xu Weiguo. Digital Architectural Design Theory and Methodology. China Architecture & Building Press, 2019.
3. Liu Dongwei. Prefabricated Building System Integration and Design-Construction Methods. China Architecture & Building Press, 2020.
4. Huang Jian, Fang Tingchen. Digital Construction. China Architecture & Building Press, 2020.
5. Hao Jiping, Xue Qiang. A Systematic Study on Prefabricated Buildings. Journal of Xi'an University of Architecture & Technology, vol. 2019, no. 02, 2019, pp. 12-20.
6. Marble Scott. Digital Workflows in Architecture. Birkhäuser, 2012.
7. Qi Bin, Yang Zheng. Fine Craftsmanship and Smart Operation in the Beijing Olympic Park B27-2 Project. China Art, no. 01, 2019.
8. Liu Chao, Qi Bin, Shuai Yunjing. Research on Detailed Design of Large Complex Spaces Based on BIM Technology. Architectural Techniques, no. 06, 2018.