

The Synergistic Application of Prefabricated Buildings and Smart Management Models

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Abstract. With the introduction of the dual-carbon goal, the construction industry, as a high-energy-consuming and high-emission industry, is urgently in need of a green transformation. Based on the concept of green development, this article explores the construction path of the intelligent construction site management mode and the collaborative application with prefabricated buildings. It first analyzes the guiding role that the concept of green development has in the construction industry. It then systematically presents the core requirements of the intelligent construction site management model from three dimensions: intelligent personnel management and health guarantee, construction site environment monitoring and early warning linkage, and construction progress and material management based on BIM. On this basis, taking the first phase project of Suzhou Aerospace Industrial Park as a case study, the actual application of the intelligent construction site management platform in personnel management, safety management, and quality management of prefabricated buildings is specifically analyzed. Practice shows that the synergy between the intelligent construction site platform and the prefabricated building system is rather remarkable. Deeply integrating the intelligent construction site management mode with prefabricated buildings can effectively raise the building safety level, resource utilization efficiency and management refinement degree, thereby creating a replicable practical path for the construction industry to realize the dual-carbon goal.

Keywords: Green development, Smart construction site, Building information modeling, Prefabricated building

1. Introduction

With the increasing intensification of global warming, low-carbon development has turned into a common vision of all the countries in the world. China has also put forward the dual-carbon goal, which has given rise to new ideas for the green and low-carbon development of various industries. As a significant pillar of the national economy, the construction industry, which has a high proportion of the total social energy consumption throughout its entire life cycle and also ranks at the top among all industries in terms of carbon emissions, is in urgent need of a low-carbon and green transformation. In recent years, the carbon emissions of China's construction industry all reach the level that is 2.27 billion tons, accounting for 50.9% of the national carbon emissions, and also account for 45% of the national energy consumption [1]. Compared with green buildings, traditional

buildings with increasingly prominent problems of high energy consumption and high emissions do not meet the development requirements of the dual-carbon goal. The establishment of a smart construction site management platform has paved a new path for the construction industry to transform towards green and environmental protection. This platform makes use of building information modeling (BIM) and by means of various hardware devices like sensors and monitors to carry out modularized management, changing passive control into active management, thereby making it possible to have visual and collaborative safety management throughout the whole life cycle of the building. As an important practical form of green buildings, prefabricated buildings which are characterized by factory production and modular installation highly match the information management approaches of the intelligent construction site management platform, providing typical scenarios for the intelligent management mode. From the perspective of green development, this paper constructs an intelligent construction site management platform, takes prefabricated buildings as an example, and analyzes the specific practices of transitioning from the traditional construction mode to the low-carbon intelligent management mode, thus promoting the green development transformation of the construction industry and contributing to the national dual-carbon goal.

2. The guiding role of the green development concept in the construction industry

2.1. The core connotation of the green development concept

Green buildings are concrete forms of the green development concept in the construction industry. Their core goal is to reduce environmental impacts throughout the building life cycle. The realization of this goal relies on the technologies and management methods provided by intelligent construction site platforms. Prefabricated buildings, in turn, serve as important carriers of the green building concept during the construction phase. The core connotation of the green development concept comprises low-carbon, energy-saving, and efficient aspects, and its values are reflected in environmental, economic, and social dimensions.

The core connotation of green transformation reflected in environmental value is low-carbon. Green buildings are able to effectively reduce energy consumption throughout the entire life cycle of building construction. In the design phase, reasonable material planning can avoid waste caused by excessive materials. In the construction phase, suitable management models and production plans can cut down carbon emissions, and the emissions of building waste gases and waste waters will also be significantly reduced, thereby easing the pressures of environmental pollution and energy shortage.

The main connotation of green development in the aspect of economic value lies in energy conservation, which is mainly manifested in the new-type building materials, construction technologies and building equipment used in the construction management process throughout the whole life cycle of green buildings. In terms of short-term implementation effects, green and low-carbon design may increase material costs and design inputs, yet from the perspective of long-term development, it can reduce energy consumption costs and building maintenance costs and also prolong the service life of buildings.

The manifestation of green development in social value is quite effective. Green buildings can improve the internal environment, enhance user experience, provide the public with healthy and environmentally friendly living spaces, and guide the public to form green and low-carbon lifestyle and consumption habits [2].

2.2. The specific application of the green development concept in building construction

The traditional construction industry management and construction models, which mainly focus on the project progress speed and the rapid operation of economic benefits, neglect things like energy consumption control and ecological environment protection. During the construction process, a large amount of redundant energy is wasted; its value is not fully utilized, various types of construction waste are casually piled up or discarded, and directly discharged into the natural environment without proper treatment. Such a widespread practice not only brings a heavy burden to the ecological environment around the construction site but also runs counter to the requirements of green and sustainable development.

The green development concept brings new demands to the industry. The first is to reduce carbon emissions, which contributes to controlling the global greenhouse effect, reducing construction dust, noise pollution, and waste discharge. The second is to recycle and reuse construction waste, which can enhance resource utilization efficiency. Guided by the green development concept, green building projects aim to scientifically manage resources within a reasonable range, maximize their value, and eliminate unnecessary waste. The core of building energy conservation lies not in reducing the amount of use, but in improving energy utilization efficiency.

3. Construction of the core management model of smart construction sites

3.1. Intelligent personnel management and health protection model

An intelligent construction site management platform has developed a comprehensive intelligent personnel management system that integrates multiple management modules such as personnel positioning, attendance, health monitoring, and real-time protection. Based on biometric recognition technologies like fingerprint recognition, facial recognition, and iris recognition, the platform is able to accurately identify the workers on the construction site. Meanwhile, with the assistance of radio frequency identification (RFID) positioning terminals, real-time positioning and tracking of workers can be carried out, achieving the visual monitoring of personnel activity trajectories. This personnel management platform also establishes an intelligent attendance database, which gives each employee an independent real-name account and links it with their biometric information, enabling electronic clock-in. Since biometric features have individual uniqueness, this technology can effectively prevent proxy clocking-in. Managers can, through the intelligent management platform, promptly grasp the workers' attendance status and reasonably arrange work tasks, thereby avoiding safety accidents caused by insufficient personnel or excessive fatigue. On the construction site, the intelligent wearable devices are used to locate the construction workers and managers, monitoring in real time the distribution of personnel and feeding back the monitoring information to the management platform in a timely manner. Smart wearable devices can also collect workers' physical indicators in real time, such as blood pressure and heart rate. When the platform detects that physiological indicators like heart rate and blood pressure are abnormal or the positioning signal remains stationary for a long time, it immediately triggers an alarm signal so that rescue measures can be taken in time to ensure the life safety of personnel [3]. Meanwhile, according to different building environment characteristics such as noise, dust and chemical harmful substances, the platform will provide protection recommendations to managers based on preset thresholds and data analysis results, assisting them in formulating targeted prevention and control plans.

3.2. Construction site environmental monitoring and early warning linkage

In the key areas of the construction site, relevant construction environment monitoring equipment is installed. The intelligent construction site management platform can be connected to the dust and noise monitoring equipment deployed in key areas of the construction site, thus obtaining the real-time data of the on-site dust concentration and the noise decibel level. This platform will automatically compare the data with the pre-set control limits. Once the numerical value is detected to exceed the standard, the on-site sprinkler system for dust reduction will be directly activated, and corresponding noise reduction measures will be implemented simultaneously. In addition, the alarm information will be pushed to the management personnel to ensure that the pollution problem can be quickly responded to and effectively solved. Moreover, depending on the long-term accumulation and in-depth analysis of dust and noise monitoring data, not only can the actual effectiveness of construction site environmental governance be evaluated quantitatively, but also solid data support can be provided for optimizing green construction plans and refining environmental protection management measures. This will support the continuous improvement of on-site environmental management toward refinement, low-carbon performance, and green development.

Additionally, in order to cope with the influence of the natural environment, the intelligent construction site management platform is equipped with a meteorological monitoring station that can collect all-round meteorological information of the construction site in real time, like temperature, humidity, wind speed, wind direction and rainfall. This meteorological monitoring station is not only an important guarantee for construction safety—when encountering adverse weather such as heavy rain, strong winds, or lightning, it can promptly halt the high-altitude operation, shut down large equipment like tower cranes, and also take preemptive protection measures and so on—but also a key tool for the project to practice green development. Through the early warnings based on meteorological data, the construction arrangements can be optimized in advance to avoid inefficient operations and equipment idleness under adverse weather, thus directly reducing the existing energy consumption and material waste. Meanwhile, it can also reduce the resource waste that is caused by facility damage, reworking and repairing because of disasters, thereby contributing to the dual-carbon goal by reducing carbon emissions at the source.

3.3. Bim-based construction progress and material management

The construction project has a rather extensive scope with a great number of overlapping processes and the construction organization is quite complicated. An intelligent construction site management platform based on BIM technology has developed a four-dimensional visual progress management model. The management team, through BIM models, carries out a comprehensive analysis on the pipeline layout, and in advance identifies the collision positions between equipment pipelines and structural components, and then formulates preventive measures. The BIM platform that deeply integrates the construction progress with the three-dimensional entity model generates intuitive construction simulation animations and provides the basis for the coordination of various professional processes [4]. Based on the time-space information in the BIM model, the system automatically identifies the overlapping operation areas, optimizes the process sequence, and reduces the mutual interference between multiple professions during the construction process. Project managers can also rely on the virtual construction environment built by the platform to verify the practicability of construction technologies, systematically arrange construction sites, and plan the operating ranges of large-scale mechanical equipment [5]. Through BIM simulation and process optimization, idle labor and equipment downtime during construction can be reduced,

unnecessary energy consumption and material waste can be decreased, thereby achieving the coordinated improvement of construction progress and green benefits.

4. Application of the smart construction site management platform in prefabricated buildings

4.1. Overview of prefabricated buildings

Against the backdrop of the dual-carbon goal and the transformation of the construction industry, prefabricated buildings, with their advantages in prefabricated components and on-site assembly, have become an important way for the green development of civil engineering and also better meet the construction requirements of smart construction sites. The prominent advantage of prefabricated buildings lies in that components are prefabricated in factories and only need to be assembled and installed on the construction site which greatly reduces wet operations on site [6]. When prefabricated construction and an intelligent construction site management platform are combined, a relatively complete construction plan can be formulated at the early stage of construction. Meanwhile, by introducing the BIM technology, the precise amounts of steel bars, concrete, and various decorative materials can be calculated, so the materials can be used in accordance with the quota and purchased as needed, thereby reducing resource consumption at the source.

4.2. Project overview

The phase-one project of the aviation industrial park that is located at the intersection of Kangyuan Road and Chengyue Road in Xiang Cheng District, Suzhou has a total land area of 41,000 square meters and a total floor area of 184,000 square meters. The above-ground portion comprises 19 storeys with a total height of 90 meters, while the two-story underground area covers approximately 64,000 square meters. This project includes four commercial office buildings in a point-type layout. This park mainly centers around comprehensive office and supporting commercial facilities, with an office area of 110,000 square meters and a commercial area of 7,000 square meters. This industrial park engages in intelligent construction management, and by means of the digital construction platform, the key elements of construction projects like "personnel, machinery, materials, methods, environment" are digitized, thereby realizing the comprehensive perception and real-time interconnection of the construction site. This is interconnected with the cloud-based digital virtual construction site, thereby establishing an intelligent construction site management platform. The combination of intelligent control and prefabricated construction can lead to a highly efficient and rapid construction, at the same time, it can also cut down the energy consumption and environmental pollution in the construction process [7] .

4.3. Personnel management application

The intelligent construction site management platform has proposed customized and targeted training programs for special operation posts, realizing the targeted skill development for specific work capabilities. With big data technology as the core tool, this platform transforms workers' daily work performances into quantifiable evaluation indicators, establishing a digital and detailed performance evaluation system. The intelligent management system is able to dynamically optimize the on-site personnel configuration, flexibly allocate human resources in accordance with the rhythm of the project progress, and then maximize labor efficiency. This platform also innovatively integrates a function of evaluating workers' skill levels, carrying out hierarchical certification

management on workers' professional abilities, thereby providing a decision-making basis for project departments to select technical personnel. Through the production and assembly of prefabricated buildings, and through the reasonable utilization of the intelligent construction site management platform, the management efficiency can indeed be effectively enhanced. By means of the platform's big data, attendance records can also be recorded in real time, which protects the legal rights and interests of the workers and also avoids labor disputes.

4.4. Safety management application

Lifting operations are the top priority in the construction process of prefabricated buildings. The parameters of prefabricated components that the BIM model carries and the information of RFID tags are associated and then imported into the big data platform of the intelligent construction site, so that the pre-simulation and dynamic optimization of the lifting plan can be completed in advance, realizing more precise risk classification and control as well as more efficient process sequencing and coordination. Risk classification and control is no longer dependent on manual judgment; instead, it is based on data like component weights, size specifications, installation heights, and operation difficulties, and the platform automatically finishes the risk level classification of lifting operations [8]. Among these, the components whose weight exceeds ten tons and the high-altitude lifting operations above twenty-five meters will automatically be classified as level 1 risks. The system will then mandate safety technical disclosure, generate inspection checklists (including rigging inspection, lifting point verification, and tower crane condition checks), and trigger a supervision mechanism with dedicated safety personnel on duty. According to the construction and installation sequence of prefabricated components this platform can automatically decompose the lifting operations of each floor into multiple lifting batch groups and will intelligently sort them in line with the principle that later installation does not interfere with earlier ones, thereby minimizing the idling and stopping time of the tower crane to the greatest extent and then improving the work efficiency of component assembly and connection.

4.5. Quality management application

Relying on the intelligent construction site management platform, a whole-life cycle management system for prefabricated components is established through BIM technology and RFID technology. This system encompasses the production stage, the transportation stage as well as the installation stage. The production stage manages the entire process of dispatching prefabricated components from the factory. Project personnel place orders through the platform for component production including RFID tag information, component specifications, and design grades, and then arrange workshop production according to priority. In the transportation phase, the transportation stage is responsible for transporting the components from the production factory to the project site and connecting them. Relying on BIM technology, the transportation routes of the prefabricated components are optimized, and combined with the specified transportation plans and the real-time feedback from the construction end, it accurately guides the on-site loading and unloading operations. The installation stage is the core implementation stage in which the prefabricated components are assembled on-site to form a physical building. It is mainly composed of two parts, one part is the installation process management, and the other is the on-site component warehouse management. Progress management coordinates each process node and controls the overall construction rhythm, while warehouse management handles temporary storage and circulation of on-site components, providing efficient material support for continuous installation [9].

4.6. Application effect analysis

By applying the intelligent construction site management platform and BIM technology, the five-dimensional life cycle management of "personnel, machinery, materials, methods, and environment" in prefabricated buildings is realized. The safety performance in each key aspect of this project has been significantly improved, and the specific implementation effect data are shown in Table 1.

Table 1. Comparison of safety risk control implementation effects of the smart construction site management platform

Risk Dimension	Pre-control Indicator Value	Post-control Indicator Value	Control effect
Personnel	Training coverage rate 78%	Training coverage rate 100%	Violation operations decreased by 62%
Machinery	Large equipment utilization rate 94.1%	Large equipment utilization rate 99.2%	Rework caused by incorrect installation reduced by 100%
Materials	Waste recycling rate 40.7%	Waste recycling rate 80.1%	Construction costs significantly reduced
Management	BIM on-site synchronization rate 70%	BIM on-site synchronization rate 95%	Incorrect and erroneous installation incidents reduced to zero
Environment	Severe weather caused construction delays	System response rate 100%	Zero delay in high-altitude operation instructions

The above-mentioned practice shows that the synergy between the intelligent management platform and prefabricated buildings is particularly evident in the two aspects of safety control and resource utilization. The intelligent construction site management platform and the prefabricated building system cooperate with each other, which effectively raises the safety level of the project and efficiently promotes the project management process, thereby creating a replicable and popularizable practical example for the safe and efficient implementation of high-assembly-rate, high-rise residential projects [10].

5. Conclusion and outlook

5.1. Conclusion

From the perspective of the green development concept, this article systematically constructs the core management mode of the smart construction site, and then verifies its application effect through the case study of prefabricated buildings. By integrating the next-generation information technologies like the Internet of Things, BIM, and RFID, the technology of the smart construction site can realize the real-time control over the personnel, the real-time monitoring of the construction site environment, and the precise management of the construction materials. As an important carrier for transformation and upgrading, prefabricated buildings effectively address prominent problems in traditional construction, such as on-site wet operations, material waste, and construction dust. Through the deep integration of prefabricated construction and intelligent construction site

management models, prefabricated construction will develop in a more digital and intelligent direction. At the same time, the concepts and practices of intelligent construction sites are fully reflected in the application of prefabricated construction, forming a management system that fits the dual-carbon goal and also brings new ideas to the innovation of the construction industry.

5.2. Outlook

At present, the in-depth application of the intelligent construction site management system still has several limitations, for example the requirement of professional talents to support the BIM technology operation and maintenance, the relatively high initial investment cost of RFID hardware facilities, and the lack of a unified technical standard in the industry. In the future, it is necessary to strengthen the integration of BIM with the Internet of Things and big data technologies, promote the standardized deployment of sensing devices such as RFID in the construction industry, reduce the cost of information exchange between systems, thereby providing technical support for the construction industry to realize the dual-carbon goal.

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