2025 Volume 3, Issue 8
Educational Innovation Research
ISSN: 3029-1844(Print)
ISSN: 3029-1852(Online)

Quality Management Measures for Prefabricated Buildings under the Background of Intelligent Construction

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Abstract

The in-depth penetration of intelligent construction technology has brought revolutionary changes to the quality management of prefabricated buildings. Relying on core technologies such as BIM, the Internet of Things, big data, and artificial intelligence, the quality management model of prefabricated buildings has achieved an all-round upgrade. Through digital modeling, intelligent monitoring, data-driven traceability, and other means, quality management has shifted from traditional post-event remediation to pre-event control. The full-lifecycle quality information has become traceable, and management decisions have become more scientific and forward-looking. Based on the technical characteristics of intelligent construction, this paper analyzes the core value of quality management for prefabricated buildings, elaborates on the specific application scenarios of relevant technologies, and proposes quality management measures, including the construction of a collaborative platform, the establishment of a traceability system, the implementation of intelligent acceptance, and the execution of dynamic early warning. It provides practical reference for improving the engineering quality of prefabricated buildings and promoting the high-quality development of the industry.

Keywords

Intelligent construction; Prefabricated buildings; Quality management; BIM technology; Internet of Things; Full lifecycle; Risk early warning

Online publication: September 26, 2025

1. Introduction

Prefabricated buildings, featuring factory prefabrication of components and on-site assembly construction, have significant advantages such as high construction efficiency, low resource consumption, and minimal environmental impact. They have become an important direction for the transformation and upgrading of China's construction industry. With the acceleration of the new-type construction industrialization process, the proportion of prefabricated buildings in urban and rural construction has continued to rise, but the field of quality management still faces many challenges [1]. The traditional management model relies on manual experience, resulting in a poor connection between design and construction. Information is fragmented in links such as component production, transportation, and installation, making it difficult to detect and trace quality problems in a timely manner, which restricts the sustainable development of the industry. As a new construction model integrating digital and intelligent technologies, intelligent construction provides a key path to solving the quality management problems of prefabricated buildings. Its core lies in reconstructing the quality management process through the integrated application of BIM, Internet of Things (IoT), artificial intelligence (AI), big data, and other technologies, realizing precise control throughout the entire cycle from design to operation and maintenance [2]. In this context, exploring quality management measures for prefabricated buildings supported by intelligent construction technology, optimizing the management system, and improving quality control efficiency not only meets the requirements of the times for the high-quality development of the construction industry, but also lays a solid foundation for the large-scale promotion of prefabricated buildings, which has important practical significance and practical value.

2. The value of quality management for prefabricated buildings under the background of intelligent construction

2.1. From post-event remediation to pre-event control

Traditional quality management of prefabricated buildings mostly relies on acceptance testing after construction. Quality problems are discovered too late, leading to high rectification costs and affecting project progress. The application of intelligent construction technology has changed this passive situation [3]. The 3D digital model constructed by BIM technology can complete collaborative collision checks among various professions in the design stage, and identify potential problems such as component size conflicts and pipeline layout contradictions in advance. Simulation technology can restore the entire construction process and predict construction difficulties such as unreasonable hoisting sequences and node connection risks [4]. Through digital means of early intervention, quality hazards are eliminated at the bud, the incidence of quality problems is greatly reduced, and quality management is transformed from passive response to active prevention.

2.2. Realization of full-process data-driven quality traceability

The production, transportation, installation, and other links of prefabricated building components involve multiple subjects. Under the traditional management model, the transmission of quality information is prone to omissions and distortions, making it difficult to accurately define quality responsibilities. The application of IoT, RFID, and other technologies breaks down the barriers of information transmission. From the start of component production in the factory, information such as raw material specifications, production process parameters, and quality inspection results is recorded in the system in real time. During transportation, GPS positioning technology records the transportation trajectory and environmental conditions of components. The construction personnel, operation processes, and acceptance results in the on-site installation link are also uploaded synchronously [5]. The digital recording of full-lifecycle quality information ensures that quality problems can be queried and responsibilities can be traced, providing a reliable basis for handling quality disputes.

2.3. Driving intelligent quality management decisions

Traditional quality management decisions for prefabricated buildings mostly rely on the experience and judgment of managers, which is highly subjective and difficult to cope with complex quality data. Under the background of intelligent construction, the combination of big data and AI algorithms realizes the scientific upgrading of quality management decisions. The system collects and integrates massive quality data from design, production, construction, and other links, and through in-depth analysis by AI algorithms, automatically identifies the laws and patterns of quality risk occurrence [6]. Based on the analysis results, the system can early warn high-risk links and provide targeted optimization suggestions for managers, transforming decisions from experience-driven to data-driven, and improving the accuracy and effectiveness of quality management.

3. Specific applications of intelligent construction technology

3.1. Digital building model design

Digital building model design is centered on BIM technology, breaking the limitations of traditional 2D design. By constructing a 3D model containing multi-dimensional data such as component geometric information, material properties, and process requirements, the integrated expression of design information is realized [7]. During the design process, professionals from various fields work collaboratively based on the same model, sharing design ideas and modification contents in real time, and reducing design conflicts between professions. The model can be directly connected to component production factories, accurately transmitting design parameters to production equipment, avoiding information deviations in the traditional drawing transmission process, ensuring that component production is highly consistent with design requirements, and laying the foundation for subsequent quality management [8].

3.2. Intelligent construction process control

Intelligent construction process control achieves precise management and control of the construction process by leveraging automated equipment and information systems. In the component hoisting phase, unmanned aerial vehicle (UAV) surveying and mapping technology plans the hoisting path in advance. Automated hoisting equipment, equipped with laser positioning devices, completes component positioning and installation according to preset procedures, with errors controlled at the millimeter level—greatly reducing deviations caused by manual operations. For key processes such as steel bar binding and sleeve grouting, intelligent construction equipment is adopted. Sensors are used to monitor construction parameters in real time, including grouting pressure and vibration frequency [9]. If the data exceeds the standard range, the equipment automatically shuts down for adjustment immediately, ensuring the construction process complies with quality standards. During the construction process, the system automatically records information such as the construction time of each process, operators, and equipment operation status, forming an immutable construction data chain. This enables the construction process to be monitorable and controllable, providing a complete basis for subsequent quality traceability [10].

3.3. Visual construction management

Visual construction management realizes the intuitive presentation and dynamic control of the construction process through technologies such as digital twins and virtual reality/augmented reality (VR/AR). Digital twin technology constructs a virtual model that synchronously maps with the physical project, real-time updating the construction progress and quality status. Managers can remotely view the overall project situation via computer or mobile terminals; by clicking on a virtual component, they can access the corresponding physical component's construction records and quality inspection data, allowing timely detection of quality issues during construction [11]. VR/AR technology overlays the design model with the real scene of the construction site. Construction workers, by wearing intelligent devices, can see precise positioning markers for component installation and guidance on operation steps—reducing quality risks caused by misunderstandings. Meanwhile, the visual platform supports real-time marking of quality issues and collaborative rectification. Personnel from all parties can directly communicate through the platform, clarify rectification requirements and time limits, and track the rectification progress throughout the process. This makes quality management more intuitive and convenient, improving management efficiency and control effectiveness [12].

3.4. IoT-driven full-cycle component management

IoT technology runs through the entire cycle of component production, transportation, installation, operation, and maintenance, realizing intelligent and refined component management. In the production stage, sensors real-time monitor environmental parameters such as temperature and humidity during component production to ensure stable production processes. In the transportation stage, the combination of RFID tags and GPS positioning technology real-time tracks the transportation location and status of components, avoiding component damage or loss [13]. In the installation stage, IoT equipment collects data such as component installation accuracy and connection quality to ensure that the installation meets specifications. In the operation and maintenance stage, sensors continuously monitor the service status of components, providing data support for later maintenance and realizing full-cycle quality control of components.

4. Quality management measures for prefabricated buildings under the background of intelligent construction

4.1. Constructing an integrated digital collaborative management platform

The integrated digital collaborative management platform is centered on the BIM model, integrating resources from design, production, construction, supervision, and other parties, and breaking information silos [14]. The platform connects the data interfaces of design software, production management systems, and construction monitoring equipment to realize the real-time flow and sharing of quality information. The design party uploads the BIM model and quality control requirements on the platform, the production party real-time feeds back the component production progress and quality inspection results, the construction party uploads on-site installation quality data, and the supervision party completes quality acceptance and rectification supervision online [15]. All quality inspection, acceptance, and rectification records are documented online, forming a complete quality file. All parties communicate and work collaboratively in real time through the platform, solving quality problems in a timely manner, ensuring the transparency and efficiency of the quality management process, and improving the overall control level.

The platform has data integration and analysis functions, automatically summarizing quality data from various links, generating quality analysis reports, and providing managers with a comprehensive view of quality status. At the same time, the platform supports hierarchical permission management, ensuring that different participants can only obtain information within the scope of their relevant permissions and ensuring information security. Through integrated collaboration, quality management is transformed from decentralized to centralized, and from fragmented to systematic, providing solid technical support for the quality management of prefabricated buildings.

4.2. Establishing a unique component coding and traceability system

Formulate unified component coding rules, and assign a unique identity code to each component based on key information such as component type, production batch, and specification size. The coding is deeply integrated with IoT technology, attached to the component surface through QR codes or RFID tags, realizing rapid identification and retrieval of component information [16]. Scanning the tag can obtain complete information of the component, including raw material suppliers, production equipment parameters, quality inspection data during production, factory inspection reports, transportation vehicle information, transportation trajectory, on-site installation time, operators, acceptance results, etc.

This system clarifies the main quality responsibility body. Once a quality problem occurs, it can quickly be traced back to the specific production batch, construction link, and the relevant responsible person, providing an accurate basis for the investigation and rectification of quality problems. At the same time, the coding system facilitates the inventory management and scheduling of components, avoiding quality hazards caused by incorrect or mixed use of components [17]. The unified coding rules ensure that different participants have a consistent understanding of component information, improve communication efficiency, provide reliable information support for full-life-cycle quality management, and strengthen the quality responsibility awareness of all links.

4.3. Implementing intelligent quality acceptance based on AI vision

Deploy high-definition cameras, laser scanners, and other equipment at key process nodes of the construction site, and combine AI visual recognition algorithms to build an intelligent quality acceptance system [18]. For key indicators that are difficult to inspect manually and highly subjective, such as sleeve grouting fullness, component connection node installation accuracy, steel bar spacing, and concrete pouring quality, AI algorithms automatically analyze the collected images and data. The system presets quality acceptance standards, automatically identifies construction parts that do not meet the specifications, generates quality problem reports, and clarifies the location, type, and severity of the problems.

Intelligent quality acceptance replaces part of manual inspection, which not only greatly improves acceptance efficiency and reduces labor costs, but also avoids judgment deviations caused by human factors, improving the objectivity and accuracy of acceptance results. Acceptance data is uploaded to the management platform in real time, and managers can timely grasp the construction quality status and urge the construction party to rectify within a time limit. For complex quality problems, the system can retain image data, providing a basis for subsequent analysis and traceability [19]. Through the in-depth application of AI vision technology, intelligent and standardized quality acceptance is realized, ensuring the construction quality of key processes.

4.4. Implementing data-driven dynamic risk early warning

Integrate multi-source data throughout the construction process of prefabricated buildings, including environmental data, equipment operation data, process parameter data, component quality data, etc., to build a quality risk prediction model. Environmental data includes meteorological information such as temperature, humidity, wind speed, and rainfall at the construction site. Equipment data includes the operation status, fault records, and maintenance conditions of construction machinery. Process data involves operating parameters and construction time of various construction processes. Through big data technology, these data are cleaned, integrated, and analyzed to explore the correlation between data and identify the inducing factors and evolution laws of quality risks.

When the system detects abnormal data, such as ambient temperature exceeding the allowable range for component installation, equipment operation parameters deviating from standard values, and process operations not complying with specifications, the risk prediction model automatically triggers an early warning mechanism. It pushes early warning information to managers through short messages, platform messages, etc., clarifying the risk location, risk level, and possible quality consequences. Managers take timely intervention measures according to the early warning prompts, such as adjusting the construction plan, overhauling equipment, or suspending construction, to avoid the expansion of quality risks. Dynamic risk early warning realizes the transformation of quality management from passive response to active prevention, improves the forward-looking and effectiveness of quality management, and ensures the stability of project quality.

5. Conclusion

Intelligent construction technology has brought new opportunities for the quality management of prefabricated buildings, promoting the transformation of the quality management model from traditional experience-driven to digital intelligence-driven. Through the realization of core values such as pre-event control, full-process traceability, and intelligent decision-making, the accuracy and efficiency of quality management for prefabricated buildings have been significantly improved. The specific applications of technologies such as digital modeling, intelligent construction, and visual management have provided diversified technical support for quality management. Measures such as building an integrated collaborative platform, establishing a component traceability system, implementing intelligent quality acceptance, and carrying out dynamic risk early warning have formed a full-cycle and multi-level quality management system.

In the future, with the continuous innovation and in-depth application of intelligent construction technology, the quality management of prefabricated buildings will develop in a more intelligent, efficient, and precise direction. The industry should further strengthen technological research and development and promotion, improve relevant standards and specifications, promote the collaborative cooperation of all parties, give full play to the enabling role of intelligent construction technology, continuously improve the engineering quality of prefabricated buildings, help the construction industry achieve high-quality development, and inject lasting momentum into the process of new-type construction industrialization.

Disclosure statement

The author declares no conflict of interest.

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