Research on visual monitoring of prefabricated component assembly process based on workflow and BIM

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Abstract. With the vigorous development of prefabricated construction, data management and dynamic monitoring in the assembly process of prefabricated components have become key challenges. This research thoroughly integrates workflow and BIM technologies, innovatively constructing a comprehensive visual monitoring system. By reshaping the business process, establishing a refined data management model, and designing an efficient visual monitoring system, precise control and management of the assembly process of prefabricated components have been achieved. This system has achieved remarkable results in practical engineering applications. Future research will focus on the in-depth integration of Internet of Things technology and intelligent decision-making optimization, promoting the management of prefabricated construction to a higher level of intelligence.

Keywords: Prefabricated components; prefabricated construction; workflow; BIM; visual monitoring.

1. Introduction

Under the sweeping wave of global intelligent manufacturing [1, 2], prefabricated construction, as a core development model of construction industrialization, is gradually reshaping the architecture industry landscape [3]. However, due to the dynamics and complexity of the assembly process of prefabricated components, traditional management models find it difficult to fulfill the demands of real-time data management, collection, and dynamic monitoring. Although previous research has achieved certain results in production supply [4, 5], transportation scheduling [6-8], and on-site installation monitoring [9-10], there are still significant deficiencies in the effective monitoring of the overall assembly process of prefabricated components. This study aims to fill this gap and build an efficient visual monitoring system suitable for the entire assembly process of prefabricated components.

2. Optimization of the Business Process in the Assembly Process of Prefabricated Components

The traditional "one-way instruction" management mode, which organizes construction resources based on construction tasks, lacks unified and standardized management for the fragmented multi-party management mode of prefabricated construction. This easily affects the transparency and timeliness of the assembly process of prefabricated components, resulting in unclear component status tracking and chaotic assembly instructions during the process, leading to resource waste. Therefore, based on the traditional one-way instruction management mode, this study introduces an active control mode of "site demand-driven + production collaborative allocation" to restructure the assembly process, including the three stages of prefabricated production, distribution, and installation, and embeds a three-level control mechanism of "assembly plan, construction task, and daily assembly plan" to improve the management efficiency of the assembly process.

2.1 Component Factory Production

The traditional component production relies on the delivery list of on-site demand, which increases the risk of idle production resources. The active production mode proposed in this study actively determines the actual component demand list based on the on-site overall assembly plan and technical scheme and forms an accurate production plan through in-depth communication and adjustment with on-site management. This transformation not only improves the accuracy of the production plan but also significantly enhances the turnover efficiency of production resources, optimizing the starting link of the assembly process from the source.

2.2 Component Distribution and Transportation

The distribution and transportation link is easily affected by the disconnection between the overall assembly plan and the daily assembly plan, resulting in an imbalance in component supply. To achieve this, the study decomposes the overall assembly plan into assembly tasks with specific constraint conditions, tightly associating them with the daily assembly plan to formulate a precise daily demand plan. Logistics personnel conduct outbound distribution and delivery according to this plan and complete the transportation process after on-site inspection, ensuring seamless docking between the overall and daily plans, effectively avoiding the problems of component shortage or redundancy, and realizing efficient collaborative allocation of resources.

2.3 Component On-site Assembly

During the on-site assembly stage of components, the assembly team simultaneously conducts assembly process acceptance and dynamic data collection when executing the daily assembly plan. The collected data covers key information such as component progress, personnel operations, and safety and quality. Through timely collection and updating, the credibility and timeliness of the data are substantially enhanced, laying a solid foundation for subsequent visual management and facilitating the refinement and digitalization of assembly process management.

3. Construction of the Data Management Model in the Assembly Process of Prefabricated Components

3.1 Data Classification and Collection

3.1.1 Collection of Prefabricated Component Status Data

(1) Progress Data: Quantitative Evaluation of Assembly Process: Taking the completion rate of assembly process nodes as the core indicator of progress data, the assembly progress of each component is accurately quantified through a scientific calculation formula, providing a key basis for the dynamic adjustment of the overall assembly plan.

(2) Quality Data: Integration of Full-process Quality Information: By automatically linking the quality acceptance processes of each link, information such as acceptance data, images, problem descriptions, and handling procedures is comprehensively integrated, constructing a comprehensive quality traceability chain to ensure precise localization and effective management of quality issues.

(3) Component Logistics Data: Dynamic Monitoring of Circulation Status: Based on the state changes of key assembly process nodes, data related to the production, transportation, and installation of components in the logistics process are automatically obtained, realizing real-time dynamic tracking of the logistics status of components throughout their life cycle.

3.1.2 Collection of Assembly Process Management Data

(1) Node Data: Real-time Capture of Operation Details: During the acceptance process of assembly process nodes, detailed information such as operators, operation time, results, and attachments is automatically obtained, providing microscopic data support for the refined management of the assembly process.

(2) Process Status Data: Update Driven by Human-computer Interaction: Through human-computer operation or QR code scanning, the process status is updated in real-time, accurately reflecting the states of nodes such as not started, in progress, completed, or delayed, ensuring that the management decision-making layer can timely grasp the process dynamics.

(3) Assembly Plan Construction Data: Association Analysis between Plan and Execution: Closely associated with the assembly plan, integrating node data and progress data to achieve a comprehensive analysis of the actual execution of the plan, providing a data-driven basis for plan optimization and resource allocation.

3.2 Construction of the Data Collection Model

The assembly data collection model based on the process deeply integrates component on-site inspection, assembly process nodes, and the BIM model, and nests the data collection process seamlessly into the assembly process. This innovative design enables the rapid location of component technical information within the assembly process, greatly improving the efficiency and quality of data collection and laying a solid foundation for the effective organization and real-time management of data.

3.3 Establishment of the Visual Model

Using workflow technology to construct a visual model, a flowchart is created according to the rules of the assembly process, integrating multi-source data such as assembly technical schemes, list information, quality specifications, and progress information. Through the instantiation of the assembly process, the automatic transfer and efficient operation of information among different management parties are realized, effectively assisting the precise execution of the assembly construction process and the scientific formulation of management decisions.

4. Design of the Visual Monitoring System in the Assembly Process of Prefabricated Components

4.1 Construction of the Data Organization Model Based on IFC Standards

4.1.1 Data Storage Management: Integration and Association of Multiple Data

Combining the advantages of relational database business processing and the fast access characteristics of XML files, an innovative data storage model is constructed according to IFC standards. The assembly site data is divided into three categories: structured, semi-structured, and unstructured, and is deeply associated with the BIM model. The unique identifier is used to achieve efficient integration and associated access of various data, transforming complex and diverse data into structured data resources that are easy to manage and process.

4.1.2 Data Expression Management: Digital Representation of Assembly Process Elements

Through in-depth analysis of the relationships of assembly activity elements, an information expression method grounded in IFC standards is developed, where abstract assembly activity elements are transformed into information models. The relationships between entities are meticulously defined, the personnel organization structure is refined, and strong connections between organizations, personnel, and activities are forged, realizing the digital and accurate expression of assembly process elements and providing a standardized framework for data processing and analysis of the system.

4.2 Construction of the Electronic Kanban for the Assembly of Prefabricated Components

(1) Data Acquisition: Integration of Omnidirectional Data Sources: The system comprehensively gathers static data, such as preset attributes of the BIM model and IFC files, as well as dynamic data encompassing on-site operations and process statuses, ensuring the comprehensiveness and diversity of data sources and furnishing a robust information foundation for system operation.

(2) Data Matching: Collaborative Management of Multiple Types of Data: Responsible for the accurate matching and storage management of the information in the data layer of the monitoring system, realizing the sharing and interoperability of structured, semi-structured, unstructured, and monitoring data, constructing an efficient data management background to support the collaborative operation of each functional module of the system.

(3) Data Processing: Full-process Data Operation and Optimization: In the business processes such as component production, distribution and transportation, and on-site installation, all-round addition, deletion, query, modification, and update operations are performed on the data to realize the real-time update and process optimization of the data, ensuring that the data is closely integrated with the actual business and providing real-time and accurate data support for decision-making.

(4) Data Visualization: Multi-dimensional Information Display and Interaction: The application layer data is organized and visually managed in a modular manner, integrating functional modules such as prefabricated component tracking, quality inspection analysis, and progress warning. Through the human-computer interaction layer, the information of the assembly process is intuitively displayed and interactively operated, providing a convenient and efficient monitoring interface for managers.

5. System Implementation and Application

5.1 Assembly Plan Decomposition and Model Association

Fig.1 Assembly plan decomposition and BIM model association of prefabricated components

As shown in Figure 1, after receiving the assembly plan from the project department, the on-site administrator subdivides it into specific tasks and accurately associates them with prefabricated components and technical schemes. The system automatically generates a flowchart composed of assembly nodes, realizing a seamless transformation from the technical process to the instantiated assembly process, providing a detailed execution framework for the assembly process, and ensuring the accuracy and efficiency of plan execution.

5.2 Real-time Collection of Dynamic Assembly Data

Fig.2 Electronic signature

Fig.2 Operation records

As shown in Figures 2 and 3, the labor workers conduct assembly construction according to the BIM model and initiate the acceptance application on the APP after completion. Through operations such as filling in opinions, associating attachments, initiating rectifications, and hierarchical approvals by the management personnel, the system automatically completes the real-time collection and update of the component assembly data in the closed-loop management process of approval - rectification - acceptance, covering key information such as component status, process status, and assembly progress, ensuring the timeliness and accuracy of the data and realizing data-driven management of the assembly process.

5.3 Assembly Data Progress Analysis

Fig.4 Comparative analysis of assembly progress and planned progress

As shown in Figures 4, the system automatically completes the in-depth statistical analysis of the overall assembly progress, component progress, and other information based on the collected data and displays the progress situation in intuitive forms such as comparative analysis charts and monthly analysis charts. These analysis results provide timely and accurate decision-making basis for managers, helping to optimize resource allocation, adjust the construction plan, and ensure the timely and high-quality completion of the assembly project.

5.4 Visual Monitoring Board in the Assembly Process of Prefabricated Components

Fig.5 Visual Monitoring Board for the Assembly Process Based on the Overall Project

As shown in Figure 5, the visual monitoring board consists of six parts: safety and quality problem statistics, project progress summary, general information, progress visualization, announcements, and monthly statistical analysis. It displays key project information in diverse forms, such as using a three-dimensional model to show the actual progress and presenting various data statistics in charts, providing a panoramic view of the project for managers.

6. Summary

This study successfully constructs a visual monitoring system for the assembly process of prefabricated components based on workflow and BIM technology. Through innovative business processes, refined data management models, and efficient monitoring system designs, the problems of data management and monitoring in the assembly process of prefabricated components are effectively solved. The practical engineering application verifies the feasibility and effectiveness of this system, providing important technical support and practical experience reference for the intelligent development of the prefabricated construction industry. Future research directions will further promote the in-depth development of this field towards intelligence and automation, helping the sustainable development of the prefabricated construction industry.

Although the visual monitoring system constructed in this study has achieved remarkable results in the management of the assembly process of prefabricated components, there is still room for further improvement. Future research will focus on the following two aspects: one is to develop Internet of Things-based tools for collecting progress and safety and quality information in the assembly process, reducing manual intervention, improving the automation and accuracy of data collection, and reducing the operational difficulty for managers; the other is to conduct in-depth research on the automatic decision-making analysis model of prefabricated components and assembly processes in the assembly process with the daily construction plan as the core, introducing artificial intelligence and big data analysis technology to realize the intelligent optimization of management decisions and further improve the overall efficiency and quality of prefabricated construction management.

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