Optimization and Implementation of Key Technologies in Prefabricated Building Construction-A Case Study from Zhengzhou

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Abstract. With the rapid advancement of construction industrialization, prefabricated buildings have become a crucial development direction due to their advantages in efficiency, environmental protection, and energy conservation. However, in practical construction, numerous technical issues such as insufficient precision in component production and installation, suboptimal joint connection designs, and poor coordination among construction processes frequently occur. This study focuses on a project in Zhengzhou and systematically applies theoretical analysis and engineering practice to comprehensively explore the key technical problems in prefabricated building construction and proposes highly targeted optimization strategies. The results show that the optimized construction techniques significantly enhance the precision of component installation, the stability of joint connections, and the coordination of construction processes, thereby providing a solid scientific foundation and practical reference for the development of prefabricated building construction technology.

Keywords: Prefabricated buildings; Optimization of construction technology; Component precision; Node connection; Coordination of construction process

1   Introduction

Amid the construction industrialization drive, prefabricated buildings have gained wide acceptance in China for their advantages. However, issues like component precision, node connections, and process coordination hinder construction quality and efficiency[1]. The Zhengzhou project, with an assembly rate over 50% and diverse prefabricated components, faces problems such as reinforcing bar height adjustment in composite slabs and node connection instability[2]. Our study focuses on systematically analyzing and optimizing these key technical problems. While previous research has addressed some of these aspects separately, our work attempts to integrate and deepen the understanding of their combined impacts and solutions. By doing so, it provides a

more comprehensive reference for similar projects and contributes to the development of prefabricated building construction technology in a more systematic way.

2   Overview of the Zhengzhou Project

2.1   Basic Project Information

The Zhengzhou project, located at the northwest corner of the intersection of Zhengshang and Huxi Roads in Zhengzhou, covers a total area of about 338,578.20 m². It comprises several high-rise buildings and supporting facilities. Four of them adopt prefabricated construction technology, attaining an assembly rate over 50%. The structure is of frame-shear wall type. It uses various prefabricated components like precast exterior walls, bay windows, composite slabs, air-conditioning panels, staircases, and precast internal partition walls with integrated pipelines. These are factory-produced and assembled on site, improving efficiency but also causing some issues.
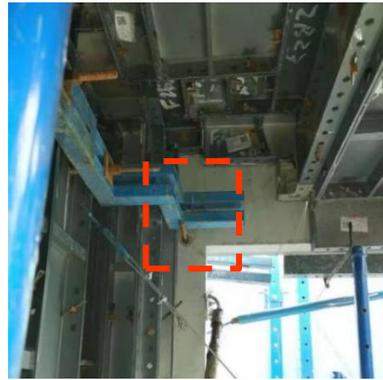
2.2   Challenges Faced During Construction

2.2.1. Component Production and Installation Precision Problems.

Certain prefabricated composite slab truss reinforcements exhibit height deviations of up to ±2 mm from the design specifications, necessitating on-site adjustments (Figure 1.). The positioning of reserved holes in prefabricated components deviates by 5 - 10 mm from the aluminum formwork backing ribs, augmenting the risk of concrete leakage (Figure 2.). On-site measurements reveal that the installation deviation of some components exceeds (Table 1) ±10 mm, far exceeding the allowable design tolerance of ±5 mm, severely impacting construction quality.

Fig. 1. A deviation between the reserved window of the PC component and the detailed design of the aluminum formwork.

Fig. 2. The reserved holes are inconsistent with the aluminum formwork backing ribs.

Table 1. Allowable Deviations and Inspection Methods of Components

Project		Allowable Deviation (mm)	Inspection Method
Length	Floor slabs, beams, columns, trusses <12m	±5	Measuring
	≥12m and<18m	±10	
	≥18m	±20	
	Wall panels	±4	
Width, Height (Thickness)	Floor slabs, beams, columns, trusses	±5	Measure at one end and the middle, take the larger absolute value of the deviation
	Wall panels	±4	
Surface Flatness	Inner surface of floor slabs, beams, columns, wall panels	5	Measured with a 2m straightedge and feeler gauge
	Outer surface of wall panels	3	
Lateral Bending	Floor slabs, beams, columns	l/750 and≤20	Measured with a string line and straightedge at the maximum lateral bending point
	Wall panels, trusses	l/1000 and≤20	
Warping	Floor slabs	l/750	Measured with a leveling ruler at both ends
	Wall panels	l/1000	
Diagonal	Floor slabs	10	Measured with a ruler on both diagonals
	Wall panels	5	
Reserved Holes	Centerline Position	5	Measurement
	Hole Size	±5	
Reserved Openings	Centerline Position	10	Measurement
	Opening Size, Depth	±10	
Embedded Parts	Centerline Position of Embedded Plate	5	Measurement
	Height Difference between Embedded Plate and Concrete Surface	0,-5	
	Embedded Bolts	2	
	Exposed Length of Embedded Bolts	+10,-5	
	Centerline Position of Embedded Sleeve and Nut	2	
	Height Difference between Embedded Sleeve, Nut and Concrete Surface	±5	

2.2.2. Node Connection Technical Problems.

The design of the installation support for the first-floor precast concrete (PC) components of the bay window on the southern side is flawed(Figure 3.), resulting in insufficient bearing capacity of the node connections. During construction, conspicuous deformation occurs, endangering structural safety. Some node connections employ traditional rebar sleeve grouting techniques. However, due to construction errors and variations in grouting equipment performance, the quality of sleeve grouting is unstable, with issues such as insufficient grouting and voids, significantly degrading the mechanical performance of the nodes.

Fig. 3. Installation support problem of the first-floor PC components at the south-side bay window.

2.2.3. Construction Process Coordination Problems.

The position of the floor slab reverse edge deviates by 5 - 10 mm(Figure 4.), clashing with the installation position of prefabricated components, making installation arduous and requiring a substantial number of on-site adjustments, severely affecting construction efficiency. There are also frequent conflicts between the suspended formwork of kitchen and bathroom partition walls and PC components(Figure 5.). In multi-trade concurrent operations, due to irrational construction planning and poor information communication, the process coordination is poor, and the rework rate is high.

Fig. 4. The position deviation of the floor slab reverse edge.

Fig. 5. The suspended formwork of kitchen and bathroom partition walls clashes with PC components in position.

3   Analysis of Key Technical Issues in Construction

3.1   Issues Pertaining to Component Production and Installation Precision

3.1.1. Problem Description.

In prefabricated building construction, the precision of component production and installation is of paramount importance for ensuring the overall quality and efficiency of the project. In the Zhengzhou project, the following issues were identified in the production and installation of PC components:

The height deviation of the prefabricated composite slab truss reinforcement is substantial, with some parts deviating from the design requirements by ±2 mm, leading to a significant amount of on-site labor and time consumption for secondary adjustments. The misalignment between the reserved holes in prefabricated components and the aluminum formwork backing on-site, with a deviation range of 5 - 10 mm, heightens the risk of concrete leakage during pouring and adversely affects the quality of component formation. Except for the top slab meeting the requirements, the verticality, flatness, and door and window opening compliance rates of other components still leave room for improvement.

3.1.2. Theoretical Analysis.

The installation precision deviations of components primarily stem from manufacturing errors, transportation-induced deformations, and on-site installation positioning errors[4]. On-site measurement was conducted using standard measuring tools such as tape measures, levels, and theodolites to precisely quantify the deviations of components in different dimensions. The reason for choosing these tools was their wide availability and reliability in the construction field, enabling us to obtain accurate data on the actual conditions of the components. By comparing the measured values with the design requirements, we could clearly identify the specific problems and their magnitudes. Theoretical analysis was based on the well-established principle of three-dimensional vector synthesis. The formula (equation (1)) was applied to systematically evaluate the installation accuracy of components.

$$\Delta = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \tag{1}$$

This allowed us to comprehensively consider the potential error sources in the production process, including mold manufacturing errors, rebar processing and installation inaccuracies, and concrete pouring variations, as well as the impacts of transportation and on-site installation conditions.

3.2   Node Connection Technical Issues

3.2.1. Problem Description.

Node connections are vital for ensuring the stability of prefabricated building structures, and their design and construction quality directly impact the overall safety of the structure[3]. In this project:

The installation support design for the first-floor PC components of the south-side bay window is inadequate, and the node connection bearing capacity cannot withstand the actual construction loads, resulting in obvious deformation during construction and posing a serious threat to structural safety. Some node connections utilize traditional rebar sleeve grouting methods. However, due to construction errors and differences in grouting equipment performance, the sleeve grouting quality is unstable, with defects such as insufficient grouting and voids, which greatly reduce the mechanical performance of the nodes.

3.2.2. Mechanical Analysis.

The bearing capacity of node connections can be calculated by the formula:

$$N_u = \varphi(A_s f_y + A_c f_c) + M_u/W \qquad (2)$$

where N_u is the node bearing capacity, A_s is the cross-sectional area of the rebar, f_y is the yield strength of the rebar, A_c is the cross-sectional area of the concrete, f_c is the compressive strength of the concrete, M_u is the bending moment, and W is the section modulus. Finite element simulation analysis reveals that the original node design exhibits an uneven stress distribution when subjected to actual construction loads, resulting in local stress concentrations and insufficient bearing capacity. Therefore, it is essential to optimize the node connection form to ensure structural safety. In the finite element simulation, models are established based on the actual component dimensions, material properties, and connection methods, taking into account the load effects under different working conditions to analyze the stress performance and deformation characteristics of the nodes.

3.3   Coordination Issues in Construction Processes
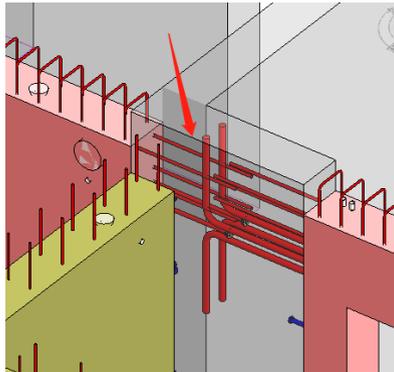
3.3.1. Problem Description.

Construction process coordination represents a significant challenge in prefabricated building construction. In this project:

The deviation of the floor slab reverse edge position is 5 - 10 mm, which conflicts with the installation position of prefabricated components, making installation difficult and requiring a large number of on-site adjustments, seriously affecting construction efficiency. There are frequent conflicts between the kitchen and bathroom partition wall suspended formwork and PC components. In multi-trade concurrent operations, due to unreasonable construction planning and poor information communication, the process coordination is poor, and the rework rate is high.

3.3.2. Information Management Analysi.

Employing BIM technology to simulate (Figure 6.) and analyze the construction process discloses that process conflicts mainly occur in the floor slab installation and pipeline layout stages[5]. The BIM model integrated the information from architecture,

structure, and electromechanical systems. By creating a virtual construction environment, we could identify potential clashes and inefficiencies in the construction process, especially in the floor slab installation and pipeline layout stages. The traditional construction management approach often suffered from information silos and lack of real-time coordination, leading to frequent rework and delays. BIM technology's visualization and data integration capabilities offered a solution to these problems. It enabled us to proactively detect and resolve conflicts, optimize the construction sequence, and improve overall construction efficiency. This was the main rationale for choosing BIM technology in this aspect of our study.

Fig. 6. A rebar collision when installing YWQ3 and YWQ1 components.

4   Optimization Strategies

4.1   Enhancement of Component Production and Installation Technologies

4.1.1. Component Production Phase.

During the design stage, in light of potential construction errors based on previous project experience and relevant standards, it is necessary to make appropriate adjustments to the reserved dimensions of components. For example, the reserved hole dimensions can be increased by 5 - 10 mm compared to the design specifications. High-precision molds with a manufacturing tolerance controlled within ±1 mm should be utilized, and regular maintenance and inspection should be carried out. Automated production equipment such as automated rebar processing and concrete pouring equipment should be introduced to minimize production errors caused by human factors.

4.1.2. Component Installation Phase.

High-precision measuring instruments such as total stations with an accuracy of 1" and laser levels with a precision of ±0.5 mm/km should be equipped to precisely measure and position components. Intelligent installation equipment such as component lifting and installation devices based on sensor and automation control technologies should

be developed to automatically adjust the position and attitude of components and improve installation precision.

4.2   Optimization of Node Connection Technology

4.2.1 Node Design Optimization.

A combined support structure of precast concrete and steel should be adopted. For instance, steel brackets and precast concrete connectors can be installed at critical nodes to enhance the bearing capacity of the nodes. The dimensions and reinforcement of steel brackets and precast concrete connectors should be determined through mechanical calculations and finite element analysis to ensure that the nodes possess sufficient strength and stiffness under the design load.

4.2.2 Construction Process Improvement.

Non-destructive testing technologies such as ultrasonic testing should be introduced to monitor the quality of node connections in real-time during and after the grouting process. Detailed inspection standards and procedures should be established, stipulating that the grouting fullness must reach more than 95% to be considered qualified, thereby ensuring the construction quality.

4.3   Strengthening Coordination Management of Construction Processes

4.3.1 Information Management Platform.

A construction process coordination management platform based on BIM technology and cloud computing should be constructed to realize real-time sharing of construction information among different processes. On this platform, construction personnel from various trades can access information such as construction progress, component installation locations, and pipeline layouts at any time, facilitating the timely discovery and resolution of problems.

4.3.2 Construction Plan Optimization.

A detailed construction plan and process should be formulated using network planning technology to clarify the sequence and logical relationship of each process and rationally allocate construction resources and time. For example, in floor slab construction, the installation of precast composite slabs should be prioritized, followed by pipeline laying and floor slab concrete pouring to avoid process conflicts. At the same time, a dynamic adjustment mechanism for construction progress should be established to adjust the construction plan in a timely manner according to the actual situation on the construction site.

5   Conclusion and Future Directions

This study focuses on the analysis and optimization of key construction technology issues in the Zhengzhou prefabricated building project. By implementing the proposed optimization strategies, we have effectively enhanced the precision of component installation, improved the stability of node connections, and optimized the coordination of construction processes. This not only resolves the specific problems encountered in the Zhengzhou project but also provides valuable practical experience and technical references for other similar projects. It helps to promote the overall quality and efficiency improvement of prefabricated building construction.

Future research should concentrate on the following aspects: in terms of component production and installation, we can explore more advanced manufacturing technologies and quality control methods to further reduce errors. In node connection technology, we can study new connection materials and structures to enhance the performance of node connections. In construction process coordination, we can integrate more intelligent management systems to improve the real-time and accuracy of information communication. These future research directions are all based on the limitations and potential for improvement identified in this study, aiming to continuously promote the development of prefabricated building construction technology.

Acknowledgments

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