Construction process optimisation and cost analysis in assembly building project management

Jun YU

Anhui Poly Real Estate Development Co., Ltd., Hefei, Anhui, 230000, China

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Abstract: As China's construction industry advances its transformation and upgrading, prefabricated construction has gained widespread adoption as a green, low-carbon, and efficient building method. In actual project management, however, prefabricated construction often faces challenges such as poor process integration, inefficient management, and difficult cost control due to its involvement in multiple stages including component design, production, transportation, hoisting, and on-site construction. This paper focuses on construction process optimization and cost analysis to explore the characteristics and challenges of prefabricated building project management. It identifies key issues such as complex construction organization, difficult supply chain coordination, and high on-site management requirements. It proposes process optimization pathways across three dimensions—design-construction integration, supply chain and logistics management, and construction organization with on-site management—emphasizing the vital role of BIM technology and digital tools in enhancing collaborative efficiency. The paper analyzes the cost structure of prefabricated construction and suggests strategies for cost reduction and efficiency gains through standardized design, scaled production, and comprehensive, meticulous management throughout the entire process. Scientific construction process optimization not only shortens project duration and improves quality but also effectively reduces overall costs, providing management insights and practical references for promoting prefabricated construction.

1. Introduction

As China's construction industry transitions from extensive to intensive and green development, prefabricated construction is emerging as a key direction for industry advancement due to its energy efficiency, environmental benefits, shortened schedules, and controllable quality [1]. Compared to traditional cast-in-place methods, prefabricated construction fundamentally transforms building practices through factory-produced components and rapid on-site assembly [2]. This approach aligns with national “dual carbon” strategic goals while advancing industrialization and intelligent development in construction [3].

However, numerous management challenges persist in the practical implementation of prefabricated construction projects [4]. On one hand, prefabricated construction involves multiple stages—design, production, transportation, hoisting, and installation—where delays or errors in any phase can disrupt the entire process, compromising project quality and schedule [5]. The standardization of components, on-site construction organization efficiency, and supply chain coordination directly impact construction costs [6]. Balancing cost reduction with quality and safety assurance remains a core issue in prefabricated construction management. This tension becomes particularly pronounced during large-scale implementation, where optimizing construction workflows and controlling costs increasingly clash.

Academic and industry efforts have explored numerous approaches to prefabricated construction management, including BIM technology integration throughout the lifecycle, supply chain optimization strategies, and smart construction methods. These have alleviated some pain points in project management. However, overall, existing research and practices still suffer from incomplete systems and management models that require further refinement. How to establish a scientific and efficient construction process management system tailored to the unique characteristics of prefabricated buildings, supplemented by systematic cost analysis and control measures, remains an urgent topic requiring in-depth research.

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This paper focuses on "construction process optimization and cost analysis" to examine the characteristics and challenges of prefabricated building project management. It proposes optimization pathways across three dimensions: integrated design and construction, supply chain and logistics management, and construction organization and site management. By analyzing cost composition features, targeted cost control strategies are suggested to provide reference for the high-quality development of prefabricated construction.

2. Characteristics and Challenges of Prefabricated Building Project Management

As a key direction for the transformation and upgrading of the construction industry in recent years, prefabricated construction differs significantly from traditional cast-in-place methods [7]. Its defining feature lies in the factory production of components and rapid on-site assembly. This approach effectively shortens construction schedules, reduces wet operations, minimizes environmental pollution, and enhances the controllability of building quality through front-loaded fabrication processes and standardized construction workflows. However, this "front-end dependency" model also introduces management complexities. The design, production, transportation, and on-site installation of components are highly interconnected. Deviations in preliminary design or inadequate control during production directly lead to installation difficulties, potentially triggering rework and delays, thereby increasing project risks and costs. Total project cost decomposition

$$C_{total} = C_{design} + C_{production} + C_{transport} + C_{installation} + C_{management} \quad (1)$$

Compared to traditional construction, prefabricated building management involves more stakeholders and collaborative stages. Design firms, component factories, transportation companies, construction contractors, and supervision agencies must maintain high levels of information sharing and schedule coordination. Delays in any single link can create bottlenecks, impacting overall progress and quality. Poor coordination between transportation and installation schedules may idle lifting equipment and labor, incurring extra costs [8]. Incomplete design information transfer can cause component mismatches with on-site structures, halting construction. Prefabricated construction management demands higher standards for end-to-end coordination and dynamic control than traditional methods.

The construction organization of prefabricated buildings exhibits distinct characteristics. Since on-site operations primarily involve lifting and assembling large components, they heavily depend on construction machinery, lifting paths, and component stacking sequences. Without proper planning for site layout, transportation routes, and component storage management, work overlapping, site congestion, and even machinery accidents can easily occur [9]. This high-precision demand for organization and scheduling requires managers to possess stronger overall planning and on-site control capabilities, showed in Figure 1:

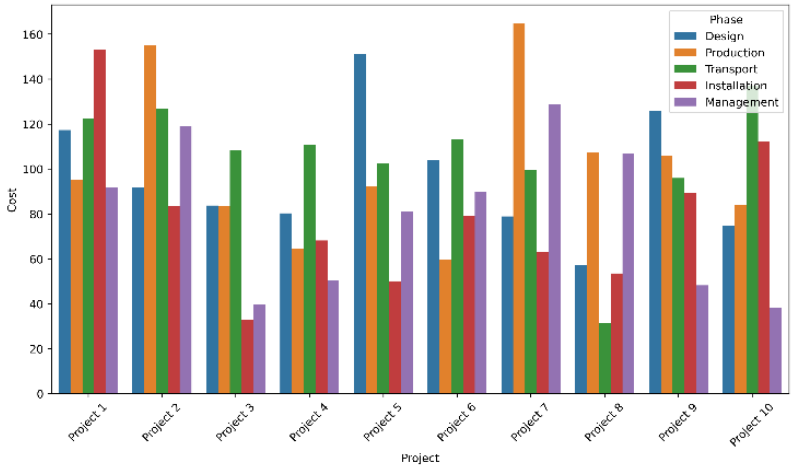

Figure 1 Cost composition by project phase

Quality and safety management also present significant challenges in prefabricated construction. Project quality depends not only on on-site construction techniques but is also directly influenced by the manufacturing precision of components. Dimensional deviations in factory-produced components can complicate on-site assembly and compromise overall structural integrity. Frequent high-altitude lifting and handling of large-volume components elevate safety risks significantly beyond traditional construction. Particularly during node connections and structural assembly, any procedural oversight may create severe safety hazards [10]. Quality and safety management must therefore encompass the entire lifecycle from factory production to on-site construction.

Regarding costs, prefabricated construction generally faces higher investment requirements during its promotion phase. Factory-based component production necessitates specialized equipment and facilities, while transportation and hoisting rely on heavy machinery. Construction sites also require management tools like BIM technology and digital platforms, collectively increasing both direct and indirect project costs. If construction workflows are inefficient or resource allocation is suboptimal, cost control pressures intensify, thereby slowing the adoption rate and undermining the market competitiveness of prefabricated construction. Time–cost trade-off function

$$C(T)=C_0+\alpha\cdot\frac{1}{T} \tag{2}$$

At the management level, prefabricated construction is characterized by strong process front-loading, complex coordination requirements, meticulous organizational demands, prominent quality and safety risks, and significant cost control pressures. These issues reflect both the distinctiveness of prefabricated construction compared to traditional methods and present new challenges for project management. They must be addressed through scientific construction process optimization and systematic cost analysis.

3. Pathways and Strategies for Construction Process Optimization

The inherent complexity and challenges in prefabricated construction project management necessitate a holistic and systematic approach to process optimization. This optimization transcends isolated improvements, encompassing the entire lifecycle from design and production to transportation, installation, and post-construction management—a comprehensive endeavor involving multiple stakeholders and interlinked stages. Only through establishing efficient collaborative mechanisms and scientific management models can the quality, schedule, and cost of prefabricated buildings be maintained within reasonable parameters. Specifically, construction process optimization can be pursued through three key approaches: 1. Strengthening pre-construction planning and information sharing via integrated design-construction management, leveraging BIM technology as the core for full-process coordination. 2. Optimizing supply chain and logistics management to streamline the interface between component production, transportation, and on-site installation, thereby reducing resource waste and time delays. 3. Improving construction organization and site management to enhance the rationality of work sequencing and on-site safety, achieving dual gains in construction efficiency and management effectiveness.

3.1 Integrated Design and Construction Management

The primary task in optimizing prefabricated building construction processes is achieving integrated design and construction management. Unlike traditional construction where design and construction operate relatively independently, prefabricated buildings require components to be factory-prefabricated. Consequently, the design phase must consider production and installation feasibility from the outset. Without effective communication between design and construction teams, components may fail to match on-site conditions, leading to rework, delays, or quality issues. Integrated management requires establishing cross-disciplinary and cross-organizational collaboration mechanisms early in the project to tightly align design outcomes with construction requirements, enabling seamless information transfer and sharing. Standardization effect on unit cost

$$C_{unit}=\frac{C_{fixed}}{Q}+C_{variable} \tag{3}$$

BIM technology plays a central role in this process. The BIM platform not only enables three-dimensional visualization modeling of building components but also allows for the simulation of component dimensions, joint details, and construction techniques through parametric design. This enables the identification and resolution of potential conflicts during the design phase. This information-driven approach effectively reduces uncertainties at the construction site and significantly improves the alignment between design and construction. BIM technology can also be integrated with construction schedules and cost budgets to form a lifecycle information management platform, providing a scientific basis for subsequent production and installation.

Integrated management is further reflected in standardized and modular design. The economic viability and efficiency of prefabricated construction heavily depend on the standardization of components. By unifying design standards and promoting modular components, design complexity and production costs can be effectively reduced while enhancing component interchangeability and applicability. Standardized design minimizes on-site installation errors while improving construction efficiency and safety. Early collaboration between design and construction teams in establishing standards and modular solutions not only reduces redundant work during design but also provides more actionable drawings and plans for the construction phase. Cost performance index (CPI)

$$CPI=\frac{EV}{AC} \tag{4}$$

Integrated design-construction management requires establishing a dynamic feedback mechanism. During actual construction, unforeseen circumstances may arise—such as changes in site conditions, limitations in construction techniques, or adjustments in material supply—that were not fully anticipated in the design. Integrated management requires construction sites to promptly report issues back to the design team, enabling rapid response and adjustments through digital platforms to ensure continuity and rationality in the construction process. Through this “closed-loop management,” design transforms from a static deliverable into a dynamic, interactive process aligned with construction practice, achieving scientific control throughout the entire lifecycle.

3.2 Optimizing Supply Chain and Logistics Management

In the construction process of prefabricated buildings, supply chain and logistics management are critical to ensuring smooth project execution. Since the production, transportation, and installation of components are closely interlinked, delays at any stage can cause the entire construction schedule to fall behind. Optimizing supply chain and logistics management not only enhances project efficiency but also effectively reduces resource waste and unnecessary costs, showed in Figure 2:

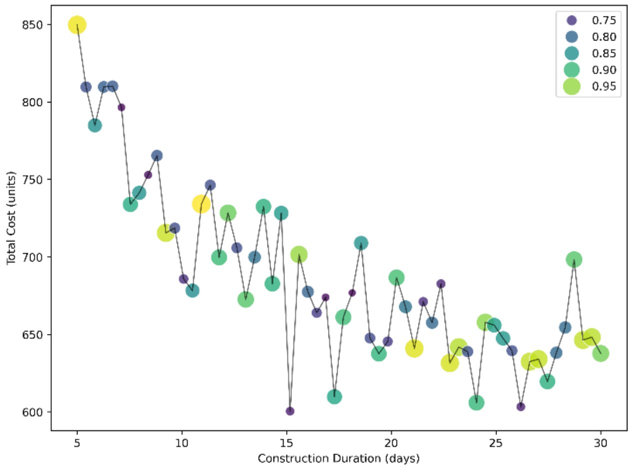

Figure 2 Time vs Cost trade-off with variance

Supply chain optimization should begin at the component production stage. Prefabricated components for prefabricated buildings are typically manufactured centrally in specialized factories, where production cycles and quality directly impact subsequent construction progress. Rational production planning, combined with “on-demand production” aligned with actual site requirements, avoids storage pressures from premature manufacturing while minimizing resource wastage from last-minute adjustments. Production information must be synchronized with construction progress to ensure timely delivery of components matching the construction schedule.

Logistics and transportation represent both a focal point and a challenge in prefabricated construction. Due to the large size and heavy weight of components, high demands are placed on transport vehicles and road conditions. Improper transportation scheduling can easily lead to site congestion or disorderly component storage. Logistics management requires meticulous planning aligned with hoisting sequences to achieve “immediate installation upon arrival,” minimizing on-site storage and secondary handling. Leveraging information platforms and IoT technology enables real-time monitoring and scheduling of transportation, enhancing coordination efficiency between transport and construction.

Optimizing supply chain and logistics management hinges on establishing information-sharing mechanisms. Component manufacturers, transport companies, and construction firms should communicate via a unified data platform to ensure all parties have real-time access to progress updates and demand changes, enabling dynamic coordination. Establishing cross-organizational collaboration mechanisms not only accelerates response times but also reduces delays and losses caused by information asymmetry. Long-term, this collaborative supply chain and logistics management model fosters a stable and efficient industrial chain system, supporting the large-scale adoption of prefabricated construction.

3.3 Improvements in Construction Organization and Site Management

In prefabricated construction workflows, on-site organization and management serve as the pivotal link connecting front-end design, component manufacturing, and logistics transportation. Their efficiency and proficiency directly determine overall construction quality and schedule adherence. Compared to traditional construction, prefabricated projects involve fewer on-site operational phases but rely more heavily on organizational coordination and scheduling—particularly during component hoisting, assembly, and joint detailing. Minor missteps in these areas can lead to construction delays or even safety incidents. Therefore, enhancing construction organization and site management is indispensable for optimizing the construction process.

First, construction organization requires meticulous planning centered around hoisting operations. Given that prefabricated components are typically large and heavy, hoisting sequences, stacking locations, and transport routes must be scientifically planned to ensure smooth workflow on-site. By rationally scheduling processes, optimizing construction section divisions, and adopting flow or parallel work modes, project duration can be significantly shortened while reducing waiting times. Simultaneously, BIM-based construction simulations can preemptively identify lifting path conflicts and spatial occupancy issues, enabling pre-construction optimization adjustments to prevent on-site chaos.

Second, on-site management must prioritize dual control of quality and safety. Joint connections in prefabricated buildings are critical quality control points; improper handling at these junctions directly compromises structural stability and durability. Therefore, standardized construction techniques must be strictly enforced on-site, with enhanced quality inspections and process supervision. Furthermore, hoisting operations involving large-scale components carry elevated risks, necessitating robust safety management systems and intelligent monitoring tools to mitigate hazards. For instance, sensors and video surveillance can track hoisting activities in real time, enabling prompt detection and resolution of anomalies to ensure construction safety. Process optimization objective function

$$P=\frac{Q_{installed}}{T_{work}} \qquad (5)$$

Finally, improvements in construction organization and site management rely heavily on information technology and intelligent solutions. Establishing a construction site information platform enables real-time coordination of personnel, machinery, materials, and other resources, enhancing utilization rates and management transparency. The introduction of drone inspections, IoT monitoring devices, and intelligent construction equipment not only elevates management precision but also provides data support for dynamic optimization during construction. This information- and intelligence-driven management model further enhances the construction efficiency and management quality of prefabricated buildings, laying the foundation for achieving refined management throughout the entire project lifecycle.

4. Cost Analysis and Control Measures for Prefabricated Buildings

The cost structure of prefabricated buildings differs significantly from traditional construction, primarily encompassing design refinement, prefabricated component production, transportation and hoisting, as well as on-site construction and management. The design phase requires more detailed refinement and BIM technology application, resulting in relatively higher investment. However, rational design effectively reduces later rework, yielding benefits throughout the entire lifecycle. Precast component production costs are influenced by factory equipment investment, mold usage, and quality inspection. Particularly during the initial promotion phase, unit costs tend to be high due to the absence of economies of scale. Concurrently, transportation and hoisting costs for large-scale components cannot be overlooked, as road conditions, transport distances, and machinery rentals may all increase expenses. Regarding on-site construction and management, while wet operations decrease, demands for construction organization, information management, and safety control rise, leading to corresponding increases in management costs.

Regarding cost control measures, design optimization is considered key to reducing overall expenses. Promoting standardized and modular designs can decrease the number of non-standard components, simplifying design complexity and production difficulty. Concurrently, leveraging BIM technology to achieve deep integration between design and construction enables not only simulating construction processes in a virtual environment to identify issues early but also linking with schedule plans and cost budgets to form quantifiable decision-making bases. This upfront optimization based on information technology helps minimize rework and additional expenditures later on, achieving cost control at the source. Productivity of installation work

$$P=\frac{Q_{installed}}{T_{work}} \tag{6}$$

In the production and transportation of components, scaling up and refining processes are effective ways to reduce costs. Production should adopt assembly-line operations and standardized component manufacturing to fully leverage economies of scale and lower unit costs. Simultaneously, implementing “production on demand” avoids excessive inventory and storage space occupation. Transportation and hoisting require meticulous organization, with optimized batch scheduling and lifting sequences to achieve “arrival-to-installation” efficiency, minimizing secondary handling and temporary storage. Real-time monitoring via IoT and intelligent dispatch systems enhances transportation efficiency while mitigating risks.

During construction and management phases, scientific work sequencing and digital platform development remain critical cost control measures. By rationally dividing construction sections and implementing parallel operations, project duration can be shortened, reducing equipment rental and management costs. A comprehensive cost monitoring system enables dynamic tracking of labor, machinery, and materials, improving resource utilization and minimizing waste. Concurrently, the application of intelligent construction equipment, drone inspections, and sensor monitoring enhances management precision and safety levels, thereby reducing additional costs stemming from quality issues or safety incidents. Through the comprehensive implementation of these measures, the cost structure of prefabricated construction will gradually optimize, continuously enhancing its economic viability and market competitiveness.

5. Conclusion and Outlook

As a key direction for the modernization of China's construction industry, prefabricated construction demonstrates unique advantages in promoting energy conservation and emission reduction, improving construction efficiency, and ensuring project quality. However, compared to traditional construction models, it presents characteristics such as strong process advancement, complex inter-process coordination, specialized construction organization, concentrated quality and safety risks, and significant cost control pressures in project management. This paper proposes an optimization pathway based on a systematic analysis of the prefabricated construction process and cost structure, focusing on three aspects: integrated design and construction management, supply chain and logistics optimization, and improvements in construction organization and site management. It further explores specific cost control measures. Research indicates that only through scientific planning throughout the entire process and meticulous management across all stages can prefabricated construction efficiency be effectively enhanced and unnecessary cost expenditures reduced, thereby achieving a harmonious balance between project quality, schedule, and economic benefits.

Looking ahead, prefabricated construction will see broader application as building industrialization and intelligence advance. The deep integration of emerging technologies—BIM, big data, IoT, and AI—will further synergize design, production, transportation, and construction, enabling dynamic optimization and intelligent control throughout the entire process. Concurrently, as the industrial chain matures and economies of scale emerge, production and construction costs will gradually decrease, enhancing economic viability and competitiveness. Moreover, green building and low-carbon development goals provide both policy and market drivers for the promotion of prefabricated construction, whose role in future urban development and sustainable growth will become increasingly vital.

Therefore, the advancement of prefabricated construction requires not only continuous innovation in technology and management but also the combined support of policy guidance, industrial collaboration, and talent development. Through persistent exploration and practice in optimizing construction processes and controlling costs, prefabricated construction is poised to become a key pathway for driving the transformation and upgrading of China's construction industry and achieving green development in the future.

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