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A Review of Cost Control Research in Prefabricated Construction under EPC Mode

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Aims: Amidst the accelerating global urbanization and growing demand for sustainable development, prefabricated construction emerges as a pivotal transformational force in the construction industry due to its efficiency and environmental friendliness. This paper comprehensively reviews cost control research in prefabricated construction under the EPC (Engineering, Procurement, Construction) model.
Study Design: The study adopts a literature-based approach, incorporating findings from domestic and international scholars, to uncover the critical issues and challenges in cost control within the EPC framework. Additionally, it analyzes the application of technological innovations such as BIM (Building Information Modeling) and DEMATEL (Decision Making Trial and Evaluation Laboratory) in cost control, offering a theoretical foundation and practical guidance for prefabricated construction under EPC.

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Place and Duration of Study: The research spans various regions globally, examining recent practices and theoretical advancements in cost control for prefabricated construction projects under EPC over the past decade to ensure timeliness and comprehensiveness.
Methodology: The methodology encompasses a systematic literature review to construct a theoretical framework, coupled with an analysis of case studies showcasing effective cost control measures. Furthermore, the study explores the utilization of BIM and DEMATEL to enhance cost prediction accuracy, process monitoring, and decision-making support.
Results: The findings reveal that the EPC model facilitates more systematic and efficient cost control in prefabricated construction. The application of BIM significantly improves cost forecasting precision and process transparency, enabling timely cost deviation identification and correction. DEMATEL effectively identifies key cost drivers and their interrelationships, informing targeted cost control strategies.
Conclusion: This paper underscores the significance of cost control in prefabricated construction under the EPC model and highlights the pivotal role of BIM and DEMATEL in enhancing cost control effectiveness. It concludes by advocating for deeper integration of prefabricated construction with the EPC model to propel the green, intelligent transformation and sustainable development of the construction industry.

Keywords: EPC Model; prefabricated buildings; cost control; BIM technology.

1. INTRODUCTION

With the acceleration of the global urbanization process and the deepening awareness of sustainable development concepts, the construction industry is facing unprecedented transformations and challenges. Prefabricated construction, as an emerging architectural form, has gradually emerged as a crucial direction for the transformation and upgrading of the construction industry due to its characteristics of high efficiency, environmental protection, and energy conservation. Meanwhile, the EPC (Engineering-Procurement-Construction) model, an integrated approach encompassing engineering, procurement, and construction, has been widely adopted in large-scale and complex engineering projects due to its advantages in effectively integrating resources, shortening project durations, and controlling costs. Combining the EPC model with prefabricated construction not only leverages the strengths of both but also further promotes the green and intelligent development of the construction industry [1,2].

Under the EPC framework, cost containment in prefabricated construction has emerged as a critical concern. Prefabrication introduces distinct challenges across design, production, logistics, and construction phases, necessitating innovative cost management strategies. Additionally, the EPC model demands enhanced comprehensive management capabilities from general contractors, making the concurrent optimization of costs, quality, schedule, and safety a formidable task.

This study systematically examines the current research trends in cost management for prefabricated construction within the EPC paradigm, conducting an in-depth analysis of pivotal factors influencing cost control. Additionally, it presents actionable optimization strategies to enhance efficiency and precision in cost containment. It not only enriches the theoretical foundation by refining relevant frameworks but also provides invaluable practical insights and operational guidelines for EPC contractors to implement cost-effective measures in real-world projects. By enhancing project management efficiency and effectively controlling costs, it can facilitate the deep integration of prefabricated construction and the EPC model, thereby promoting the green, intelligent transformation, and sustainable development of the construction industry.

2. COST ANALYSIS METHOD FOR ASSEMBLED BUILDINGS IN EPC MODE

Overview of EPC Model: The EPC model, an acronym for Engineering, Procurement, and Construction, represents an efficient approach to project general contracting. Under this model, the general contractor assumes full responsibility for the entire process, from project planning, design, material procurement, through construction and subsequent services. A notable feature of this model lies in its integrated management, which significantly reduces coordination difficulties among various stages and effectively controls total project investment through fixed-price contracts. Furthermore, highly specialized management ensures high-quality project completion.

An overview of Prefabricated Construction: As a pivotal achievement in modern construction technology, prefabrication revolves around industrialized production methodologies. This approach entails the pre-manufacturing of building components in controlled factory environments, subsequently facilitating expedited on-site assembly through efficient transportation. This form of construction not only drastically improves construction efficiency and shortens construction cycles but also achieves a more environmentally friendly and energy-efficient building process by reducing wet work and construction waste on site. The quality of prefabricated construction is also better controlled due to factory production, minimizing uncertainties in on-site construction. Additionally, prefabricated construction encompasses various types such as precast concrete structures, steel structures, and timber structures, offering diverse options for different types of construction projects.

Combining the EPC model with prefabricated construction can further leverage the strengths of both, achieving seamless integration of design, procurement, construction, and component production. This collaboration drives the transformation and upgrading of the construction industry, enhancing the efficiency and quality of project management. Simultaneously, it promotes the realization of green buildings and sustainable development.

2.1 Analysis of Cost Control Status of Prefabricated Construction under EPC Model

The EPC (Engineering, Procurement, and Construction) general contracting model originated in the United States in the 1960s, during a period of robust growth in the country's construction industry. With the increasing number of large and complex construction projects, owners demanded tighter control over project costs and timelines, which traditional management models struggled to meet. Consequently, the EPC general contracting model emerged. Leveraging its efficient management capabilities, the EPC model flourished in the 1970s, gradually matured in the 1980s, and by the 1990s had become the mainstream engineering contracting model internationally, primarily applied to large-scale projects requiring significant investments, long durations, and high technical standards.

Barlow highlights that the costs arising from diverse demands for prefabricated construction can be controlled through standardized design and large-scale production [3].

Memon employs statistical principles and questionnaire data to identify the causes of incremental costs in prefabricated construction, concluding that poor site management, a shortage of skilled workers, and irrational contractor scheduling and planning are primary contributors [4].

Mark A. et al. conduct field investigations into the cost components of actual projects, pointing out that production and storage costs of prefabricated components are crucial elements of prefabricated construction costs [5].

Gholamreza Heravi applies lean principles to the production phase of prefabricated buildings, successfully reducing the production cycle by 34% and costs by 16% [6].

Lee J & Kim Y et al. note that the high construction costs of modular systems have led to suboptimal adoption in South Korea. They employ failure mode and effects analysis to investigate cost increases across various stages of modular projects in South Korea. From the perspective of modular construction companies and cost processes, they evaluate cost-increasing factors throughout the modular construction lifecycle, identifying key drivers of cost escalation [7].

Bari N AA et al. analyze four low-rise construction projects using prefabricated and traditional methods, revealing that prefabricated systems reduce overall costs, time, labor, and produce better housing quality compared to traditional methods. Notably, prefabrication reduces construction time by 35%, decreases labor demands, and improves quality control. Furthermore, a comparative analysis of the four cases found cost savings exceeding 10% [8].

Jaillon L & Pooh C S emphasize that prefabrication technology can yield significant economic and environmental benefits, particularly in densely populated urban environments like Hong Kong. Among these benefits, economic gains (primarily input and output) are a primary concern for stakeholders. Short-term incremental costs associated with industrialized construction have emerged as a major barrier to its wider adoption. Case studies and interviews reveal that the degree of design standardization and transportation costs of prefabricated components significantly impact construction costs [9].

The development of prefabricated construction in China started early but stagnated subsequently due to various reasons. For instance, during the Tangshan Earthquake, prefabricated buildings at that time demonstrated poor seismic resistance, leading to widespread destruction and significant casualties. This triggered widespread aversion towards prefabricated construction. However, in the early 21st century, driven by relevant policies and market demands, prefabricated construction underwent a period of recovery, development, and innovation. While Chinese scholars have conducted research on prefabricated construction, resulting in the establishment of some technical and standardization frameworks, these are still incomplete and unsystematic, with significant room for improvement in modularity and standardization.

Domestic scholars' research on prefabricated construction costs primarily focuses on the construction phase, with only a few studies examining influencing factors across the entire construction process.

Wu Guohua analyzed the key factors contributing to the high costs of prefabricated construction in Nanning, adopting a combination of subjective and objective methods. He determined the weights of 19 influencing factors using DEMATEL and entropy weight methods, conducted surveys, and proposed corresponding control strategies and recommendations to facilitate the promotion of prefabricated construction in Nanning [10].

Based on extensive literature review, Jia Lei integrated system dynamics theory and modeling methods with cost control in prefabricated construction projects. Leveraging the dynamic, systematic, and holistic characteristics of system dynamics, he analyzed costs across design, production, transportation, and installation phases. By constructing an SD model for prefabricated construction cost control, his research findings were rendered more scientific and reasonable [11].

Xue Hong systematically analyzed the formation of stakeholder collaboration mechanisms driven by construction cost, identified functional elements of such mechanisms in prefabricated construction projects, explored stakeholders' resource integration capabilities under cost constraints, and proposed organizational and governance mechanisms for stakeholder collaboration. Her study also investigated the impact of stakeholder collaboration on construction costs and provided feedback on collaboration performance [12].

In their paper "Research on Difficulties and Countermeasures of Cost Control in Prefabricated Construction," Li Hao et al. analyzed the characteristics of prefabricated construction costs, identified control difficulties based on current situations, and proposed optimization strategies to promote prefabricated construction development [13].

Cui Yinhong initiated her study from the cost components of PC (Prefabricated Concrete) construction, analyzed influencing factors, and established a corresponding indicator system. She used Structural Equation Modeling (SEM) to explore key cost drivers and System Dynamics (SD) to analyze the dynamic evolution of PC construction costs under the influence of these key factors [14].

Lu Zhixiang et al. established a BIM (Building Information Modeling) information model to facilitate information exchange in prefabricated component management. Based on this model, they innovatively proposed a bill of quantities to promote the transformation of procurement and transportation models for prefabricated components [15].

Wang Shutang et al. analyzed the application of BIM models in a prefabricated residential project, demonstrating how BIM can simulate site layouts, pre-check for "collisions," and optimize costs, schedules, and quality benefits in prefabricated construction projects [16].

Fei Anqing and Zheng Xin focused on petrochemical projects, analyzing cost control across pre-implementation, in-progress, and post-completion stages. They summarized strategies for achieving better project economics, providing insights for EPC general contractors to implement timely cost control [17].

Ma Shixiao et al. studied procurement costs in prefabricated construction, applying JIT (Just-In-Time) procurement methods throughout the prefabricated component procurement process. This allowed for timely and flexible adjustments based on project progress, reduced secondary handling and storage costs by transporting components according to real-time demands and construction sites [18].

Chang Chunguang et al. investigated cost control in the design and production stages of prefabricated construction. They used a countermeasure plan table system to identify potential cost overruns in prefabricated construction design and production, covering aspects such as design drawings, mold design, production scale, and prefabricated component production [19].

Li Jinhua et al. compared EPC general contracting with traditional project management modes, concluding that EPC can optimize cost-effectiveness in prefabricated construction. Employing dynamic programming, they analyzed resource allocation and cost occurrence across various construction stages, validating EPC's cost-saving potential [20].

Table 1. Comparison of current status of cost control research

Researchers	Advantages	Disadvantages	Key Research Application Areas
Barlow	Cost control through standard design and mass production	May limit design innovation	Cost control strategies for prefabricated construction, standardization, and mass production
Memon	Quantified causes of incremental costs, data-driven insights	Subjectivity in data collection, no proposed solutions	Analysis of incremental costs in prefabricated construction, site management, and resource scheduling
Mark A. et al.	Identified key cost components precisely	Does not cover all cost influencing factors	Analysis of cost components in prefabricated construction, production and storage costs
Gholamreza Heravi	Significant cost and time reduction through lean principles	Challenges in implementation, potential high costs	Application of lean management in prefabricated construction production stages
Lee J & Kim Y et al.	Identified cost-increasing factors in Korean modular projects	Region-specific, potential limitations in solutions	Analysis of cost-increasing factors and strategies for Korean modular construction
Bari N AA et al.	Significant reductions in cost, time, and labor	Small sample size, limited variable consideration	Comparison of prefabricated systems with traditional methods in low-rise buildings
Jaillon L & Pooh C S	Notable economic and environmental benefits	Short-term incremental costs hinder adoption	Economic and environmental benefits of prefabricated technology in densely populated urban environments (e.g., Hong Kong)
Wu Guohua	Combines subjective and objective analysis; Identifies key influencing factors; Proposes targeted control strategies	Weight determination may be subjectively influenced; Region-specific analysis	Analysis of key cost influencing factors and control strategies for prefabricated construction in Nanning
Jia Lei	Integrates system dynamics theory and modeling; Provides a dynamic and systematic analysis; Results are scientific and reasonable	Model construction complexity; Limited practical validation	Cost control analysis throughout the design, production, transportation, and installation phases of prefabricated construction projects

Researchers	Advantages	Disadvantages	Key Research Application Areas
Xue Hong	Systematically analyzes stakeholder collaboration mechanisms; Identifies functional elements; Proposes rigid contract and flexible trust dual governance mechanisms	Collaboration mechanism implementation challenges; Long performance feedback cycle	Research on stakeholder collaboration mechanisms and their impact on construction costs in prefabricated construction projects
Li Hao et al.	Analyzes cost characteristics and control difficulties; Proposes optimization strategies	Strategy implementation effects need further validation; Targeted approach	Research on difficulties and countermeasures for cost control in prefabricated construction
Cui Yinhong	Builds a comprehensive index system; Explores key influencing factors using SEM; Analyzes dynamic evolution using SD	Data analysis complexity; Limited model interpretability	Analysis of key cost influencing factors and dynamic evolution processes in PC construction costs
Lu Zhixiang et al.	Establishes BIM information models to facilitate information exchange; Innovates bill of quantities	BIM model application requires technical support; Standardization issues	Research on innovation in component management and procurement/transportation modes for prefabricated construction
Wang Shutang et al.	Analyzes BIM model application in a prefabricated housing case study; Optimizes cost, schedule, and quality benefits	High BIM technology adoption threshold; Limited case study representativeness	Research on the application of BIM technology to optimize cost, schedule, and quality benefits in prefabricated construction projects
Fei Anqing, Zheng Xin	Analyzes cost control across pre-project, in-project, and post-project phases; Provides economic strategies	Petrochemical project specificity; Cross-industry validation needed	Research on cost control strategies for EPC-mode petrochemical projects
Ma Shixiao et al.	Applies JIT procurement methods to prefabricated component procurement; Enables flexible adjustment and cost savings	Depends on real-time project progress information; High supply chain coordination requirements	Research on cost control in the procurement phase of prefabricated construction
Chang Chunguang et al.	Uses countermeasure planning tables to systematically identify potential cost control hazards; Targeted approach	Extensive hazard identification process; Long-term data support needed	Research on cost control in the design and production phases of prefabricated construction
Li Jinhua et al.	Compares EPC mode with traditional project management modes; Validates cost savings using dynamic programming	Limited comparison analysis samples; Complex dynamic programming application	Research on cost-benefit optimization of prefabricated construction under the EPC contracting mode

In summary, both domestic and international research on prefabricated construction cost control under the EPC model has made progress, albeit with different emphases and challenges. Foreign research focuses on comprehensive project management and risk mitigation, leveraging BIM and other technologies for precise cost estimation project and optimization, emphasizing innovative strategies to address uncertainties. In contrast, domestic research, fueled by has policy and market forces, gradually revived, with innovations in construction phase cost control but insufficient research on lifecycle cost control. Challenges include inadequate technical standardization and ineffective project.

2.2 Analysis of Key Factors for Cost Control in Prefabricated Construction under EPC Mode

Against the current domestic and international research backdrop, cost control in prefabricated construction under the EPC (Engineering, Procurement, Construction) model exhibits complex characteristics intertwined with multiple stages and factors.

The design phase, as the starting point of cost control, hinges on the rationality and economy of design schemes, the standardization and modularization of prefabricated components, and effective management of design changes. By introducing advanced technologies such as BIM (Building Information Modeling) for 3D simulation and optimization design, design efficiency and quality can be significantly enhanced, thereby reducing cost waste resulting from design changes. Simultaneously, strengthening cost estimation and budget control during the design phase lays a solid foundation for subsequent stages.

Entering the procurement phase, the core of cost control lies in supplier selection and management, rational formulation of procurement plans, and effective prevention and control of procurement risks. Establishing long-term partnerships with high-quality suppliers ensures material quality and price advantages. Detailed procurement plans are formulated to reasonably arrange procurement timing and quantities, reducing capital occupation and storage costs. Strengthening risk management in the procurement process, such as addressing price fluctuations and supply disruptions, ensures smooth procurement activities.

The construction phase represents the concrete implementation stage of cost control, with a focus on optimizing construction organization and management, implementing refined management on construction sites, and strictly controlling construction changes and claims. By developing scientific construction schemes and schedules, construction efficiency and quality are improved. Implementing refined management on construction sites reduces material waste and labor costs. Establishing strict processes for managing construction changes and claims, clarifying responsible parties and cost-sharing mechanisms, effectively controls additional cost expenditures.

In summary, cost control in prefabricated construction under the EPC mode necessitates a holistic approach spanning design, procurement, and construction phases. In each phase, different key factors are addressed with corresponding optimization strategies to achieve the ultimate goal of cost control. Through collaborative efforts and continuous optimization across all phases, the cost control level of prefabricated construction under the EPC mode can be continuously enhanced, driving sustainable development in the construction industry.

2.3 Optimization Strategies for Cost Control in Prefabricated Construction under EPC Mode

In the EPC mode, cost control in prefabricated construction constitutes a systematic project encompassing the entire process from design to procurement to construction. In light of current domestic and international research status, optimization strategies must closely revolve around the core elements of each phase to achieve effective cost control.

During the design phase, advanced technologies like BIM should be fully utilized for 3D simulation and optimization design, ensuring the rationality and economy of design schemes while enhancing the standardization and modularization of prefabricated components, thereby reducing the likelihood of design changes. By strengthening cost estimation and budget control during the design phase, a solid foundation for cost control in subsequent stages is laid. Furthermore, enhancing communication and collaboration between design and construction teams to ensure the feasibility of design schemes is crucial for cost control during the design phase.

In the procurement phase, a robust supplier evaluation and selection mechanism must be established to guarantee material quality and price advantages. Detailed procurement plans are formulated to reasonably arrange procurement timing and quantities, minimizing capital occupation and storage costs. Meanwhile, risk management during the procurement process is strengthened, such as establishing emergency procurement mechanisms to address price fluctuations, supply disruptions, and other contingencies. Through refined procurement management, effective control over procurement costs is achieved.

The construction phase represents the specific implementation and adjustment stage of cost control. Firstly, construction organization design is optimized to reasonably arrange construction processes and resource allocation, enhancing construction efficiency and quality. Secondly, refined management is implemented on construction sites, including material quota issuance, waste recycling, etc., to reduce material waste and labor costs. Additionally, a strict process for managing construction changes and claims is established, subjecting changes to rigorous review and assessment to ensure their rationality and necessity, thereby avoiding unnecessary cost increases. Concurrently, cost monitoring and analysis during the construction process are intensified to promptly identify and address cost overruns, ensuring project costs remain within budget.

In conclusion, cost control in prefabricated construction under the EPC mode necessitates a multi-faceted approach spanning design, procurement, and construction phases. By introducing advanced technologies, improving management mechanisms, and fostering communication and collaboration, effective cost control is achieved. This not only enhances project economic and social benefits but also supports the sustainable development of the construction industry.

3. CONCLUSION AND PROSPECT

Prefabricated construction has been vigorously promoted and developed in China, aligning with the country's requirements for low-carbon, circular, and green development. It represents a crucial path for the transformation and upgrading of China's construction industry. Prefabricated construction achieves industrialized production of buildings, enhancing production efficiency, conserving human resources, reducing energy consumption, minimizing construction waste emissions, and improving overall building performance and quality. General contractors should actively adopt advanced technologies such as BIM to achieve comprehensive integration and visualization of project information, thereby enhancing the level of refined management and enabling precise cost control. Simultaneously, they should promote standardized design and large-scale production, significantly reducing production and installation costs by enhancing the versatility and interchangeability of components. Furthermore, optimizing site management and human resource allocation, strengthening skill training for construction personnel, improving construction efficiency, and mitigating additional costs arising from poor management and human resource waste are all essential. In the future, with continuous technological advancements and the ongoing optimization of management practices, the cost control level of prefabricated construction under the EPC model will further improve, providing robust support for the sustainable and healthy development of the construction industry.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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