Analysis on cost control and cost optimization strategy of civil engineering in prefabricated building construction

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Abstract: This paper discusses the cost control and cost optimization strategy of civil engineering in assembled building construction. Firstly, the reasons for the high cost of prefabricated buildings are analyzed, and it is pointed out that the traditional cost management model is difficult to adapt to its characteristics. Then, based on the whole life cycle cost theory, a systematic cost optimization strategy system covering the four core links of "design-production-logistics-construction" is constructed. The system takes collaborative design as the source, lean production as the core, intelligent logistics as the link, and efficient construction as the foothold, forming a closed-loop management. Finally, the effectiveness of the optimization strategy is verified by empirical analysis. The results show that the overall economy of the project is significantly improved after the application of the optimization strategy.

1. Introduction

Driven by the goal of global carbon neutrality and the transformation and upgrading of the construction industry, prefabricated buildings have become the core path to promote building industrialization because of their characteristics of standardized design, factory production, assembly construction and information management. Compared with developed countries, the promotion of prefabricated buildings in China still faces significant economic bottlenecks [1]. The cost of civil engineering is higher than that of traditional cast-in-place mode, and the cost of production, transportation and on-site installation of prefabricated components is also higher, which directly restricts its large-scale application and market competitiveness [2].

The existing research shows that the high cost of prefabricated buildings lies in the fragmentation of the whole process management [3-4]. Lack of standardization in the design stage leads to a sharp increase in amortization cost of molds, insufficient scale in the production stage leads to an increase in unit cost, assembly errors in the construction stage lead to rework and waste of materials, and inefficient cooperation in the management stage leads to an increase in hidden costs [5]. The traditional cost management mode focuses on the post-event accounting in the construction stage, which is difficult to adapt to the deep integration of design, production and construction of prefabricated buildings. It is urgent to build a dynamic cost control system covering the whole life cycle.

This study breaks through the limitation of traditional single-stage analysis of cost management, and constructs an assembly building cost optimization model based on the life cycle cost theory (LCC). Provide a cost control toolkit for construction enterprises, and provide data support for the government to formulate differentiated subsidy policies and industrial planning. Through systematic strategic design, the prefabricated buildings will be transformed from "policy-driven" to "market-driven", which will help the high-quality development of the construction industry and realize the goal of "double carbon".

2. Core problems of civil engineering cost control in prefabricated buildings

As a modern architectural way, prefabricated buildings have attracted more and more attention

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for their advantages of high efficiency, environmental protection and energy saving [6]. In the construction of prefabricated buildings, the cost control and cost optimization of civil engineering is an important link to ensure the maximum economic and social benefits of the project. The cost control of civil engineering refers to the scientific prediction, calculation, supervision and management of the engineering cost at all stages of the assembled construction project, so as to ensure that the engineering cost does not exceed the budget and realize the optimization of the cost [7]. Effective cost control can not only reduce unnecessary expenses, but also improve the utilization efficiency of resources and ensure the smooth progress of the project.

Design stage is the key link of civil engineering cost control [8]. Reasonable design scheme can reduce the changes and rework in the construction process, thus reducing the project cost. In addition, adopting standardized and modular design can realize the interchangeability and reuse of components, reduce design cost and improve production efficiency [9]. Material cost is an important part of civil engineering cost. The cost of materials can be effectively reduced by centralized procurement, reasonable selection of suppliers and adoption of green materials. Labor costs account for a large proportion in civil engineering. By improving construction efficiency, optimizing personnel allocation and adopting labor dispatch, labor costs can be effectively controlled. Equipment costs include the purchase, lease, repair and maintenance of construction equipment. Reasonable purchase and lease of equipment and strengthening equipment maintenance can reduce equipment costs. Management costs include project management, design management, quality control and other expenses. Strengthening project management, optimizing design and strengthening audit can effectively control management costs. Other costs include transportation, warehousing, insurance, taxes, etc. Other costs can be reduced by optimizing transportation scheme, strengthening storage management and paying taxes and fees reasonably. The cost control of civil engineering of prefabricated buildings is a complex systematic project, which needs to start from design, materials, labor, equipment, management and other aspects, and take effective control strategies and measures to achieve cost optimization.

3. Whole process cost optimization strategy system

Based on the LCC theory of assembled building civil engineering, this study proposes a systematic cost optimization strategy system covering the four core links of "design-production-logistics-construction" (Figure 1). The system takes collaborative design as the source, lean production as the core, intelligent logistics as the link and efficient construction as the foothold, forming a closed-loop management.

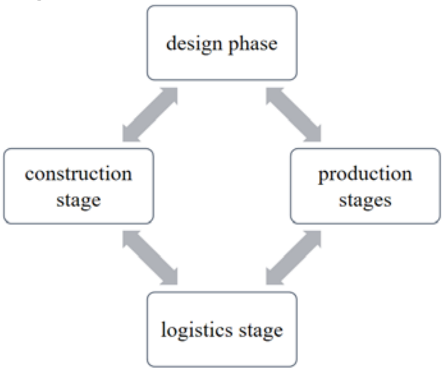

Figure 1 Systematic cost optimization strategy system

3.1 Design stage: collaborative design of standardization and parameterization

Adopting modular design combined with value engineering (VE) analysis to improve the standardization and reuse rate of components, effectively reduce the demand for mold types and design change frequency, and thus control costs; At the same time, integrating BIM technology enables full chain collaboration of Design Production Construction (DfMA), automatically generating component processing drawings and Bill of Materials (BOM), breaking down information barriers, reducing resource waste and cost redundancy caused by information silos, and comprehensively improving design efficiency and construction accuracy.

Correlation model between standardization rate and cost:

$$C_d = C_b \times (1 - \alpha S_r) \quad (1)$$

Where C_d is the cost per unit area in the design stage (yuan/m²); C_b is the benchmark design cost (unit cost of traditional cast-in-place mode); α is the standardization coefficient (empirical value, generally 0.15 ~ 0.25); S_r is standardization rate (%) = number of standardized components/total number of components.

3.2 Production stage: lean and large-scale production

Dynamic production scheduling model optimizes production scheduling plan based on order quantity, mold reuse rate and capacity utilization rate, and reduces production line switching cost. Set the cost control threshold [10] according to the unilateral concrete cost, steel bar loss rate and other indicators of the advanced precast factory in the standard industry. The unit production cost model of prefabricated components is described as follows:

$$C_p = \frac{(C_m + C_l + C_e)(1+\beta)}{Q} \quad (2)$$

Where, C_p is the production cost of a single prefabricated component (yuan/piece); C_m is the material cost (concrete, steel bars, embedded parts, etc.); C_l is labor cost (direct production personnel); C_e is equipment amortization and energy consumption cost; β is the coefficient of management fee and rejection rate (usually 10% ~ 15%); Q is the number of components produced, and under the scale effect, C_p decreases with the increase of Q.

3.3 Logistics stage: integrated optimization of transportation and inventory

In the logistics stage, by applying the path optimization algorithm based on GIS, the transportation route is scientifically planned, which can effectively shorten the transportation distance, reduce the waiting time and improve the transportation efficiency. At the same time, JIT (just-in-time) distribution mode is implemented, and the demand time of components is dynamically deduced according to the construction progress, so as to accurately control the arrival rhythm of components, reduce the occupation of on-site yard and the cost of secondary handling, and realize the integration and optimization of transportation and inventory, thus reducing the overall logistics cost and ensuring the continuity of construction.

Among them, the transportation cost optimization model can be expressed as:

$$C_t = \sum_{i=1}^{n} (d_i c_{km} + t_i c_{wait}) N_i \quad (3)$$

In the above formula, C_t is the total transportation cost; d_i is the transportation distance of the first i train (km); c_{km} is the transportation cost per unit distance (yuan/km); t_i is the on-site waiting time (hours); c_{wait} is the waiting time cost (yuan/hour, including driver's working hours and vehicle idleness); N_i is the number of trains.

3.4 Construction stage: assembly and digital field management

Build a hoisting efficiency model, comprehensively consider the working radius, hoisting times and component weight of tower crane or truck crane, scientifically optimize the hoisting sequence and construction rhythm, and improve the assembly efficiency; Combining RFID technology and BIM platform, digital site management can be realized, and the arrival, installation and status information of components can be tracked in real time, so as to ensure the dynamic coordination between construction progress and design plan, effectively avoid the phenomenon of delayed work, wrong installation or rework, improve the construction accuracy and management transparency, and ensure the efficient and orderly progress of the project. The field installation cost model is as follows (4).

$$C_s = (T_{base} + kA)c_{crew} \quad (4)$$

Where C_s represents the total cost of site installation; T_{base} represents the basic operation time (days); k represents the installation time coefficient per unit area (day/m²); A represents the total assembly area (m²); c_{crew} represents the daily work fee of the shift (yuan/shift day).

3.5 LCC integration verification

In order to comprehensively evaluate the economy of prefabricated buildings, LCC net present value model is used to discount the costs of design, production, transportation, construction and operation and maintenance into present values for comprehensive calculation. The model includes design cost (C_d), production cost (C_p), transportation cost (C_t), construction cost (C_s) and operation and maintenance cost (M_t). By setting a reasonable discount rate (r) and building service life (n), the prefabricated construction mode is quantitatively compared with the traditional cast-in-place mode, so as to scientifically judge its long-term economic benefits and provide data support for decision-making.

$$LCC = C_d + C_p + C_t + C_s + \sum_{i=1}^{n} \frac{M_t}{(1+r)^t} \quad (5)$$

On this basis, relying on BIM platform to integrate the cost data of each stage, a "prefabricated building cost cockpit" is built to realize the dynamic monitoring and visual management of LCC. The system can identify the cost deviation in real time and automatically trigger early warning, promote the information linkage and collaborative optimization among design, production, logistics and construction, form a closed-loop cost control mechanism, and comprehensively improve the refined and intelligent level of project cost management.

4. Empirical analysis and effect verification

A prefabricated residential project in a city (with a building area of 50,000 m²) is selected as the empirical analysis object. By comparing the key economic indicators before and after applying the optimization strategy, the cost control effect is evaluated. In this case, a residential project with 25 floors above ground and a prefabrication rate of 50% is taken as the research object. The main prefabricated components include laminated slabs, stairs and inner wallboard. The traditional decentralized management model is set as the benchmark scenario, and the scenarios in which the optimization strategies such as standardized design, lean production and JIT distribution are applied with the component standardization rate increased to 70% are compared. By setting the key parameters such as 5% discount rate and 50-year building life cycle, the economic improvement of the proposed integrated optimization strategy on LCC is systematically evaluated.

By calculating and simulating the cost data of two scenarios, the key results shown in Table 1 were obtained. The results showed that in the optimized scenario, due to the implementation of standardized design, lean production, and JIT distribution, design costs were reduced by 17.6%, component production, logistics transportation, and on-site installation costs were reduced by 6.3%, 16.7%, and 10.0%, respectively. The total cost of construction and installation engineering decreased from 1455 yuan/m² to 1330 yuan/m², a decrease of 8.6%; After taking into account the discounted operation and maintenance costs, the LCC decreased from 1580 yuan/m² to 1435 yuan/m², a decrease of 9.2%, indicating that the optimization strategy significantly improved the overall economy of the project. Through the following Figure 2, it can be intuitively seen that the total cost comparison under the two scenarios has brought significant economic benefits through the application of optimization strategies.

Table 1 Single cost (yuan/m²) key item cost comparison

Cost breakdown	Reference scene	Optimize the scene	Amplitude of variation
Design cost	85	70	-17.6%
Component production cost	950	890	-6.3%
Logistics transportation cost	120	100	-16.7%
Field installation cost	300	270	-10.0%
Total cost of Jian' an project	1455	1330	-8.6%

Note: The total cost of Jian 'an project does not include the later operation and maintenance expenses; LCC cost has been discounted.

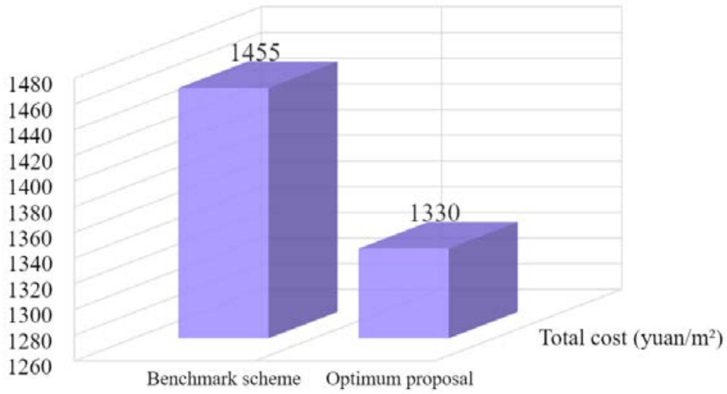

Figure 2 Comparison of total cost before and after application of optimization strategy

5. Conclusion

In this paper, the cost control and cost optimization of civil engineering in prefabricated building construction are deeply discussed, and a set of systematic strategy system based on LCC is put forward. By analyzing the four core links of design, production, logistics and construction, this study constructs strategies such as standardized and parametric collaborative design, lean and large-scale production, integrated optimization of transportation and inventory, assembly and digital field management, and forms a closed-loop management mechanism. The empirical analysis shows that after applying these optimization strategies, the total cost of Jian 'an project of prefabricated building projects is significantly reduced, and the LCC net present value model verifies its long-term economic benefits. Specifically, the design cost decreased by 17.6%, the component production cost decreased by 6.3%, the logistics and transportation cost decreased by 16.7%, the site installation cost decreased by 10.0%, and the total cost of the overall Jian 'an project decreased by 8.6%. After taking into account the discounted operation and maintenance cost, the LCC cost was further reduced by 9.2%. These achievements not only provide a cost control tool kit for construction enterprises, but also provide data support for the government to formulate differentiated subsidy policies and industrial planning. In the future, with the continuous progress of technology and the accumulation of management experience, prefabricated buildings are expected to play a greater role in realizing the goal of "double carbon" and promote the transformation of construction industry to high-quality development.

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