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THE PRICE OF INNOVATION: DETERMINING COST FACTORS IN PREFAB HOUSING

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Abstract: The rapid pace of urbanization and population growth has necessitated innovative solutions to urban housing challenges, leading to the proliferation of high-rise residential construction. Prefabricated building techniques have emerged as a fast, efficient, and sustainable approach to address these demands. In recent years, prefabricated high-rise residential buildings have gained prominence for their ability to enhance construction quality, shorten project timelines, and minimize resource consumption. However, despite their advantages, prefabricated homes encounter significant cost-related challenges. This paper underscores the importance of conducting a comprehensive evaluation and analysis of the cost factors associated with prefabricated housing to enhance its economic viability and sustainability. By systematically examining the various cost elements involved in prefabricated construction, stakeholders can identify opportunities for cost optimization and efficiency improvement. Such evaluations are essential for informing decision-making processes and guiding policy interventions aimed at promoting the widespread adoption of prefabricated building methods. Drawing upon insights from contemporary literature and empirical studies, this paper elucidates the key cost factors influencing the economic performance of prefabricated housing projects. It explores factors such as material costs, labor expenses, transportation logistics, regulatory compliance, and project management overheads, among others. Through a comprehensive analysis of these cost drivers, stakeholders can develop strategies to mitigate cost escalations and enhance the overall affordability and feasibility of prefabricated housing solutions.

Keywords: Prefabricated housing, Cost factors, Economic viability, Sustainability, High-rise residential construction.

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1. Introduction

With the acceleration of urbanization and the demand of population growth, the construction of highrise housing has become an important means to solve the problem of urban residence. As a fast, efficient and sustainable building method, prefabricated building has been widely concerned and applied in recent years [1]. As an important part of prefabricated buildings, prefabricated high-rise residential buildings have unique advantages in improving construction quality, shortening construction period and reducing resource consumption. However, prefabricated homes still face a series of challenges and difficulties in terms of cost [2]. Therefore, the comprehensive evaluation and analysis of the cost factors of the prefabricated housing is of great significance to improve the economy and sustainability of the prefabricated housing [3].

The factors affecting the cost of prefabricated housing involve many aspects, including design stage, manufacturing stage, transportation and installation stage. These factors are interrelated and influence each other, so a comprehensive evaluation is needed to reveal their specific contribution and impact on the cost of prefabricated homes [4].Domestic and foreign scholars have done a lot of research on this. Liu Guoqiang et al. based on a large amount of data, the factors affecting the construction cost of prefabricated buildings are procurement stage, installation stage and dynamic influence [5].Luo LAN et al. believe that the high cost makes the application of prefabricated buildings lag behind in china, and the cost influencing factors are divided into external factors, decision-making and design stage, generation and transportation stage, and construction stage [6].Lou N et al. studied the key cost drivers and cost control paths of prefabricated buildings, regarded the construction cost of prefabricated buildings as a dynamic formation process, and systematically studied the product system, technical system, construction process, management mode and other aspects [7]. Wei Hongliang and other factors affecting the cost of prefabricated buildings are divided into four aspects: environment, design, generation and other aspects [8].Peng J et al. set up an index system of influencing factors for the cost of prefabricated buildings from four aspects of design, management, technology, policy and environment from the perspective of hidden costs, and conducted a comprehensive analysis of hidden costs by combining qualitative and quantitative methods [9].Luo Xiang et al. divided the influencing factors into four aspects: design, technology, management and environment. However, in the present research, a complete, systematic and operational evaluation framework of cost influencing factors has not been formed [10].Starting from the whole life cycle of prefabricated buildings, Li N et al. selected four stages of design, component production, transportation and construction and proposed an evaluation framework of influencing factors of prefabricated building cost based on game theory-cloud model to ensure scientific and accurate index weights [11].Lv Zheqi et al. believe that the LCC theoretical framework is applied to analyze the cost influencing factors from the four levels of product, management, technology and other levels, and construct the cost evaluation index system of prefabricated buildings [12].Zhao Liang et al. studied and controlled the influencing factors of the life cycle cost increment of prefabricated buildings
[13].

By evaluating and analyzing cost influencing factors, we can identify the key points of cost optimization and potential improvement space, so as to propose effective cost control strategies and measures to further promote the development and application of prefabricated housing. Therefore, through comprehensive literature analysis, expert interviews and empirical data collection, this study will build a comprehensive, scientific and operable evaluation framework for the influencing factors of the cost of prefabricated housing, and apply it to the evaluation of practical cases. Provide decision support and technical guidance to the prefabricated construction industry to promote the sustainable development of prefabricated housing.

2. Determine the index system of influencing factors of prefabricated housing cost

2.1. Construction steps of evaluation index system

According to the scientific principle, systematic principle, operability principle and practicability principle, the evaluation index system of influencing factors of prefabricated housing cost is constructed. The specific steps are as follows:

(1) Collect related literature and materials of prefabricated housing cost: review and analyze related literature of prefabricated housing cost, including academic journals, papers, etc.

(2) Identification of factors affecting the cost of prefabricated housing: Analyze and summarize the collected literature and data to identify potential factors related to the cost of prefabricated housing. By means of expert interviews, questionnaires and other methods, the opinions and suggestions of professionals on the factors affecting the cost of prefabricated housing are obtained.

(3) Indicators of influencing factors of the cost of prefabricated housing: The identified influencing factors of the cost of prefabricated housing are screened and sorted, and evaluated according to their importance and operability. Using expert evaluation, statistical analysis and other methods to determine the main influencing factors and secondary influencing factors.

(4) Determine the evaluation index system of the influencing factors of the cost of prefabricated housing: establish a complete index system according to the selected influencing factors of the cost. The hierarchy structure of evaluation index is designed to ensure the scientificity and operability of the evaluation index system.

2.2. Selection of prefabricated housing cost index

The purpose of identifying the cost influencing factors is to understand and evaluate the influence degree of each factor on the cost in the construction process of prefabricated housing comprehensively and accurately. In order to comprehensively evaluate and study the cost of prefabricated housing, this paper uses the literature analysis method to identify the cost influencing factors. The main steps are as follows:

(1) Bibliometric measurement: This paper is limited to the range of papers published by domestic scholars in the last 5 years, and is searched through the database of China National Knowledge Network. Topics were searched for "prefabricated buildings" and "costs". A total of 758 journal papers were retrieved under the prefabricated architecture theme, including 87 core journal papers of Peking University and 506 doctoral and master degree papers. Under the prefabricated housing theme, a total of 62 journal papers were retrieved, including 4 Peking University core journal papers and 70 doctoral and master degree theses.

(2) Literature induction: The obtained literature was screened according to the research objectives and subjects. First, read the title and abstract of the literature and exclude the literature that is not relevant to the study. Then, by reading the full text, the literature related to the research goal and theme is further selected. The indexes in the literature are classified and sorted, and the influencing factors of the cost of prefabricated housing at each stage are statistically analyzed, and the preliminary identification results of the influencing factors of the cost of prefabricated housing are obtained.

The indicators identified only through literature analysis may have some problems such as incomplete data, lack of consistency, and indicator selection bias. Therefore, further improvement is needed to ensure the reliability and accuracy of indicators. On the basis of the existing indicators of cost factors, this paper further analyzes and selects experts who are familiar with the development of China's prefabricated construction industry to conduct exchanges and interviews, and revise and supplement the indicators initially identified.

2.3. The construction of index system

This paper constructs the index system of influencing factors of prefabricated housing cost from the decision-making and design stage, production and transportation stage, construction stage, operation and maintenance stage, as shown in the following Table 1:

Table 1: Cost impact evaluation system of prefabricated buildings

	Primary indicator	Secondary indicator
Cost of prefabricated housing Influencing factor	Decision and design phase X_1	Prefabrication rate and assembly rate X_{11}
		Building form and scale X_{12}
		Type of PC component X_{13}
		Component standardization, modular degree X_{14}
		Competence and experience of the designer X_{15}
	Production and transportation stage X_2	Production scale and production capacity X_{21}
		Handling efficiency X_{22}
		The rationality of the transportation scheme X_{23}
		Transport distance X_{24}
	Construction phase X_3	Inter-job collaboration X_{31}
		Labor, material, machinery costs X_{32}
		Construction site management level X33
		The technical level of professionals X_{34}
		Degree of standardization of components X_{35}
	Operation and maintenance phase X_4	Energy consumption X_{41}
		Equipment replacement cost X_{42}
		Administrative costs X_{43}
	Other external factors X_5	National standard, specification X_{51}
		Tax policy X_{52}
		Degree of state financial support X_{53}

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3. Construct the cost impact assessment model of prefabricated housing

3.1. Construction of evaluation model based on GRA-TOPSIS

The advantage of TOPSIS method is that it can consider the weight of multiple indicators and the closeness of the scheme to the ideal solution, so as to provide a systematic method for ranking and selection. However, the TOPSIS method also has some limitations, such as the determination of index weights may be subjective and uncertain. The advantage of grey correlation analysis is that it can overcome the problem of incomplete data or uncertainty, and it does not need to determine the weight of factors in advance, avoiding the influence of subjective factors. The results of grey correlation analysis are used as the reference of index weights in approximate ideal value ranking to improve the accuracy of weights and make up for the shortcomings of TOPSIS method.

3.1.1. Analytic hierarchy process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method used to help decision makers determine the weight and priority in complex decision problems. It was proposed by American mathematician Thomas L. Saaty in the 1970s and has been widely used in various fields. In the analytic hierarchy process, the decision problem is decomposed into a hierarchy structure, including the goal layer, the criterion layer and the scheme layer. The goal layer is the highest level and represents the ultimate goal of the decision. The criterion layer is the next level of the goal layer and represents several aspects or criteria that need to be considered to achieve the goal. The scenario layer is below the guideline layer and includes specific decision scenarios or options. Decision makers need to compare the elements of each layer pairwise, using a judgment matrix to express their relative importance. Finally, through the analytic hierarchy process, we can get the weight of each level and the comprehensive score of each stage of prefabricated high-rise housing, so as to help decision-makers make the best decision.

3.1.2. The weighted standard matrix is constructed

(1) Determine the data matrix. It is assumed that the prefabricated housing has m projects and n cost factor index construction matrix $A=(x_{ij})_{m\times n}=\begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$, where xij is the value of the jTH item of the i th factor index $i \subseteq [1,n], j \subseteq [1,m]$.

(2) Dimensionless data processing and standardization. Since there are great differences in the measurement units and specific values of each index, we need to carry out dimensionless processing on it, and the standardized matrix $Z=(z_{ij})_{m\times n}$.The specific process is as follows:

$$Z_{ij}=\frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}\quad (i=1,2,\cdots,m,\ j=1,2,\cdots,n) \tag{1}$$

(3) According to the analytic hierarchy process, the weight of each index W is multiplied by the standardized matrix Z, and the weighted standardized Y is calculated

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$$YY = WW \bullet ZZ = yy_{iiiimm\times nn} = \begin{matrix} yy11 & \dots & yy1nn \\ \vdots & \ddots & \vdots \\ yymm1 & \cdots & yymmnn \end{matrix} \quad (2)$$

3.1.3. Determine the Euclidean distance between positive and negative ideal solutions

(1)Determine the positive and negative ideal solutions in the project system.

$$vv_{ii}^{+} = mmmmxxyy_{iiii}, \; vv_{ii}^{-} = mmiinnyy_{iiii} \quad (3)$$

$$ii \qquad ii$$

Where,vv_{ii}^{+}represents the index with the highest score among the jTH index in the system and is a positive ideal solution; vv_{ii}^{-}represents the index with the lowest score in the jTH index in the system, which is a negative ideal solution.

(2) Calculate the Euclidean distance between the evaluation index of the cost influence factor and the positive and negative ideal solution:

$$dd_{ii}^{+} = \sqrt{\sum_{j=1}^{n}(v_j^{+} - yy_{iiii}}^{2}, \; d_i^{-} = \sqrt{\sum_{j=1}^{n}(v_j^{-} - yy_{iiii}}^{2} \quad (4)$$

Where dd_{ii}^{+} represents the distance between the jTH index and the positive ideal solution, and dd_{ii}^{-}represents the distance between the jTH index and the negative ideal solution.

3.1.4. Determine the gray correlation degree between the evaluation object and the positive and negative ideal solution

According to the grey relational analysis method, the grey relational degree rr_{ii}^{+}, $rr_{ii}^{-}$of project i with positive and negative ideal solutions as reference Grey correlation degree of ideal solution:

$$^{+} = \frac{1}{-}\sum \qquad zz$$

$$mmiinnmmiinnvv_{ii}^{+} - yy_{iiii} + \xi\xi mmmmmm_{ii}\, mmmmmm_{ii}\, vv_{ii}^{+} - yy_{iiii}$$

$$ii \quad ii$$

$$rrii \quad zz\, ii=1 vvii+-yyiiii+\xi\xi mmmmmmii\; mmmmmmii\; vvii+-yyiiii$$

(5)

Grey correlation degree of negative ideal solution:

$$zzmmiiiinnmmiiiinnvv_{ii}^{-} - yy_{iiii} + \xi\xi mmmmmm_{ii}\, mmmmmm_{ii}$$

$$vv_{ii}^{-} - yy_{iiii}$$

$$rrii^{-} = \frac{1}{-}\sum \qquad zz \quad ii=1$$

$$vvii--yyiiii+\xi\xi mmmmmmii\; mmmmmmii\; vvii--yyiiii \quad (6)$$

In the formula, ξ is the resolution coefficient, generally 0.5.

3.1.5. The approximation degree between the evaluation object and the ideal solution is calculated (1) The gray correlation degree and Euclidean distance are standardized respectively.

$$RRii+ = mmmmmmrrii+rrii+, \; RRii- = mmmmmmrrii-rrii- \quad (7)$$

$$DDii+ = mmmmmmddii+ddii+, \; DDii- = mmmmmmddii-ddii- \quad (8)$$

(2) The relative proximity to positive and negative ideal solutions MM_{ii}^{+} and $MM_{ii}^{-}$are calculated respectively. $MMii+ = \alpha d_i^{*} + \beta\beta RRii+$

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$MM-_{\beta\beta RRii}-$ (9) $= \alpha d_i^+ +$

ii

Where, and is the preference coefficient $\alpha\alpha$=$\beta\beta$= 0.5.

(3) The comprehensive approximation degree SS_{ii} to the ideal solution is calculated.

$$SSii = \frac{MM_{ii}^+}{MM_{ii}^+ + MM_{ii}^-} \quad (10)$$

SS_{ii} represents the comprehensive close degree of the i project scheme relative to the evaluation objective. The larger the SS_{ii} value, the better the project scheme.

4. Empirical analysis

4.1. Data Sources

His paper takes the data of 5 prefabricated houses of a construction company in Jiaxing as sample data, with project numbers from 1 to 5. Each project shows its own characteristics, and TOPSIS and grey correlation analysis algorithm are used to study it.

4.2. Implementation of TOPSIS and grey correlation analysis algorithm

4.2.1. Determination of weighted standard matrix

Table 2: Weighting matrix of influencing factors of prefabricated construction cost

Evaluation index	Engineering project				
	1	2	3	4	5
Prefabrication rate and assembly rate X11	0.0142	0.0126	0.0155	0.0129	0.0143
Building form and scale X12	0.0028	0.0043	0.0049	0.0051	0.0064
Type of PC component X13	0.0074	0.0080	0.0083	0.0063	0.0071
Component standardization, modular degree X14	0.0098	0.0083	0.0093	0.0100	0.0095
Competence and experience of the designer X15	0.0107	0.0129	0.0087	0.0145	0.0140
Production scale and production capacity X21	0.0036	0.0046	0.0042	0.0038	0.0062
Handling efficiency X22	0.0081	0.0068	0.0065	0.0064	0.0077
The rationality of the transportation scheme X23	0.0116	0.0136	0.0123	0.0155	0.0098
Transport distance X24	0.0148	0.0149	0.0118	0.0129	0.0138
Inter-job collaboration X31	0.0150	0.0151	0.0207	0.0125	0.0074
Labor, material, machinery costs X32	0.0092	0.0080	0.0100	0.0101	0.0085
Construction site management level X33	0.0312	0.0280	0.0388	0.0366	0.0369
The technical level of professionals X34	0.0276	0.0268	0.0212	0.0205	0.0239

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Degree of standardization of components X35	0.0090	0.0140	0.0156	0.0108	0.0129
Energy consumption X41	0.0049	0.0044	0.0055	0.0038	0.0043
Equipment replacement cost X42	0.0034	0.0042	0.0052	0.0049	0.0042
Administrative costs X43	0.0095	0.0089	0.0062	0.0078	0.0076
National standard, specification X51	0.0061	0.0057	0.0049	0.0065	0.0053
Tax policy X52	0.0079	0.0072	0.0078	0.0085	0.0071
Degree of state financial support X53	0.0022	0.0022	0.0018	0.0017	0.0020

According to the characteristics of the cost influencing factors in different stages of the whole life cycle of the prefabricated housing, the paper classifies the cost influencing levels of the prefabricated housing by referring to relevant literature and conducting expert interviews. In the form of questionnaire survey, 10 experts in related fields and 5 practitioners were invited to score 17 non-quantitative factor indicators of 5 engineering projects according to the 10-point system. And the weighted standard matrix is calculated by formula (1) and (2), as shown in Table 2:

4.2.2. Evaluation result

From formula (4) to (8), Euclidean distance D_i^+,D_i^-and grey correlation degree R_i^+,R_i^-of positive and negative ideal schemes after normalization can be calculated respectively, as shown in Table 3:

Table 3: DD_{ii}^{+}, DD_{ii}^{-}, RR_{ii}^{+}, RR_{ii}^{-} *of the project*

Engineering project	1	2	3	4	5	6
Euclidean distance $DD_{ii}^{+}$of the ideal solution	0.0984	0.0838	0.1298	0.1214	0.1233	0.0984
Euclidean distance $DD_{ii}^{-}$of the negative ideal solution	0.0969	0.0824	0.1277	0.1191	0.1212	0.0969
The gray correlation degree of the ideal solution is RR_{ii}^{+}	0.6542	0.6924	0.5836	0.5978	0.5950	0.6542
Grey correlation of negative ideal solution RR_{ii}^{-}	0.8349	0.8316	0.8225	0.8234	0.8317	0.8349

The comprehensive proximity degree of the project can be calculated by formula (9) and (10) respectively, as shown in Table 4:

Table 4: MM_{ii}^{+}, MM_{ii}^{-}, SS_{ii} *of each project*

Engineering project	1	2	3	4	5	6
The relative approximation of the ideal solution MM_{ii}^{+}	0.3763	0.3881	0.3567	0.3596	0.35915	0.3763
The relative closeness of the negative ideal solution MM_{ii}^{-}	0.4659	0.457	0.4751	0.47125	0.47645	0.4659
Comprehensive approach degree SS_{ii}	0.4468	0.4592	0.4288	0.4328	0.4298	0.4468

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5. Suggestions and conclusions

From the above evaluation results, in the initial stage of prefabricated housing projects, cost analysis should be carried out to encourage and support the increase of prefabricated rates to determine the most reasonable design and scale. Promote advanced precast technology and process in production and transportation stage, construction stage, operation and maintenance stage, train technical personnel, improve the quality and efficiency of precast components; Strengthen communication and collaboration with supply chain partners to optimize material procurement and supply, reduce costs, and improve quality; Encourage the use of renewable materials and green building technologies to reduce environmental impact and long-term operating costs. In terms of policy, establish an effective project control mechanism to ensure the control of construction progress and quality to avoid additional costs and delays.

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