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Research Article

Impact Evaluation of Prefabricated Buildings Cost on Game Theory-Cloud Model

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Prefabricated buildings have the advantages of energy-saving, high efficiency, and high quality, which is energetically promoted in China's construction industry. But the prefabricated buildings' high construction cost hinders their rapid development. Around the higher construction cost of prefabricated buildings, this paper starts with the full life cycle of prefabricated buildings and selects four stages: design, component production, transportation, and construction. And constructs the evaluation index system of influencing factors of the prefabricated buildings cost. Based on this, this paper proposes an evaluation framework based on the game theory-cloud model to evaluate the influencing factors of prefabricated buildings costs. Taking a prefabricated building in Tianjin as the research object, the game theory combinatorial empowerment method and cloud model are used to evaluate the impact effect of prefabricated buildings cost. Game theory is used to optimize the subjective and objective weights determined by the attribute hierarchy model and the entropy weight method and to confirm the comprehensive weight of the evaluation index. The index's weight is scientific and accurate, and the subjective influence of a single process is avoided or does not conform to the actual situation and so on. The cloud model is used to evaluate the cost impact of prefabricated buildings comprehensively. The experimental results show that the model is feasible; the scientific and accurate evaluation results are improved; and the model is simple to operate and has some reference value.

1. Introduction

With the development of building industrialization, the traditional architecture has not conformed to the concept of a green four sections and one environmental protection advocated by the state. The traditional architecture construction method has low production efficiency, serious environmental pollution, long construction period, and so on [1, 2]. At present, national are actively promoting prefabricated buildings. The prefabricated building is a building that is finished in the factory and transported to the construction site for safe and reliable installation [3]. Prefabricated buildings have the advantages of green energy saving and high efficiency, in line with the national green, high-quality development of strategic requirements. However, prefabricated buildings' high-cost problem has restricted the rapid development of prefabricated buildings [4, 5]. The cost of prefabricated buildings is affected by many factors. If the cost management is improper in the construction process of prefabricated buildings, it may lead to cost overruns and delays in the construction period [6, 7]. It will suspend the construction in serious cases. Therefore, we should fortify control of prefabricated buildings costs and virtually lessen the construction cost. It has important guiding significance for the development of prefabricated buildings.

At present, domestic and foreign scholars have some research results on the cost of prefabricated buildings, as shown in Table 1. Peng et al. [8] studied the cost of prefabricated buildings from the perspective of hidden cost by using the fuzzy interpretive structure model (FISM) and Bayesian network (BN) and found out the key factors leading to hidden cost. Chang and Zhang [9] analyzed the main problems existing in assembly parts production using the strategic planning table method and putting forward corresponding control countermeasures. Wu and Qi [10] used the fuzzy TOPSIS method to

Table 1: Literature review.

Study	Key research points	Research method
[8]	From the perspective of hidden cost, an index system of influencing factors of prefabricated buildings cost from five dimensions of design, management, technology, policy, and environment is established, including 13 factors. And the hidden cost analysis model has been proposed based on FISM-BN; this model combines a fuzzy interpretive structure model (FISM) with a Bayesian network(BN). The conclusion is that the probability of hidden costs is 26%.	FISM-BN
[9]	From the perspectives of component processing drawing design, mold design, mold production, and use and component on-site production, the strategic planning table is used. This paper summarizes and analyzes the main problems and causes of cost control in the production stage of prefabricated components and puts forward the corresponding control measures.	Strategic planning table
[10]	The weight of each index is calculated by AHP. The closeness of four prefabricated high-rise building projects located in Fujian province to the optimal cost is calculated and sorted by the fuzzy TOPSIS method.	AHP, fuzzy TOPSIS
[11]	This paper establishes the evaluation index system of prefabricated buildings cost risk from the four aspects of the economy, technology, environment, and management; uses the method of AHP to determine the subjective weight of the index, the improved critical method to determine the objective weight, TOPSIS method to combine the weights; and uses the cloud model to determine the cost risk evaluation level to evaluate the cost risk of prefabricated buildings.	AHP, improved CRITIC, TOPSIS
[12]	The strategic planning table method is used to compare the cost between prefabricated buildings and traditional buildings.	Strategic planning table
[13]	This paper analyzes the influencing factors of prefabricated buildings cost from four aspects, such as design factors, management factors, technical factors, and policy factors, and calculates the weight of cost influencing factors by using AHP.	AHP
[14]	Based on the existing literature and expert opinions, 23 key factors affecting the quality management of prefabricated buildings are summarized, and the hierarchical relationship between factors is analyzed by ISM-MICMAC method.	ISM-MICMAC
[15]	Establish the increase and decrease model of the prefabricated buildings project cost before and after “replacing business tax with value-added tax,” analyze and calculate the increase and decrease balance point of the model, and study the influence range and change trend of “replacing business tax with value-added tax” on prefabricated buildings cost.	
[16]	A hybrid model is used to evaluate the environmental impact of prefabricated buildings and traditional in-situ cast buildings in the building life cycle.	A hybrid model

study the closeness between the prefabricated high-rise building project and the optimal cost in Fujian province. Xun et al. [11] used AHP and improved CRITIC methods to determine the subjective and objective weights and TOPSIS method to determine the total weight and evaluated the cost risk of actual prefabricated buildings according to the cloud model. However, the cost risk lacked the evaluation of the dynamic process. Scholars have also made many achievements in the comparison of the cost of traditional buildings and prefabricated buildings [12], the exploration of influencing factors [13, 14], cost management, and cost control [15, 16].

To sum up, we can see from the literature analysis:

(1) Some achievements have been made in the cost study of prefabricated buildings. However, most of the research scope is limited to a certain stage, such as more design and construction stages, and less consideration is given to the cost impact of the entire life cycle of prefabricated buildings.

(2) Scholars have adopted many methods to study the cost of prefabricated buildings. However, if there are too many factors affecting the cost, many methods will be very troublesome and time-consuming to operate. In addition, a single model is difficult to overcome subjectivity or objectivity in the research process.

Therefore, this paper proposes an evaluation framework based on the game theory-cloud model to evaluate the influencing factors of prefabricated buildings costs. The calculation process is simple and easy. The game theory is used to optimize the subjective and objective weights determined by the attribute hierarchy model and the entropy weight method and to confirm the comprehensive weight of the evaluation index. The index’s weight is scientific and accurate, and the subjective influence of a single process is avoided or does not conform to the actual situation and so on. The cloud model is used to evaluate the cost impact of prefabricated buildings comprehensively. The cloud model realizes the uncertainty mapping of each evaluation index, takes into account the randomness and ambiguity of evaluation index quantification and grade division, and makes the evaluation result objective.

In summary, this paper combine game theory with the cloud model from the perspective of starting with the full life cycle of prefabricated buildings in this study. The qualitative and quantitative analyses have been combined to analyze the cost of prefabricated buildings systematically and dynamically. Firstly, based on the extensive collection of data and questionnaire survey, this paper analyzes the influencing factors of the four stages of design, component production, transportation, and construction on the cost of prefabricated buildings and constructs the evaluation index system of the influencing factors of the cost of prefabricated buildings. Then, the subjective and objective weights are calculated by the attribute hierarchy model and entropy weight method. Based on game theory, the subjective and objective weights are optimized to determine the comprehensive weight of each influencing factor. Finally, the rating level and cloud model parameters are determined by using cloud model theory, and the impact of prefabricated buildings cost is comprehensively evaluated. Taking specific prefabricated buildings in Tianjin as an example to verify the rationality of the model, this paper proposes the corresponding cost control optimization countermeasures according to the research results to further promote the development of prefabricated buildings make them have a broader market.

This study is organized as follows: Section 2 establishes the evaluation index system and method model according to the problems raised. Subsequently, Section 3 introduces the case and implements the proposed method model. Finally, Section 4 puts forward the discussion, and Section 5 puts forward the conclusions and prospects.

2. Materials and Methods

2.1. Establishment of the Evaluation Index System. Prefabricated buildings mainly use integrated architectural design and construction, greatly saving labor resources and building materials; construction duration is short. However, the construction cost of prefabricated buildings is maybe ¥1,000/square meter, which is higher than that of traditional buildings. The cost of prefabricated buildings includes the cost of designing, producing, transporting, and hoisting prefabricated components compared to traditional buildings. Based on the reference to the existing literature [17, 18], this paper starting with the full life cycle of the prefabricated buildings and selects four stages of design, component production, transportation, and construction to study and construct the evaluation index system of influencing factors of prefabricated buildings cost, as shown in Figure 1. The evaluation index is scientific and accurate.

2.1.1. Design Stage. The cost of prefabricated buildings in the design stage mainly includes prefabricated components, technical planning, preliminary, overall, and construction of five design links. Prefabricated buildings costs are higher than traditional building costs, mainly due to prefabricated component design. Prefabricated component design is jointly designed by the design unit and the manufacturing plant according to the drawings. The cost is mainly affected by the type and complexity of prefabricated components. Therefore, the cost of prefabricated components should be reasonably designed and managed. In addition, the rationality of the overall design, the standardized design of prefabricated components, and other reasons will also directly affect the cost of subsequent prefabricated buildings construction.

2.1.2. Production Stage. The production stage of prefabricated buildings is mainly the production of prefabricated components; traditional construction requires a large number of on-site labor, whereas prefabricated buildings only need modern machinery and equipment and a small number of exceptional technical employees. The cost of production of prefabricated components in the factory is high, and the labor cost is lower. The cost of prefabricated components in the production stage is mainly component production technology, mold cost, pre-buried parts setup fee, and so on. Among them, the mold cost will be affected by the type and complexity of the prefabricated components, and the greater the type and complexity, the production cost of the mold will also increase. If the production technology of prefabricated components is not skilled, it may be operated incorrectly, resulting in the re-production of prefabricated components, which will also greatly increase production costs.

2.1.3. Transportation Stage. The transportation stage of prefabricated buildings is mainly the transportation of prefabricated components. The transportation of prefabricated components is much more complex than traditional buildings, and the cost is high. The transportation stage is divided into four steps:

(i) After the factory manufactures, the vehicle goes to the factory warehouse and completes the crane operation of the prefabricated components through the lifting equipment.
(ii) The vehicle sends the prefabricated components to the construction site according to the prearranged route.
(iii) After arriving at the construction site, the construction personnel hoists the prefabricated components.
(iv) After the hoisting is completed, the vehicle returns to the prefabricated factory.

Therefore, factory prefabrication close to the construction site should be selected. Before transport needs to plan transport routes and means of transport, timely cooperation with the destination saves some unnecessary transportation and installation costs. If the transportation route is unreasonable, it will lead to excessive use of vehicles, which will significantly increase the cost of transportation.

2.1.4. Construction Stage. The construction stage of the prefabricated buildings is mainly the setting and partial pouring, which need to be checked and repaired after installation. Compared with traditional buildings, prefabricated buildings have higher installation and hoisting engineering requirements in the construction process, resulting in increased setting up and hosting costs. Prefabricated buildings in the construction stage are mainly artificial, mechanical, hoisting, installation, and tool amortization costs. For example, because prefabricated components are heavier than standard pouring components, hoisting mechanical equipment costs increased. Good construction site management improves equipment efficiency, reduces consumables consumption, and can effectively control costs.

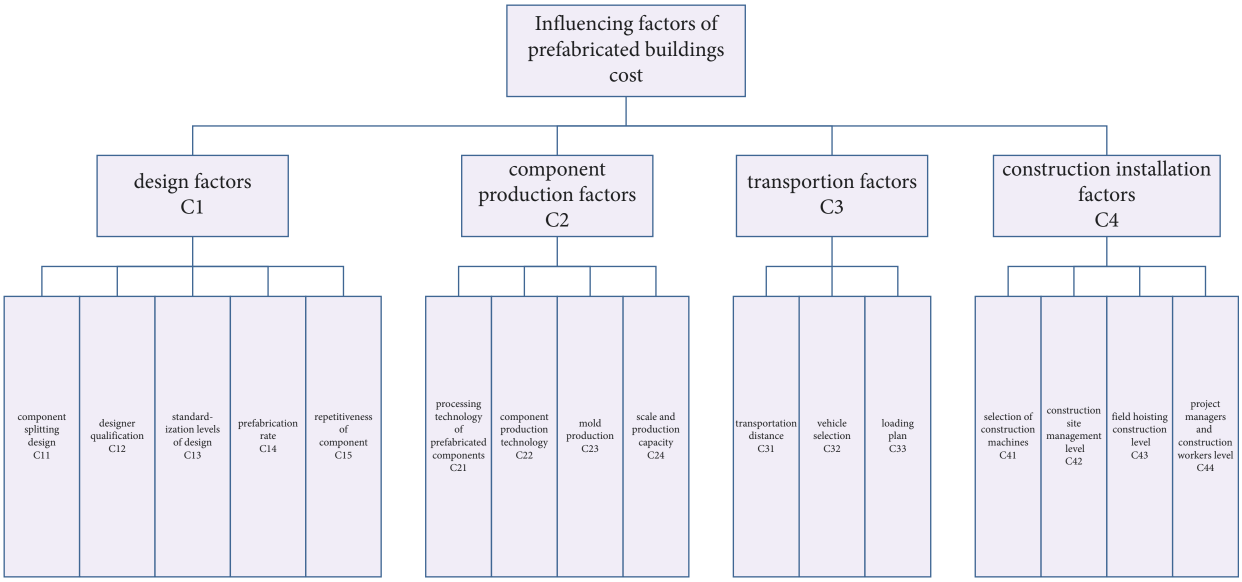

Figure 1: Evaluation index system of influencing factors of prefabricated buildings cost.

2.2. Combinatorial Empowerment Determines the Weight

2.2.1. AHM. Attribute Hierarchy Model (AHM) is an unstructured decision method based on analytic hierarchy process (AHP) [19, 20]. The modeling and calculation process of AHM's subjective weight is easy without calculating feature vectors and consistency checking. The steps for the use of AHM are as follows:

Step 1: Construct a judgment matrix. According to the 1–9 proportional scaling table, as shown in Table 2, the importance of the two factors influencing the cost of prefabricated buildings is compared, and the matrix composed of the comparison results is called the judgment matrix $A = (a_{ij})_{n\times n}$.

Step 2: Calculate the attribute judgment matrix. According to the following formula, transform the constructed judgment matrix $A = (a_{ij})_{n\times n}$ into an attribute judgment matrix $B = (b_{ij})_{n\times n}$.

$$b_{ij} = \begin{cases} \dfrac{\beta k}{\beta k + 1}, & a_{ij} = k, \\ 0.5, & a_{ij} = 1, \quad i \neq j, \\ 0, & a_{ij} = 1, \quad i = j, \\ \dfrac{1}{\beta k + 1}, & a_{ij} = \dfrac{1}{k}, \end{cases} \tag{1}$$

where k is a positive integer greater than 1 and β often takes 1 or 2.

Step 3: Determine the subjective weight. The relative property weight W_1 of each indicator is calculated by the following formula:

$$W_1 = \frac{2}{n(n-1)} \sum_{i=1}^{n} b_{ij}. \tag{2}$$

2.2.2. The Entropy Weight Method. The entropy weight method is an objective weighting method that can calculate the size of information entropy by evaluation index, which is used to determine the objective weight of the evaluation index [21]. The calculation process of obtaining objective weight by the entropy weight method is simple and easy. The steps for the use of the entropy weight method are as follows:

Step 1: Standardized processing. Invite n prefabricated building-related experts to evaluate the cost factors, form the evaluation index matrix and data standardization processing, and thus obtain a standardized matrix of dimensionless data.

Step 2: Determine the objective weight. The information entropy $E_1, E_2, \ldots, E_k$ of each indicator is calculated by formulas (3) and (4), and the objective weight W_2 of the indicator is determined according to formula (5):

$$p_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}, \tag{3}$$

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln p_{ij}, \tag{4}$$

$$W_2 = \frac{1 - E_j}{k - \sum E_j} \, (j = 1, 2, 3, \ldots, k), \tag{5}$$

where p_{ij} represents the frequency of the evaluation index j appearing in the i sample, $0 < p_{ij} < 1$; Y_{ij} represents the value of the j the evaluation index of i the sample after dimensionless processing; E_j represents

Table 2: 1–9 Proportional scaling table.

Factor Ci versus factor Cj	Quantitative value
Same important	1
Some important	3
Strongly important	5
Intensive important	7
Top importance	9
Intermediate value of two adjacent judgements	2, 4, 6, 8

the information entropy of evaluation index j; and k is a constant.

2.2.3. Game Theory. Game theory is a mathematical theory and method to study two or more people's strategies and decisions. The thinking of game theory is combining subjective weight with objective weight, taking the attribute hierarchy model method and entropy weight method as two participants of game theory, seeking the balance point of combining subjective weight and objective weight. Moreover, reach the optimal combination weight of equilibrium state, that is, the deviation between combination weight and subjective and objective weights is minimum [22, 23]. The steps for the use of game theory are as follows:

Step 1: The linear combination of subjective and objective weights of W_1 and W_2 obtained by AHM and entropy weight method yields the optimal weight of W; α_1 and α_2 are linear combined coefficients.

$$W = \alpha_1 W_1 + \alpha_2 W_2. \quad (6)$$

Step 2: Based on the idea of cooperative game theory, the difference between combination weight and subjective and objective weights is minimized, and α_1 and α_2 are optimized. The objective function is

$$\min \left\| \sum_{k=1}^{2} \alpha_k W_k^T - W_k \right\|_2 . \quad (7)$$

Step 3: According to the differential properties of the matrix, the objective function is transformed into the first derivative of the optimization by using the conditional expression (8), α_1 and α_2 take the absolute value get the best linear combination coefficient after normalization α^* and get the optimal combination weight W.

$$\begin{bmatrix} W_1 W_1^T & W_1 W_2^T \\ W_2 W_1^T & W_2 W_2^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} = \begin{bmatrix} W_1 W_1^T \\ W_2 W_2^T \end{bmatrix}, \quad (8)$$

$$\alpha^* = \left[\frac{\alpha_1}{\sum_{k=1}^{2} \alpha_k} \quad \frac{\alpha_2}{\sum_{k=1}^{2} \alpha_k} \right], \quad (9)$$

$$W = \sum_{k=1}^{n} \alpha_k^* W_k^T. \quad (10)$$

2.3. Cloud Model Theory. The cloud model is a kind of uncertainty conversion model between qualitative concept and quantitative representation put forward by Li and Yang [24], which combines randomness and fuzziness existing in qualitative concept to form the mapping between qualitative and quantitative, to realize qualitative and quantitative transformation. The cost impact evaluation of prefabricated buildings aims to establish the mapping between the cost impact evaluation index and qualitative conception. It shows the relationship between quantitative data and qualitative concepts and makes the transition between qualitative and quantitative.

Let U be on the domain, $x_1, x_2, \ldots, x_n$ is an accurate representation of quantitative domain space U. Fuzzy concept C is the qualitative concept on the domain. There is a random number $\mu(x) \in [0,1]$ for any element with a stable tendency in the existing field U. That is the membership degree. Its value is stable and random, which can directly reflect the certainty of attribute x to concept C. The distribution space of the membership degree $\mu(x)$ on the domain U is called the cloud, and each x becomes a cloud droplet, namely

$$\begin{aligned} \mu, U &\longrightarrow [0,1], \\ \forall_x \in U_x &\longrightarrow \mu(x). \end{aligned} \quad (11)$$

In the domain space U, a large number of cloud droplets x form a cloud, which can represent the characteristics of the qualitative concept [25]. The three digital characteristics of the cloud are acted for by expected (Ex), entropy (En), and hyper entropy (He) [26], as shown in Figure 2. Expected (Ex) is the distribution of cloud droplets in the universe space, which is the most representative point of the qualitative concept; entropy (En) is the value of the comprehensive measurement of randomness and fuzziness of the stability concept, which represents the acceptable value range of cloud droplets in the qualitative concept; hyper entropy (He) is the entropy of entropy and the comprehensive reflection of entropy fuzziness and randomness. For the problem of cost impact evaluation of prefabricated buildings, if there are m evaluation indexes, the impact level is divided into n levels; set $X_{\min}$ is the minimum boundary value of the evaluation indicator in a level of influence criterion; and $X_{\max}$ is its maximum boundary value. The boundary value of the evaluation index influence level standard is a quantitative indicator variable with bilateral. For example, $x \in [X_{\min}, X_{\max}]$, the digital characteristic formula of the cloud is

$$\begin{cases} E_x = \dfrac{x_{\max} + x_{\min}}{2}, \\ E_n = \dfrac{x_{\max} - x_{\min}}{6}, \\ H_e = k, \end{cases} \quad (12)$$

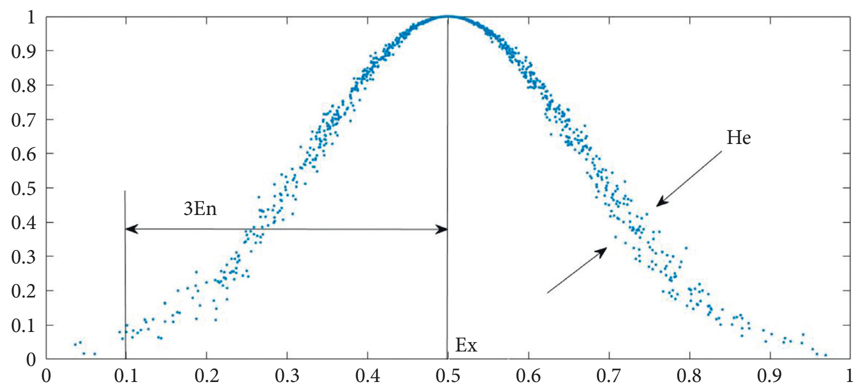

FIGURE 2: Cloud model.

where k is a constant. Hyper entropy (He) reflects the randomness of evaluation. The larger the number, the greater the error, and the impact of the final evaluation is more significant. This paper, based on the reference literature [27, 28], takes $k = 0.01$.

Cloud generation algorithms can be cured into hardware and software implementations, called cloud generator [29, 30]. The cloud generator separates into forwarding cloud generator and reverse cloud generator, as shown in Figure 3. The combination of the two can realize the mutual conversion between qualitative and quantitative concepts. The cost impact evaluation of prefabricated buildings mainly uses a forward cloud generator. Forward cloud generator generates cloud droplets based on the digital characteristics of the cloud (Ex, En, and He). Each cloud drop represents a mapping relationship between qualitative concepts and quantitative representations. The cloud model is used to transform digital cloud features and the number of cloud droplets (N) into a map composed of cloud N cloud droplets, which is output by MATLAB software.

2.4. Cloud Model Building. According to the characteristics of the impact of prefabricated buildings cost, divide the prefabricated buildings cost impact level into $V_i = \{V_1, V_2, V_3, V_4, V_5\}$ = {very important, important, general, less important, very less important}, and the score value is $[0, 1]$. In order to generate a comprehensive evaluation cloud map, a unified value standard is established for the cost impact evaluation level of prefabricated buildings, namely V_1 [0.8, 1], V_2 [0.6, 0.8], V_3 [0.4, 0.6], V_4 [0.2, 0.4], and V_5 [0, 0.2]. The expectations for the "general" level are centered, and 0 and 1 represent the expectations for the "very less important" and "very important" levels, respectively. According to the principle of approaching the "general" level, the expectation of "important" and "less important" levels can be calculated by formula (12) to be 0.691 and 0.309, respectively, and He = 0.01. According to formula (12), the evaluation rating criteria are converted into the digital characteristic parameters of the cloud model of the comment, as shown in Table 3. MATLAB forward cloud generator is used to grade the standard evaluation cloud map for each evaluation measure, as shown in Figure 4.

The evaluation indicator cloud of the cloud model was obtained through data evaluation. N experts were invited to score each evaluation indicator according to the situation of a specific project, input the obtained original data, and obtain the second-level index evaluation cloud through backward cloud generator calculation.

$$\begin{cases} \mathrm{Ex_j} = \dfrac{\sum_{i=1}^{n} \mathrm{x_{ij}}}{\mathrm{n}}, \\ \mathrm{En_j} = \sqrt{\dfrac{\pi}{2}} \sum_{i=1}^{n} \dfrac{\left|X_{ij} - \mathrm{Ex_j}\right|}{\mathrm{n}}, \\ \mathrm{He_j} = \sqrt{\left|S_j^{\,2} - \mathrm{En}_j^{\,2}\right|}, \end{cases} \tag{13}$$

where S_j^2, X_{ij}, and Ex_j, respectively, indicate the variance, evaluation value, and expectation of the i ($i = 1, 2, 3, \ldots, n$) experts on the indicator j.

Input the three digital characteristics of the cloud model into the forward cloud generator, get the cloud map of the first expert score, use the cloud map to observe the feasibility of the expert scoring data, and after the comprehensive arrangement, the results will be fed back to the experts, and the opinions will be consulted again. This will be repeated for many rounds until the expert scoring data are more scientific and accurate. The cycle is adjusted repeatedly until a satisfactory cloud map is generated. The three digital characteristics of the evaluation cloud and the comprehensive weight are calculated by formula (14) to find the integrated cloud, which is recorded as C (Ex, En, and He). Similar comparisons between the comprehensive cloud and the standard evaluation cloud are achieved through MATLAB software, to determine the impact level of prefabricated buildings cost and reflect the overall results of the evaluation index object.

$$\begin{cases} \mathrm{Ex} = \sum_{j=1}^{n} W \cdot \mathrm{Ex}_j, \\ \mathrm{En} = \sqrt{\sum_{j=1}^{n} W \cdot \mathrm{En}_j^{\,2}}, \\ \mathrm{He} = \sum_{j=1}^{n} W \cdot \mathrm{He}_j. \end{cases} \tag{14}$$

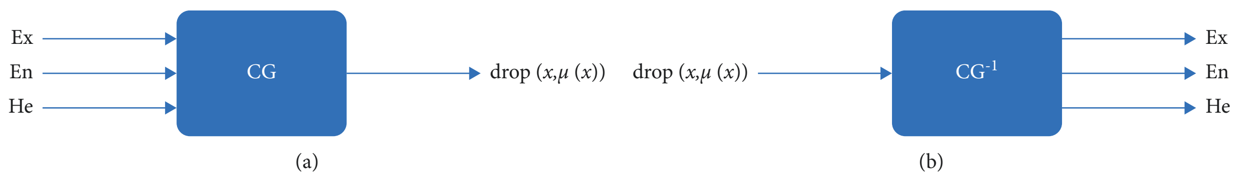

FIGURE 3: Cloud generator: (a) forwarding cloud generator and (b) reverse cloud generator.

TABLE 3: Rating level and cloud model parameters.

Rating level	Value ranges	Cloud model parameters (Ex, En, and He)
Very important	[0.8, 1]	(1, 0.1103, 0.01)
Important	[0.6, 0.8]	(0.691, 0.0636, 0.01)
Genera	[0.4, 0.6]	(0.5, 0.039, 0.01)
Less important	[0.2, 0.4]	(0.309, 0.0636, 0.01)
Very less important	[0, 0.2]	(0, 0.1103, 0.01)

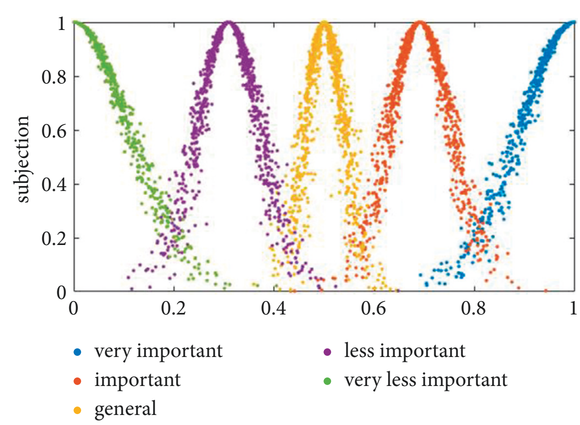

FIGURE 4: Cloud map of standard evaluation.

3. Experiments and Results

3.1. Engineering Background. Taking a specific prefabricated building in Tianjin as the evaluation object, the total construction area is 111,573.92 square meters, and the ground floor area is 69,623.05 square meters. The construction area of the northern region is 97,408.19 square meters, and the aboveground construction area is 9,430.96 square meters. The prefabricated components are prefabricated floors and prefabricated columns. Ten prefabricated buildings experts were invited to score the cost impact of the prefabricated buildings. The total weight is obtained using the combination weighting based on game theory, and the cloud model is used to evaluate the cost impact of prefabricated buildings comprehensively.

3.2. Comprehensive Weight

3.2.1. AHM. Based on existing literature research and questionnaire survey, the factors affecting the cost of the prefabricated buildings are compared, and the judgment matrix is shown in Tables 4–8.

3.2.2. The Entropy Weight Method. Invite 10 prefabricated building-related experts to evaluate the cost factors, form the evaluation index matrix and data standardization processing, and thus obtain a standardized matrix of dimensionless data. The calculation results are shown in Tables 9 and 10.

See Tables S1–S8 in the Supplementary Materials for a comprehensive table analysis.

3.2.3. Comprehensive Weight. The weight calculation is shown in Tables 11 and 12.

3.3. Comprehensive Evaluation of Cloud Model. Based on the cost impact evaluation of the project scored by ten experts, the cloud digital characteristic value of each evaluation indicator was calculated using the cloud model, and the results were shown in Tables 13 and 14.

Comprehensive evaluation cloud C (Ex, En, He) = (0.2769, 0.1457, 0.0204). MATLAB forward cloud generator is used to generate a comprehensive cloud map. The comprehensive cloud map is displayed in the evaluation standard cloud map of the cost of prefabricated buildings, as

Table 4: Judgment matrix of *C*1*i*.

C	*C*1	*C*2	*C*3	*C*4
*C*1	1	5	5	3
*C*2	1/5	1	3	1
*C*3	1/5	1/3	1	1/5
*C*4	1/3	1	5	1

Table 5: Judgment matrix of *C*1*j*.

*C*1*j*	*C*11	*C*12	*C*13	*C*14	*C*15
*C*11	1	3	5	1/3	1
*C*12	1/3	1	3	1/3	1
*C*13	1/5	1/3	1	1/3	1/3
*C*14	3	3	3	1	3
*C*15	1	1	3	1/3	1

Table 6: Judgment matrix of *C*2*j*.

*C*2*j*	*C*21	*C*22	*C*23	*C*24
*C*21	1	1/3	3	3
*C*22	3	1	3	5
*C*23	1/3	1/3	1	1
*C*24	1/3	1/5	1	1

Table 7: Judgment matrix of *C*3*j*.

*C*3*j*	*C*31	*C*32	*C*33
*C*31	1	5	3
*C*32	1/5	1	1/3
*C*33	1/3	3	1

Table 8: Judgment matrix of *C*4*j*.

*C*4*j*	*C*41	*C*42	*C*43	*C*44
*C*41	1	3	5	3
*C*42	1/3	1	3	1/3
*C*43	1/5	1/3	1	1/5
*C*44	1/3	3	5	1

Table 9: The evaluation index matrix of the first-level index.

Experts	*C*1	*C*2	*C*3	*C*4
1	9	8	7	6
2	8.5	9	7	6
3	9	9	8	6
4	9	8	7	8
5	9.5	8	7	6
6	9	8	8.5	9
7	8.5	8	5.5	5
8	8	8.5	7.5	6
9	8.5	8	7.5	8
10	6	6	7	6.5

shown in Figure 5. The similarity between each first-level index and each standard evaluation level can be seen intuitively by drawing the similarity comparison diagram between each first-level index and each standard cloud, as shown in Figure 6.

It can be seen from Figure 5 that the comprehensive cloud is between the two evaluation levels of "very less important" and "less important," and the proportion of the "less important" level is slightly larger than that in the "very less important" level, indicating that the cost impact level of the prefabricated construction project is in the less important level, which meets the project cost requirements. From the digital characteristics of the cloud model of each index in the evaluation of prefabricated buildings cost, it can be seen that the factors such as component splitting design, standardization levels of design, designer qualification, the processing technology of prefabricated components, component production technology, mold production, field hoisting construction level, project managers and construction workers level, and so on cause have a greater impact on the cost of prefabricated buildings. Prefabricated buildings have a relatively high cost in both the design and component production stages, which need to be controlled.

4. Discussion

In previous studies, most of them used subjective methods to determine the weight (such as expert evaluation method and AHP method), while only a few studies implemented the objective weight method. However, the single-use of subjective or objective weight method cannot make the determined weight scientific and accurate. In this paper, game theory is used to combine subjective and objective weights, so the subjective influence of a single process is avoided or does not conform to the actual situation and so on. Most of the weights of the indicator involved in this article are scientific and accurate, optimization of subjective and objective weights by attribute hierarchical model method, and entropy weight method based on game theory. The subjective standard weight is determined by the attribute hierarchy model method, and the objective weight is determined by the entropy weight method.

For effect evaluation, scholars generally adopt the fuzzy evaluation method. However, compared with the cloud model, the traditional fuzzy evaluation method has some

Table 10: The standardization matrix of the first-level index.

Experts	$C1$	$C2$	$C3$	$C4$
1	2.368	1.333	0.853	0.444
2	1.868	2.333	0.853	0.444
3	2.368	2.333	1.853	0.444
4	2.368	1.333	0.853	2.444
5	2.868	1.333	0.853	0.444
6	2.368	1.333	2.353	3.444
7	1.868	1.333	0.647	0.556
8	1.368	1.833	1.353	0.444
9	1.868	1.333	1.353	2.444
10	0.632	0.667	0.853	0.944

Table 11: Comprehensive weight of the first-level index.

First-level index	W_1	W_2	W
Design factors, $C1$	0.559	0.0627	0.4062
Component production factors, $C2$	0.163	0.0632	0.1323
Transportation factors, $C3$	0.066	0.063	0.0651
Construction installation factors, $C4$	0.212	0.0588	0.1648

Table 12: Comprehensive weight of the second-level index.

Second-level index	W_1	W_2	W
Component splitting design, $C11$	0.131	0.0478	0.1054
Designer qualification, $C12$	0.073	0.0471	0.0650
Standardization levels of design, $C13$	0.036	0.0476	0.0396
Prefabrication rate, $C14$	0.229	0.0470	0.173
Repetitiveness of component, $C15$	0.09	0.0472	0.0768
Processing technology of prefabricated components, $C21$	0.043	0.0467	0.0441
Component production technology, $C22$	0.085	0.0470	0.0733
Mold production, $C23$	0.019	0.0470	0.0276
Scale and production capacity, $C24$	0.016	0.0466	0.0254
Transportation distance, $C31$	0.042	0.0469	0.0435
Vehicle selection, $C32$	0.007	0.0465	0.0192
Loading plan, $C33$	0.017	0.0472	0.0263
Selection of construction machines, $C41$	0.107	0.0468	0.0885
Construction site management level, $C42$	0.03	0.0475	0.0354
Field hoisting construction level, $C43$	0.014	0.0466	0.0240
Project managers and construction workers level, $C44$	0.061	0.0467	0.0566

Table 13: Cloud digital characteristics of the second-level index.

Index	Ex	En	He
$C11$	0.785	0.1019	0.1331
$C12$	0.76	0.1081	0.137
$C13$	0.77	0.0939	0.1658
$C14$	0.66	0.0709	0.1564
$C15$	0.675	0.0709	0.1562
$C21$	0.76	0.1063	0.2121
$C22$	0.72	0.0585	0.1723
$C23$	0.715	0.0992	0.1816
$C24$	0.685	0.0576	0.1607
$C31$	0.695	0.1285	0.192
$C32$	0.685	0.0611	0.1598
$C33$	0.675	0.0957	0.1697
$C41$	0.695	0.0487	0.1904
$C42$	0.605	0.0842	0.1374
$C43$	0.7	0.0532	0.5585
$C44$	0.71	0.0514	0.1689

Table 14: Cloud digital characteristics of the first-level index.

Index	Ex	En	He
$C1$	0.3286	0.198	0.0285
$C2$	0.1235	0.1148	0.0211
$C3$	0.0611	0.0966	0.0159
$C4$	0.1399	0.1071	0.0247

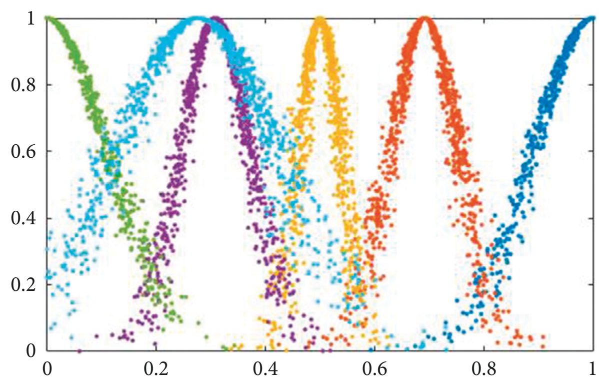

Figure 5: Comprehensive cloud map.

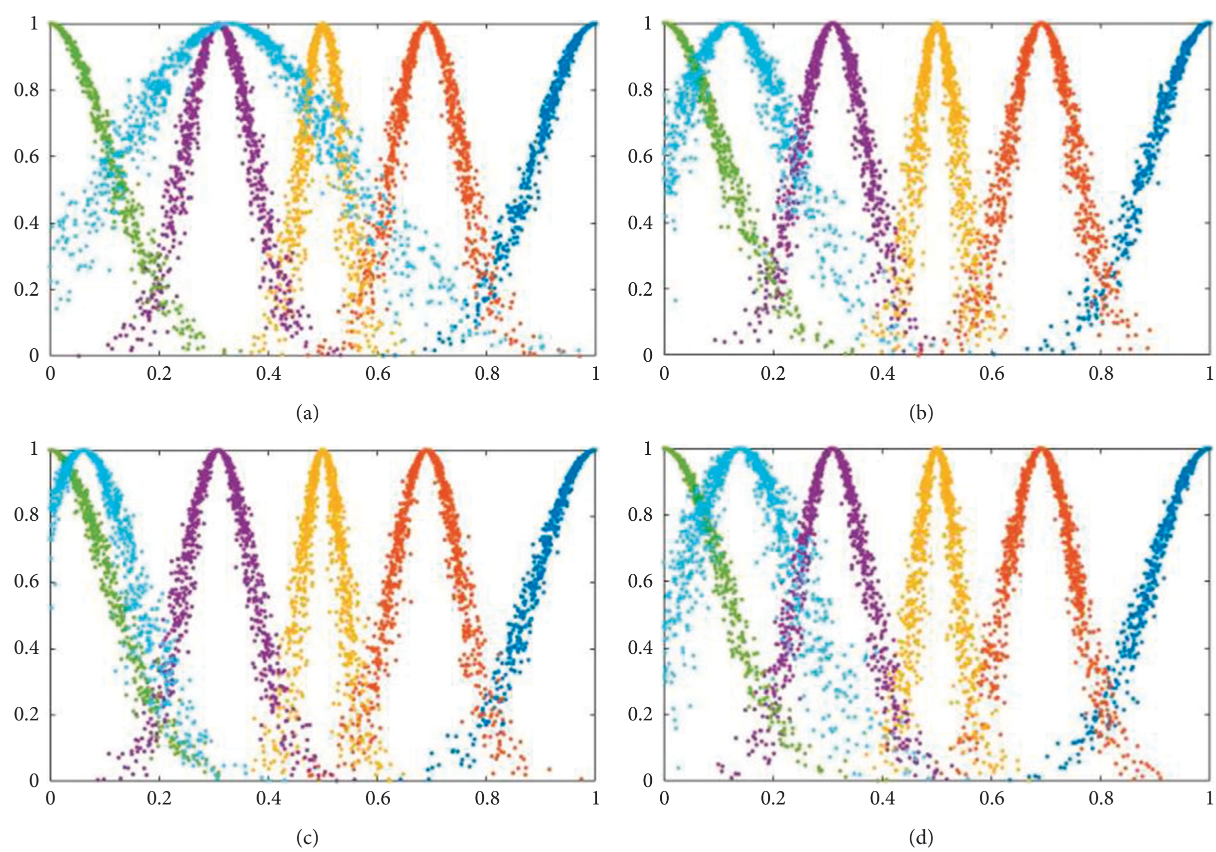

Figure 6: First level index evaluation cloud map: (a) index $C1$ evaluation cloud map, (b) index $C2$ evaluation cloud map, (c) index $C3$ evaluation cloud map, and (d) index $C4$ evaluation cloud map.

shortcomings. The evaluation results of the traditional fuzzy evaluation method do not have volatility and randomness, and the operation is relatively complex and does not reflect fuzziness [31–33]. However, as a model to deal with uncertain problems, the cloud model has randomness and fuzziness, and the operation is relatively simple. In recent years, the cloud model has been gradually improved, and fruitful research results have been achieved [34, 35]. However, the application of cloud model theory in the field of prefabricated buildings is limited.

According to the results of specific prefabricated buildings in Tianjin case studies, the research on cost control of prefabricated buildings should be carried out from the following aspects in the future.

4.1. Strengthen the Design Stage Optimization. When the prefabrication rate increases, the production scale will greatly increase; the speed of production will be accelerated; and the time will be shortened. However, the higher the coefficient, the greater the workload of site setting up, thereby increasing the workload of construction and installation entity. Therefore, designers should set a scientific and reasonable rate of prefabricated structure in the design stage to minimize costs. The design unit should make corresponding preparations before work, integrate and plan all resources, and design a reasonable general plan to reduce the transportation distance of components on the site and reasonably control the cost.

4.2. Improve Production Component Design and Mold Production. In the production stage of prefabricated components, the production necessity of the internal embedded parts location and mold shape of the prefabricated components are higher. If there is a significant error, the prefabricated components need to be corrected on a large scale. Seriously or even reordering the prefabricated components, the production cost of the prefabricated components will increase significantly. Therefore, according to the existing production experience, the design unit should put forward opinions on the design of prefabricated components, reduce the type of prefabricated components and the complication of design, and reduce the mold design and production cost on the premise of meeting the technical requirements.

4.3. Strengthen Professional Level and Train Professionals. Currently, the construction market lacks talents, but a large numeral of professional talents is necessary for the construction process of prefabricated buildings. The talent problem is one of the most crucial factors in the promotion procedure of prefabricated buildings. To farm professional talents who meet the development necessity of the prefabricated construction industry, in the future, China should focus on cultivating professional talents in the procedure of promoting prefabricated construction. Enterprises should train professionals according to their conditions, arrange more training for professionals, and strengthen the management of talents. The higher the professional level of staff, the wealthy the powerful experience, the powerful the capability, the better the effect of reducing costs, and the faster the development of prefabricated buildings.

5. Conclusions and Prospects

Prefabricated buildings have the advantages of energy-saving, high efficiency, and high quality, which is energetically promoted in China's construction industry. But the prefabricated buildings' high construction cost hinders their rapid development. From the perspective of the full life cycle of prefabricated buildings, this paper studies the impact evaluation of the cost of prefabricated buildings, establishes the index system of the influencing factors of the cost of prefabricated buildings, and constructs the game theory cloud model. First, the cost influencing factors of prefabricated buildings in each stage are analyzed from the four dimensions of design, component production, transportation, and construction. There is also a complex correlation between the influencing factors of the cost, and one single model is difficult to overcome these problems at the same time. Therefore, this paper proposes a method based on the game theory cloud model to evaluate the influencing factors of prefabricated buildings costs. The model not only can deal with the data with large uncertainty but also has no requirement for the size of sample data and can directly reflect the complex internal relationship of factors. According to the results of the model's research, it can be seen that there are many cost influencing factors in the two stages of design and component production of prefabricated component buildings, which need to be controlled. Therefore, targeted measures could be taken to reduce project costs. This provides a reference for managers to manage the prefabricated buildings cost in the actual project and also provides a new idea for the research, management, and theoretical basis of prefabricated buildings cost.

But this study also has some limitations. In this paper, the influencing factors system of cost of prefabricated buildings obtained by literature analysis and questionnaire has certain subjectivity; cost influencing factors may not be specific and complete, and so on. In addition, this paper analyzes the influencing factors of prefabricated buildings cost from four aspects: design, component production, transportation, and construction, but does not consider the cost influencing factors of early investment and later operation and maintenance stage, and the research scope needs to be further studied. In future research, combined with the shortcomings of the above two aspects, we will analyze the specific impact of various indicators on the cost of prefabricated buildings through a more scientific method, to better control the cost management of prefabricated buildings projects.

Data Availability

The data used to support the results of this study are included in the article and supplementary materials.

Conflicts of Interest

The authors declare that there are no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Supplementary Materials

Table S1: ten prefabricated building experts were invited to score the indicator *C*1*j* and form the evaluation index matrix of *C*1*j*. Table S2: according to formula (1), standardize the data in the evaluation index matrix of *C*1*j*, so as to obtain the standardization matrix of *C*1*j*. $\chi_{ij}' = (\chi_{ij} - \min(\chi_j))/(\max(\chi_j) - \min(\chi_j))$, where χ_{ij}' is the normalized value. Table S3: ten prefabricated building experts were invited to score the indicator *C*2*j* and form the evaluation index matrix of *C*2*j*. Table S4: according to formula (1), standardize the data in the evaluation index matrix of *C*2*j*, so as to obtain the standardization matrix of *C*2*j*. Table S5: ten prefabricated building experts were invited to score the indicator *C*3*j* and form the evaluation index matrix of *C*3*j*. Table S6: according to formula (1), standardize the data in the evaluation index matrix of *C*3*j*, so as to obtain the standardization matrix of *C*3*j*. Table S7: ten prefabricated building experts were invited to score the indicator *C*4*j* and form the evaluation index matrix of *C*4*j*. Table S8: according to formula (1), standardize the data in the evaluation index matrix of *C*4*j*, so as to obtain the standardization matrix of *C*4*j*. (*Supplementary Materials*)

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