Research on Safety Risk Evaluation of Assembly Building Construction Based on Gray Correlation Degree

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Abstract. Reduce the risk of the construction phase of the assembly building project and improve safety. This paper takes assembly building as the research object combines the current domestic construction engineering site management and technology level, as well as relevant expert experience and standards. It analyzes the risk influencing factors in the construction phase of assembly building and proposes the risk evaluation index system in the construction phase of assembly building. Using the combination of triangular fuzzy number and hierarchical analysis method (AHP) to determine the weight of factor combinations, using the theory of gray correlation analysis to establish a construction risk evaluation model based on gray correlation analysis, to evaluate the risk of the construction project, and through the analysis of engineering examples to show the operability and feasibility of the construction risk evaluation index system and evaluation model.

Keywords: grey correlation; assembly building; risk evaluation; site optimization

1 INTRODUCTION

The construction industry continues to play an important role in China's economic development, contributing to the smooth realization of the transformation of China's economy from high-speed growth to high-quality development. With the rapid development of assembled buildings, the drawbacks of assembled building construction have become increasingly prominent. The construction stage is the stage with the highest incidence of risky accidents in the whole life cycle of assembly buildings, but due to the late start of China's assembly building leads to the lack of relevant risk prevention training for related projects, and the risk awareness is weak. As a result, many scholars at home and abroad have carried out related research around the assembly building.

Tatari [1], in order to explore the interrelationship between the barriers of assembly building, utilized Bayesian network to develop an evaluation tool and then evaluated the five major factors affecting assembly building. Lu[2], in order to reduce the construction risk of assembly building project, established an evaluation index system

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from the factors of man, machine, material, pipe, and environment. And the evaluation model based on the combination of weighting and mutation level was constructed by combining the hierarchical analysis method, the method of correlation importance between the criteria and the mutation theory. Zhang [3] established the corresponding comprehensive evaluation index system from the perspective of the hidden cost of the assembly building, and constructed the evaluation method by combining the structural equation model and the material element to pable cloud model to evaluate the risk of the hidden cost in a relevant way. Kumi [4] compared assembled buildings and traditional buildings based on the perspective of dust health effects and accident risk, and proved that the degree of risk of assembled buildings in this aspect is less than that of traditional buildings. Fagbenro [5] for the correlation between assembled buildings and the associated psychological risk from the perspective of workers' health and safety, and to determine the correlation between the existence of assembled buildings and the risk of workers' psychological problems. Xin [6] constructed a case library, retrieval of cases, and reuse and updating of cases for the problem of delayed progress of assembled buildings, and developed a new system applied to the cases to prove the effectiveness of his research. Cai [7], in order to reduce the risk problems caused by the many participants in the assembly building supply chain, constructs a combined AHP-DEMATEL model and carries out a relevant risk evaluation of the risk impact indicator system of the assembly building supply chain. Tang [8], in order to deal with the problems of the lack of a complete evaluation and insufficient emergency response capacity in assembly buildings, combines decision-making experiments with evaluation laboratories and fuzzy cognitive maps The research method.

To realize further advancement in safety management of assembly buildings. This paper combines the current domestic safety risk management measures and related construction technology to construct a safety risk evaluation index system for assembly construction site. The combination of hierarchical analysis and triangular fuzzy number is used to determine the weights of the evaluation indexes, and the evaluation model of multi-level gray correlation analysis is established and applied to the risk evaluation of assembly construction. Quantitative evaluation of specific engineering projects, and then find out the risk elements in the project. To provide quantitative and detailed basis for the safety risk evaluation of assembly construction, and also to provide suggestions and references for the assembly construction unit to prevent the relevant risks of the project.

2 ASSEMBLY CONSTRUCTION RISK EVALUATION SYSTEM

2.1 Construction of Risk Indicator System for Assembly Construction

The selection of evaluation indicators is a key factor in the process of construction risk evaluation, this paper to reference based on previous research on the basis of the selection of personnel, equipment, management, technology, environment, five factors as evaluation indicators. The summarized factors using the expert consultation method, inviting relevant industry experts to repeatedly evaluate and summarize the results of the combination, and then arrive at the final evaluation index system (as shown in Table 1)

Table 1. Risk evaluation system for assembly construction

Level 1 indicators A_K	Level 1 weights W_K	Level 2 indicators A_{ij}	Level 2 weights W_{kj}	Combined weights
Personnel factors A_1	0.215	Basic level of construction technicians A_{11}	0.2417	0.0519
		Lack of workers' operation level A_{12}	0.2333	0.0502
		Awareness of production safety A_{13}	0.2417	0.0519
Equipment Factors A_2	0.18	Selection of hoisting machinery A_{21}	0.2417	0.0435
		Equipment failure, aging A_{22}	0.2333	0.0419
		When machinery and equipment work continuously A_{23}	0.2417	0.0435
Management Factors A_3	0.205	Poor communication at all levels A_{31}	0.2792	0.0572
		Unclear safety management system A_{32}	0.2167	0.0444
		Incomplete accident prevention management measures A_{33}	0.25	0.0512

2.2 Grading Criteria for Evaluation of Assembly Construction

The assembly construction risk evaluation system is divided into four levels, and the standard combination $\mathrm{D} = \{\mathrm{D}_1, \mathrm{D}_2, \mathrm{D}_3, \mathrm{D}_4\}$ is established to represent the definitions of D_1=excellent, D_2=good, D_3=medium, and D_4=poor, respectively; the corresponding excellent is 4 points, the good is 3 points, the medium is 2 points, and the poor is 1 point, and if it is residing in between the two, it will be in the middle decimal as the standard. (As shown in Table 2)

Table 2. Grading Criteria for Evaluation of Assembly Construction

D_1	D_2	D_3	D_4
excellent	good	medium	poor
4	3	2	1

2.3 Determination of Weights based on Fuzzy Hierarchical Analysis

The determination of the weight of the assembly construction risk evaluation index is mainly determined by the improvement of subjective assignment method, triangular fuzzy number method is based on the principle of fuzzy mathematics to improve the evaluation results will be fuzzy in favor of more objective conclusions, and its weight evaluation results have a direct relationship with the evaluated indicators, which is conducive to removing the impact of subjectivity. Therefore, this paper adopts the hierarchical analysis method combined with the triangular fuzzy number to determine the weights.

Hierarchical analysis method (AHP) is an American operations researcher Saaty (Saaty) in the early 20th century proposed a combination of quantitative and qualitative weighting method [9], this paper for the hierarchical analysis of the strong subjectivity of the problem, the introduction of triangular fuzzy number in the hierarchical analysis method, a comprehensive weighting, to make up for the shortcomings of a single method, to get the evaluation results not only to meet the subjective requirements, but also in line with objective reality to improve the accuracy of the weighted results.

The steps for determining the weights in the triangular fuzzy number hierarchy analysis are as follows:

(1) Construct a map of the meaning of the 0.1-0.9 scale (as shown in Table 3)

Table 3. Diagram of the meaning of the 0.1-0.9 scale

Scale	Meaning
0.1	When the two are compared, the latter is extremely important
0.2	The latter is strongly important when compared to both
0.3	The latter is clearly important when compared to both
0.4	The latter is slightly important when compared to both
0.5	When comparing the two. Both are equally important
0.6	When both are compared, the former is slightly important
0.7	When compared to both, the former is significantly important
0.8	When compared to both, the former is strongly important
0.9	When compared, the former is extremely important

(2) The relevant experts are asked to score and construct a triangular fuzzy number judgment matrix based on the average of the scores, which is denoted as M,and the elements in the matrix are denoted by$R_{ij}^{t} = \left(Y_{ij}^{t} U_{ij}^{t} O_{ij}^{t}\right)$。

(3) Calculation of weights: the calculation of weights in this paper is based on the generalized formula proposed by Xu Zeshui 2001 [10] (as shown in Equation 1). If is $L = \left(s_{ij}\right)_{n\times n}$fuzzy complementary matrix and$V = (V1，V2...，Vn)$ is the weight vector of L.

$$V_i = \frac{\sum_{i,j=1}^{n} s_{ij} + \frac{n}{2} - 1}{n(n-1)} \tag{1}$$

(4) Conduct consistency test The consistency test is used to compare the judgment of whether the weight values calculated by formula (2) are reasonable. Define the compatibility index$I(A, W^{*})$of the judgment matrix and the feature matrixW^{*}'s[11], and calculate the compatibility index of the judgment matrix and the feature matrix, as shown in (2), (3), (4)

$$I(A，W^{*}) = \frac{1}{n^2} \sum_{i，j=1}^{n} \left| h_{ij} + x_{ij} - 1 \right| \tag{2}$$

$$W^{*}=\frac{w_i}{w_i+w_j} \tag{3}$$

A=(h_ij)_(n×n)，W^*=(x_ij)_(n×n) (4)

Where A and W^{*} are fuzzy complementary judgment matrices. If the value of the compatibility index$I(A, W^{*})$is less than a specific threshold α (generally α=1), the judgment matrix is considered to be a satisfactory consistency matrix.

(5) Calculate the criterion level weights and the relative weights of the indicator level, respectively.

(6) Calculation of absolute indicator layer weights (quasi lateral layer weights x relative indicator layer weights)

3 EVALUATION MODEL BASED ON GRAY CORRELATION

The basic idea of the gray correlation [11] evaluation model is to find out the evaluation vector corresponding to the optimal construction project according to the actual gray background of the problem, and to determine the optimal assembly construction risk evaluation indexes and the ranking of the advantages and disadvantages of the construction risk evaluation indexes of each assembly construction project by the size of the gray correlation between the green evaluation indexes of each construction project and the corresponding optimal evaluation indexes.

The gray correlation steps are analyzed as follows:

Calculation of the gray correlation coefficient

Let the correlation coefficient $\exists_{ijl}$ be, and the calculation process is shown in Equation 5 as:

$$\exists_{ijl}=\frac{\underset{i}{min}\underset{jl}{min}\Delta_{df}+\rho\underset{i}{max}\underset{jl}{max}\Delta_{df}}{\Delta_{df}+\rho\underset{i}{max}\underset{jl}{max}\Delta_{df}} \tag{5}$$

where$\Delta_{df}=\left|X_{ojl}-X_{ijl}\right|$. $\rho\in$ (0, ∞), is the resolution coefficient. The best resolving power is achieved when$\rho\leq$ 0.546. Therefore, a is usually taken as ρ = 0.5. Thus, the correlation coefficient matrix is obtained:

$$B_j=\begin{bmatrix} B_{1j} \\ B_{2j} \\ \cdot \\ \cdot \\ \cdot \\ B_{Mj} \end{bmatrix}=\begin{bmatrix} \exists_{1j1} & \exists_{1j2} & \cdots & \exists_{1jl_k} \\ \exists_{2j1} & \exists_{2j2} & \cdots & \exists_{2jl_k} \\ \exists_{3j1} & \exists_{3j3} & \cdots & \exists_{3jl_k} \\ \vdots & \vdots & \vdots & \vdots \\ \exists_{mj1} & \exists_{mj2} & \varphi_{mj2} & \exists_{mjl_k} \end{bmatrix}(k=1,2,\ldots g) \tag{6}$$

Calculate the gray correlation degree

$$M_k = B_j \times Z_{ui} \begin{bmatrix} \exists_{1j1} & \exists_{1j2} & \cdots & \exists_{1jl_k} \\ \exists_{2j1} & \exists_{2j2} & \cdots & \exists_{2jl_k} \\ \exists_{3j1} & \exists_{3j3} & \vdots & \exists_{3jl_k} \\ \vdots & \vdots & . & \vdots \\ \exists_{mj1} & \exists_{mj2} & \varphi_{mj2} & \exists_{mjl_k} \end{bmatrix} \times \begin{bmatrix} Z_{u1} \\ Z_{u2} \\ Z_{u3} \\ . \\ . \\ Z_{U_{i_k}} \end{bmatrix} = \begin{bmatrix} m_{1k} \\ m_{2k} \\ m_{3k} \\ \vdots \\ . \\ m_{nk} \end{bmatrix} \tag{7}$$

WhereM_k is the gray correlation of the ijlth evaluation indicator to the optimal indicator sequence; the weight Z_{ui} is determined by fuzzy hierarchical analysis.

4 EMPIRICAL ANALYSIS

4.1 Project Overview

The total construction area of a shantytown residential building renovation project in a city in China is 371,260 square meters, with a total of eight 20-story buildings, six 22-story buildings, four 23-story buildings, nine 26-story buildings as well as two three-story kindergartens. This paper categorizes the project into five types according to the number of floors and types of construction by five assembly construction companies, defined as N_1, N_2, N_3, N_4, N_5. The five sites are summarized to evaluate the construction risk, and the results can be evaluated more objectively.

4.2 Confirmation of Indicator Weights

(1) Based on the scores of the three experts' assessment of the indicators, the average of the scores was taken to construct the criterion level judgment matrix. (As shown in table 4)

Table 4. IV Criteria-level judgment matrix

A	A_1	A_2	A_3
A_1	(0.5,0.5,0.5)	(0.5,0.6,0.7)	(0.3,0.4,0.5)
A_2	(0.3,0.4,0.5)	(0.5,0.5,0.5)	(0.3,0.4,0.5)
A_3	(0.5,0.6,0.7)	(0.5,0.6,0.7)	(0.5,0.5,0.5)

(2) Formation of fuzzy complementary judgment matrix by extracting the maximum possible estimates from the quasi-side layer matrices

$$\mathrm{A} = \begin{bmatrix} 0.5 & 0.6 & 0.4 \\ 0.4 & 0.5 & 0.4 \\ 0.6 & 0.6 & 0.5 \\ 0.3 & 0.6 & 0.4 \\ 0.4 & 0.6 & 0.7 \end{bmatrix} \tag{8}$$

(3) Constructing judgment matrix for consistency test

$$w^* = \begin{bmatrix} 0.5 & 0.5443 & 0.5119 \\ 0.4557 & 0.5 & 0.4675 \\ 0.4881 & 0.5325 & 0.5 \\ 0.4819 & 0.5263 & 0.4938 \\ 0.4819 & 0.5263 & 0.4938 \end{bmatrix} \tag{9}$$

Consistency test was 0.0917 < 0.1 (one-time test passed)
(4) The criterion layer weights are $A_1, A_2, A_3 (0.215, 0.18, 0.205)$
(5) Follow the steps above to arrive at each:

$$\mathrm{A}_{11}, \mathrm{A}_{12}, \mathrm{A}_{13} (0.2417, 0.2333, 0.2417)$$

$$A_{21}, A_{22}, A_{23} (0.2792, 0.2292, 0.2417)$$

$$A_{31}, A_{32}, A_{33} (0.2792, 0.2167, 0.25)$$

4.3 Gray Correlation Analysis

(1) Scoring based on criteria

Based on the above established five assembly construction companies (ABCDE) based on the assembly construction risk evaluation criteria (as shown in Table 2) for expert scoring. (As shown in Table 5)

Table 5. Results of construction risk evaluation

dimension	A_{11}	A_{12}	A_{13}	A_{21}	A_{22}	A_{23}	A_{31}	A_{32}	A_{33}
N_1	3.45	2.34	2.31	3.21	1.26	2.36	2.96	3.54	2.15
N_2	3.65	3.62	2.41	2.38	1.42	3.89	3.62	3.78	2.36
N_3	2.58	2.51	1.56	2.16	1.28	3.36	3.61	3.62	2.54
N_4	1.32	1.64	1.36	2.34	1.21	1.37	3.65	2.13	3.19
N_5	*3.21*	1.24	2.82	2.57	1.63	2.86	2.34	2.14	1.56

(2) Standardization of scoring results

The scoring data from the five assembly construction companies was normalized to produce the results (shown in Table 6)

Table 6. Results of data standardization

dimension	A_{11}	A_{12}	A_{13}	A_{21}	A_{22}	A_{23}	A_{31}	A_{32}	A_{33}
N_1	0.9142	0.4622	0.6507	1.0001	0.1191	0.3929	0.4733	0.8546	0.0024
N_2	1.0001	1.0001	0.7192	0.2096	0.5001	1.0001	0.9771	1.0001	0.0032
N_3	0.5408	0.5337	0.1370	0.0001	0.1667	0.7897	0.9695	0.9031	1.0001
N_4	0.0001	0.1681	0.0001	0.1715	0.0001	0.0001	1.0001	0.0001	0.0065
N_5	0.8112	0.0001	1.0001	0.3905	1.0001	0.5913	0.0001	0.0061	0.0001

(3) Relationship coefficient matrix

Take $\rho = 0.5$Calculate the correlation coefficient based on Eq. 5 and (as shown in Table 7) Derivation of each indicator is normalized by scoring the indicator for each assembly construction company, resulting in a matrix of normalized correlation coefficients.

Table 7. Correlation coefficient matrix

dimension	A_{11}	A_{12}	A_{13}	A_{21}	A_{22}	A_{23}	A_{31}	A_{32}	A_{33}
N_1	0.8537	0.4818	0.5888	1	0.3621	0.4517	0.4871	0.7749	0.3339
N_2	1	1	0.6405	0.3875	0.5001	1	0.9565	1	0.3341
N_3	0.5213	0.5175	0.3669	0.3334	0.3750	0.7041	0.9428	0.8378	1
N_4	0.3334	0.3754	0.3334	0.3764	0.3334	0.3334	1	0.3334	0.33348
N_5	0.7260	0.3334	1	0.4507	1	0.5503	0.3334	0.3347	0.3334

(4) Calculation of correlation coefficients

Calculate the gray correlation degree according to Equation 7, combined with the relevant weights of the assembly building risk evaluation index system (as shown in Table 1), (as shown in Table 8) the gray correlation degree calculated according to Equation 7 and the relevant weights of the evaluation index system are comprehensively calculated, resulting in a matrix of weighted correlation coefficients.

Table 8. Matrix of weighted correlation coefficients

dimension	A_{11}	A_{12}	A_{13}	A_{21}	A_{22}	A_{23}	A_{31}	A_{32}	A_{33}
N_1	0.8537	0.4818	0.5888	1	0.3621	0.4517	0.4871	0.7749	0.3339
N_2	1	1	0.6405	0.3875	0.5001	1	0.9565	1	0.3341
N_3	0.5213	0.5175	0.3669	0.3334	0.3750	0.7041	0.9428	0.8378	1
N_4	0.3334	0.3754	0.3334	0.3764	0.3334	0.3334	1	0.3334	0.33348
N_5	0.7260	0.3334	1	0.4507	1	0.5503	0.3334	0.3347	0.3334

(5) Comprehensive relevance

Composite correlation score:(N_1: 0.471786 N_2: 0.623709 N_3: 0.6281 N_4: 0.516754 N_5: 0.633891)

5 CONCLUSION

From the above results, the ranking of the green construction level of each construction project can be derived. $N_5 > N_3 > N_2 > N_4 > N_1$ ">" means "better than". The final result concludes that all the evaluation indexes of the kindergarten project are better than the other four construction projects, in which the total score of the construction risk prevention level is the highest and better than the other construction projects. The results show that the evaluation model can scientifically evaluate the risk level of assembled buildings. It provides a more practical method for evaluating the risk level of assembled buildings.

REFERENCE

1. Tatari, A. (2023). Simulating Cost Risks for Prefabricated Construction in Developing Countries Using Bayesian Networks. Journal of Construction Engineering and Management, 149(6), 04023037.DOI:10.1061/JCEMD4.COENG-13259

2. Lu, W., Fang, L., & Ai, L. (2023). A Novel Risk Assessment Model for Prefabricated Building Construction Based on Combination Weight and Catastrophe Progression Method. Tehnički vjesnik, 30(6), 1959-1967.DOI:10.17559/TV-20230802000846
3. Zhang, J., Wei, W., Chen, L., & Jiang, Z. (2023). Evaluation of Hidden Cost Risk of Prefabricated Construction Based on SEM-MEECM. Applied Sciences, 13(13), 7902.DOI:10.3390/app13137902
4. Kumi, L., Jeong, J., & Jeong, J. (2023). Assessing Dust Emissions, Health Impacts, and Accident Risks in Prefabricated and Conventional Construction: A Comprehensive Comparative Study. Buildings, 13(9), 2305.DOI:10.3390/buildings13092305
5. Fagbenro, R. K., Sunindijo, R. Y., Illankoon, C., & Frimpong, S. (2023). Influence of prefabricated construction on the mental health of workers: systematic review. European journal of investigation in health, psychology and education, 13(2), 345-363.DOI:10.3390/ejihpe13020026
6. .Xie, L., Wu, S., Chen, Y., Chang, R., & Chen, X. (2023). A case-based reasoning approach for solving schedule delay problems in prefabricated construction projects. Automation in Construction, 154, 105028.DOI:10.1016/j.autcon.2023.105028
7. Cai, Q., Du, Y., & Wang, R. (2023). Analysis on Supply Chain Risk Factors of Prefabricated Buildings Using AHP-DEMATEL-ISM Model. Tehnički vjesnik, 30(5), 1379-1386.DOI:10.17559/TV-20230508000614
8. Tang, S., Zhu, K., & Guo, P. (2023). Research on Quantitative Assessment and Dynamic Reasoning Method for Emergency Response Capability in Prefabricated Construction Safety. Buildings, 13(9), 2311.DOI:10.3390/buildings13092311
9. Smytka, D. L., & Clemens, M. W. (1993). Total cost supplier selection model: a case study. International Journal of Purchasing and Materials Management, 29(4), 42-49. https://doi.org/10.1111/j.1745-493X.1993.tb00260.x
10. Xu Zeshui. (2001) An algorithm for ranking fuzzy complementary judgment matrices[J]. Journal of Systems Engineering, (04):311-314. http://202.199.233.17:8000/rwt/CNKI/https/NNYHGLUDN3WXTLUPMW4A/kcms2/article/abstract?v=GARc9QQj0GVIIncR4VWQf3j7xcxZKiJO8Acs0yqNvs5cbAKPTJkwU3hWU-Tu86fdOilDWPHAV9nF1f-DkBhvYvVbJR6ROnXCvJbqn8OB_Hv4E-vi9ss0JWgYgHCgIw7wr&uniplatform=NZKPT&language=CHS
11. Meng, F., & Chen, X. (2017). A new method for triangular fuzzy compare wise judgment matrix process based on consistency analysis. International Journal of Fuzzy Systems, 19, 27-46.DOI:10.1007/s40815-016-0150-8.
12. Tian, G., Zhang, H., Feng, Y., Wang, D., Peng, Y., & Jia, H. (2018). Green decoration materials selection under interior environment characteristics: A grey-correlation based hybrid MCDM method. Renewable and Sustainable Energy Reviews, 81, 682-692.DOI:10.1016/j.rser.2017.08.050