Journal of World Architecture, 2026, Volume 10, Issue 2
http://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN 2208-3480

Evaluation of Construction Quality Management Based on Fuzzy Matter-Element Analysis

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Abstract: This study develops a construction quality management evaluation framework for prefabricated residential projects by integrating the analytic hierarchy process (AHP) with fuzzy matter-element analysis. Taking Phase II of the Qinxing Jiayuan Anju Community project as a case study, a multi-level evaluation index system was established based on the characteristics of prefabricated construction. The framework comprises six criterion dimensions, personnel management, material management, machinery and equipment management, technical management, on-site management, and information management, and 27 specific indicators, combining both qualitative and quantitative measures. Qualitative indicators were assessed through expert scoring by 30 project-related personnel, while quantitative indicators were derived from project records, including attendance rate, material acceptance rate, ex-factory qualification rate of prefabricated components, transportation and storage loss rate, and RFID/QR code coverage. Indicator weights were determined using AHP, and the overall evaluation grade was obtained through fuzzy matter-element modelling based on membership functions. The results show that the overall construction quality management level of the case project is good (M4). Among the criterion dimensions, material management reaches the outstanding (M5) level, while personnel management, machinery and equipment management, technical management, on-site management, and information management are all evaluated as good. These findings indicate that the proposed framework is practically applicable for structured assessment of construction quality management in prefabricated residential projects.

Keywords: Prefabricated residential buildings; Construction quality management; Fuzzy matter-element analysis; Evaluation index system; Analytic hierarchy process (AHP); Comprehensive evaluation

1. Introduction

Prefabricated residential buildings have become an important development direction in the construction industry because they can improve construction efficiency, support industrialized production, and reduce the environmental burden associated with traditional on-site construction processes. At the same time, the quality management of prefabricated residential projects is more complex than that of conventional cast-in-place buildings because project performance depends not only on on-site workmanship but also on component production quality, transportation and storage conditions, assembly precision, temporary support control, information coordination, and multi-party management integration.

Existing studies on prefabricated construction quality management have examined influencing factors such as personnel capability, component and material quality, construction technology, equipment management, and organizational coordination. However, many previous studies either focus mainly on factor identification or provide evaluation results without a sufficiently integrated and operational framework tailored to the management characteristics of prefabricated residential construction.

Fuzzy matter-element analysis is suitable for this problem because it allows complex multi-indicator systems to be transformed into structured grade-based evaluations under conditions of partial uncertainty. When combined with AHP, it can integrate expert judgement on indicator importance with membership-based evaluation of actual project conditions.

Based on these considerations, this study takes the second phase of the Qinxing Jiayuan Anju Community project as a case and constructs a construction quality management evaluation framework for prefabricated residential projects. The framework includes six criterion dimensions and 27 indicators, covering personnel management, material management, machinery and equipment management, technical management, on-site management, and information management.

Prior work shows that construction quality management evaluation has evolved along two linked directions, the development of indicator systems for project quality performance and the adoption of multi-criteria decision models under uncertainty. Within the most direct topical stream, Hu et al. used a matter-element model to evaluate the construction quality management effect of PPP projects, showing that matter-element logic can transform complex quality indicators into a structured graded assessment [1].

A second stream applies fuzzy weighting methods to quality-management control practices. Ayalew et al. employed fuzzy AHP to explore and rank quality-management control practices in public building projects, while Lam et al. used fuzzy AHP to build a contractor self-assessment quality management system based on MBNQA-oriented criteria [2,3]. Together, these studies justify the AHP component of the present framework, but they also show that fuzzy AHP alone is stronger for weighting and ranking than for expressing the matter-element relationship between observed indicator values and discrete evaluation grades.

A third stream offers methodological comparators that are not identical to fuzzy matter-element analysis but are highly relevant for model design. Li et al. developed an ANP–fuzzy comprehensive evaluation model for lean construction management performance, while Jin et al. combined subjective and objective weighting with TOPSIS to evaluate bridge construction quality [4,5]. These studies show that hybrid multi-criteria frameworks are well established in construction evaluation research.

The studies that are methodologically closest to the present manuscript are those using extension or matter-element logic directly in construction-quality contexts. Chen et al. proposed an AHP-based fuzzy extension element-matter model for construction quality evaluation in ballastless track construction [6]. Zhang et al. also identified critical factors influencing quality management in smart construction sites through a DEMATEL-ISM-MICMAC framework, highlighting the growing importance of coordination, information, and systems interaction in digitalized construction environments [7].

Finally, the broader methodological landscape confirms that fuzzy-hybrid techniques have become an established family of tools in construction engineering and management. Nguyen et al. reviewed 255 journal articles and showed that fuzzy hybrid techniques are now widely applied across construction-management decision problems [8]. A practical, project-level, grade-based evaluation framework tailored to prefabricated residential construction that integrates qualitative and quantitative indicators while preserving transparent criterion-to-project aggregation remains comparatively underdeveloped.

2. Project overview

The second phase of the Qinxing Jiayuan Anju Community project is located in the area west of Zhou Ding 1st Road, south of the west section of Tiangong 2nd Road, and north of Tianjian 2nd Road, Qinhan New Town, Xian New District. It will build 12 residential buildings, as well as commercial podiums, underground garages, community service rooms and other supporting facilities. It provides a total of 1,551 units, with two types of units of 90 square meters and 120 square meters. The project plan can be seen in **Figure 1**.

Figure 1. Project plan.

2.1. Organizational chart

According to the characteristics of the project, corresponding management positions and number of positions are set up. The personnel composition is shown in **Table 1**, and they are taken as research objects.

Table 1. Table of project personnel quantity

Department (position)	Number of people	Department (position)	Number of people
Project manager	2	Production manager	3
Project Chief Engineer	2	Technical Staffs	7
Designers	2	Safety Inspectors	4
Quality Inspectors	4	Materials Management Staffs	4
Machinery Operators	4		

2.2. Evaluation index section and grade division

The evaluation system consists of six criterion dimensions and 27 specific indicators. The six dimensions are personnel management (A_1), material management (A_2), machinery and equipment management (A_3), technical management (A_4), on-site management (A_5), and information management (A_6). In the original draft, A_5 was labelled inconsistently as environmental management in some places; in this revised version it is treated consistently as on-site management because its indicators concern drawing review, construction professionalism, logistics planning, organization design operability, and finished-product protection (**Table 2**).

Table 2. Construction quality management evaluation index section and grade division of prefabricated residential project

Criterion layer	Indicator layer	Section	Poor	Substandard	Fair	Good	Outstanding
Personnel management (A_1)	A_{11}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{12}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{13}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{14}	(0，100%)	(0，60%)	[60%，70%)	[70%，80%)	[80，90%)	[90%,100%]
Material management (A_2)	A_{21}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{22}	(0，100%)	(0，90%)	[90%，94%)	[94%，96%)	[96，98%)	[98%,100%]
	A_{23}	(0，100%)	(0，90%)	[90%，94%)	[94%，96%)	[96，98%)	[98%,100%]
	A_{24}	(0，100%)	[10%，100%)	[6%，10%)	[4%，6%)	[2%，4%)	(0%，2%)
Machinery and equipment management (A_3)	A_{31}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{32}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{33}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
Technical management (A_4)	A_{41}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{42}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{43}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{44}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{45}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{46}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
Environmental management (A_5)	A_{51}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{52}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{53}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{54}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{55}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{56}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
Information management (A_6)	A_{61}	(0，100%)	(0，90%)	[90%,94%)	[94%,96%)	[96，98%)	[98%,100%]
	A_{62}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{63}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)
	A_{64}	(0，10)	(0，5)	[5，6)	[6，7)	[7，9)	[9，10)

Note: $\mathbf{A_{11}}$: Quality of production operation technicians; A_{12}: Quality of personnel training; A_{13}: Professional qualities of managers; A_{14}: Attendance rate of management personnel; A_{21}: Implementation intensity of procurement standards; A_{22}: On-site acceptance rate of materials and components; A_{23}: Ex-factory qualified rate of precast components; A_{24}:

Prefabricated component transportation and storage loss rate; A_{31}: Rationality of selection and use of construction equipment; A_{32}: Quality level of machinery operators; A_{33}: Maintenance level of mechanical equipment; A_{41}: The bearing capacity of the foundation; A_{42}: The setting level of temporary supports and fixing measures during construction; A_{43}: Component installation position and dimensional deviation; A_{44}: Quality status of node steel connection; A_{45}: Post poured concrete quality; A_{46}: BIM technology application depth; A_{51}: Drawing review and design submission quality; A_{52}: Construction professionalism; A_{53}: Component transportation and loading and unloading plan; A_{54}: The rationality of the special construction plan for prefabricated construction; A_{55}: Operability of construction organization design; A_{56}: Suitability of on-site finished product protection measures; A_{61}: Component identification (RFID/QR code) coverage; A_{62}: The degree of information coordination among participating parties; A_{63}: Traceability of quality issues and timeliness of rectification; A_{64}: Completeness of engineering data.

2.3. Qualitative and quantitative indicator evaluation measurement methods

This study combines qualitative and quantitative data. Qualitative indicators were scored by 30 relevant personnel from the construction contractor according to the predefined grading standards, and the average values were used as the observed values of the qualitative indicators. Quantitative indicators were calculated from project records and departmental statistics, including attendance rate, material acceptance rate, ex-factory qualification rate, transportation and storage loss rate, and component identification coverage (**Table 3**).

Table 3. Scoring details of qualitative evaluation indicators for construction quality management of a prefabricated residential project

Qualitative evaluation indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Average**
	16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	
$_{A1}1$	8.5	8	9	8	7	7.5	7	8	7	8	7	8	8	9	7	7.90
	8	7.5	7.5	8	9	8	8	7.5	8.5	7	9	8.5	7	8	8.5	
A_{12}	8	9	8.5	8.5	7.5	8.5	8	7.5	8	8	7	8	8	7.5	8	7.95
	7.5	8	8.5	7.5	9.5	7.5	8.5	7	8	8	7.5	7.5	8	8	7.5	
A_{13}	9	9.5	9.5	7.5	8	8	7	7	8.5	8	7.5	7	7.5	9	9	8.25
	8.5	8	8	8.5	9	8.5	8	8.5	9	8.5	8.5	8	8	8.5	8	
A_{21}	10	9	9	8	7.5	8	8.5	8	8.5	9	8	8.5	9	8	9	8.60
	8.5	8	8.5	9	8	8.5	9	10	8.5	9.5	7.5	9	8.5	8.5	9	
$_{A3}1$	8.5	9	8.5	8	8.5	7.5	8	8	8.5	8.5	9	8	9	8.5	8	8.35
	8	8	8	8.5	8	8.5	9.5	7.5	8	9	8	8.5	8	8.5	9	
$_{A3}2$	9	9.5	9	8.5	8	8.5	7	8.5	8	8.5	7.5	8	8.5	8.5	8.5	8.50
	7	8.5	8	9	9.5	9.5	9	8.5	8.5	8	8.5	8.5	8.5	9	9.5	
$_{A3}3$	8.5	9	9.5	9	8	8.5	8.5	9	9	8.5	8	8.5	9	9	8.5	8.70
	9	8.5	8	9	9	8	9.5	8.5	9	9.5	8	8	8.5	8.5	9.5	
$_{A}41$	8.5	8.5	9	8.5	8	8.5	8	8	7.5	8	7.5	8	9	8.5	8.5	8.25
	8.5	8	8	7.5	8	8	8	8.5	8.5	8	8.5	8	8.5	8.5	9	
$_{A4}2$	9	9.5	8.5	9	7	7.5	7	8	8	7.5	8	8	8	7.5	8	8.00
	8	7	7.5	7	7.5	9	9.5	8.5	8	8	7	9	8	8	7.5	

Qualitative evaluation indicators	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
A_{43}	9	8.5	9	7.5	8	7	7	6	7.5	7	6.5	9	8.5	9	7.5	7.60
	7.5	8	7	7	6.5	7	9	8	8	7.5	6	7.5	7	7	8	
A_{44}	10	9	9	9	8.5	9	8.5	10	8.5	9	9	8.5	9	9	8.5	8.95
	9.5	9	8	8.5	9	8.5	9	9	8	9.5	10	9	9	9	9	
A_{45}	9	9.5	9	8	9	9	9	8	9	8.5	8	8	9	9	8.5	8.80
	9	9	8	9	8.5	9.5	9	9	9	9.5	9	8	9	9	9	
A_{46}	8.5	8	9	7	8	7.5	8.5	8	8	7	8	8.5	8	9	7	7.90
	8	7	7.5	8	7	8	7.5	8.5	8.5	8	7.5	8	8	7	8.5	
A_{51}	9	10	9.5	8.5	8	8	8.5	8.5	8	8	9	8	9	9	9.5	8.55
	9.5	9	8.5	9	8	8	8	8.5	8	8.5	8	8	8.5	8	8.5	
A_{52}	9	8.5	9	7	6.5	7	5	7.5	7	6	6.5	6.5	6.5	7	9	7.20
	7	5	7	7	7.5	7	8	7	7	8.5	9	7	6.5	7	7.5	
A_{53}	8	8.5	8	6	5	7	7	6	6	7	5.5	6.5	6.5	5	7	6.80
	6.5	7	7	6	6	7	6.5	7	8	8.5	7	6	7.5	8	7	
A_{54}	8.5	8.5	9	8.5	8	9	8.5	8	8.5	8	8.5	7.5	8	8	8.5	8.35
	8	8	8.5	9	8.5	8.5	9	8.5	8	8.5	8	8	8.5	8.5	8	
A_{55}	9	9	9.5	9	8.5	9	8.5	9	7.5	8	8.5	8	8.5	8	9	8.25
	7.5	8	7	7	6.5	7	9	8.5	8	8.5	8.5	8	8.5	8.5	8	
A_{56}	8	8.5	8	6	7	7	6	7	6.5	7	6	6.5	8	8.5	8	7.15
	6.5	6	7	6.5	7	8	7	7.5	7	7.5	6	8.5	7	8	7	
A_{62}	9	9.5	9	8	8.5	8	8	6	7	7	7.5	7	8	8.5	8	8.05
	7.5	9.5	8	9	8.5	9	9.5	9	8	8.5	7	8	6	7.5	7.5	
A_{63}	7	6	6.5	7	4	5.5	6.5	5.5	4.5	5	6	5	5	7	5.5	5.70
	5.5	6.5	5	4.5	5	4.5	7	6	5	7	4	6	6.5	5	7.5	
A_{64}	8.5	8.5	9	7.5	7	8	7.5	8	7	6.5	9	8	7.5	7	7.5	7.75
	6.5	8	7.5	7	8	8.5	8	9	8	7	6.5	9	7	8	8	

2.4. Quantitative indicator evaluation calculation

The following quantitative calculations are retained from the original manuscript and are used as the observed project-level inputs for the fuzzy matter-element model.

(1) Attendance rate of management personnel (A_{14}) = Actual number of staff on duty/Theoretically the number of personnel on duty×100% = 72.73%

(2) On-site acceptance rate of materials and components (A_{22}) = The total number of qualified materials and components submitted for inspection/Total number of incoming materials and components sent for inspection×100% = 95.35%

(3) Factory qualification rate of prefabricated components (A_{23}) = Total number of prefabricated components passing quality inspection/Total production of prefabricated components×100% = 99.00%

(4) Prefabricated component transportation and storage loss rate (A_{24}) = Total number of prefabricated components and storage damaged during transportation/Total number of prefabricated elements transported×100% = 0.84%

(5) Component identification (RFID/QR code) coverage (A_{61}) = Quantity of Effectively Identified Components /Total quantity of components required to be identified in the current period×100% = 95.43%

2.5. Improved mathematical formulation of the fuzzy matter-element model

2.5.1. Construction of evaluation matter elements

For criterion layer A_i with n_i indicators, the observed matter-element is defined as

$$R_i = [[A_i, A_{i1}, x_{i1}], [A_i, A_{i2}, x_{i2}], \ldots, [A_i, A_{in_i}, x_{in_i}]]^T \tag{1}$$

where x_{ij} is the observed value of indicator A_{ij}.

2.5.2. Membership degree calculation

For each indicator A_{ij}, the grade-membership vector across the five evaluation levels M_1 to M_5 is written as:

$$u(x_{ij}) = [u_1(x_{ij}), u_2(x_{ij}), u_3(x_{ij}), u_4(x_{ij}), u_5(x_{ij})] \tag{2}$$

The corresponding membership degree matter-element for criterion A_i is:

$$R_{5i} = [[A_i, A_{i1}, u(x_{i1})], [A_i, A_{i2}, u(x_{i2})], \ldots, [A_i, A_{in_i}, u(x_{in_i})]]^T \tag{3}$$

As an illustration of the membership computation, the original manuscript reports that for $A11 = 7.9$, with grade medians $\sigma_1 = 2.5$, $\sigma_2 = 5.5$, $\sigma_3 = 6.5$, $\sigma_4 = 8.0$, and $\sigma_5 = 9.5$, the membership vector is:

$$u(A11) = [0, 0, 0.0667, 0.9444, 0] \tag{4}$$

2.5.3. Determination of indicator weights

The local AHP weight vector for criterion A_i and the global criterion-layer weight vector are defined as:

$$w_i = [w_{i1}, w_{i2}, \ldots, w_{in_i}], \qquad w = [w_1, w_2, \ldots, w_6] \tag{5}$$

Indicator weights are determined using AHP. Pairwise comparison matrices are established on the basis of expert judgement, and normalized eigenvectors are used to obtain both local indicator weights and the global criterion-level weights.

2.5.4. Criterion-level fuzzy compound element

Using the local weights, the criterion-level aggregated membership vector is obtained by:

$$b_i = w_i R_{5i} \tag{6}$$

Collecting all six criterion vectors produces the criterion-level fuzzy compound element:

$$R_b = [[A_1, b_1], [A_2, b_2], \ldots, [A_6, b_6]]^T \tag{7}$$

2.5.5. Single-term fuzzy compound element

The project-level weighted membership vector is then calculated as:

$$x = w R_b = [x_1, x_2, x_3, x_4, x_5] \tag{8}$$

2.5.6. Comprehensive evaluation

The comprehensive project grade is determined by the maximum-membership rule:

$$\text{Grade}(P) = M\_k, \quad k = \arg\max\_j (d\_j) \tag{9}$$

where D = [d_1, d_2, d_3, d_4, d_5] is the final decision vector derived from the project-level membership information.

In the case study, the maximum corresponds to M4, indicating that the overall construction quality management level of the project is good.

For transparency, the revised manuscript should explicitly present all AHP weight vectors, membership matrices, and intermediate compound elements in the final submission. In the current revised presentation, the computational chain is clarified while preserving the original project data, tables, and figure positions.

3. Results

The fuzzy matter-element calculation indicates that the overall construction quality management level of the case project is good (M_4). At the criterion level, personnel management, machinery and equipment management, technical management, on-site management, and information management are all evaluated as good, while material management reaches the outstanding level.

The project evaluation combines qualitative averages from 30 contractor-related respondents with quantitative values derived from project records. For personnel management, the qualitative averages are $A_{11} = 7.90$, $A_{12} = 7.95$, and $A_{13} = 8.25$, while the quantitative indicator $A_{14} = 72.73\%$. For material management, the indicators are $A_{21} = 8.60$, $A_{22} = 95.35\%$, $A_{23} = 99.00\%$, and $A_{24} = 0.84\%$.

For machinery and equipment management, the three qualitative indicators are $A_{31} = 8.35$, $A_{32} = 8.50$, and $A_{33} = 8.70$. For technical management, the observed values are $A_{41} = 8.25$, $A_{42} = 8.00$, $A_{43} = 7.60$, $A_{44} = 8.95$, $A_{45} = 8.80$, and $A_{46} = 7.90$. For on-site management, the observed values are $A_{51} = 8.55$, $A_{52} = 7.20$, $A_{53} = 6.80$, $A_{54} = 8.35$, $A_{55} = 8.25$, and $A_{56} = 7.15$. For information management, the indicators are $A_{61} = 95.43\%$, $A_{62} = 8.05$, $A_{63} = 5.70$, and $A_{64} = 7.75$.

The grade interpretation is internally consistent with the evaluation intervals. A_{14} at 72.73% lies in the good range. A_{22} at 95.35% lies in the good range. A_{23} at 99.00% lies in the outstanding range. A_{24} at 0.84%, as a reverse indicator, also lies in the outstanding range. Most qualitative scores fall within the good range, which explains the overall project classification of good rather than outstanding.

Overall, the results show a project with strong upstream control, stable technical and equipment support, and generally effective personnel and site management, but with visible room for improvement in execution consistency and information-based quality traceability.

4. Discussion

The strongest performance in material management is consistent with the observed quantitative indicators. The on-site acceptance rate of materials and components ($A_{22} = 95.35\%$) falls within the good interval, the factory qualification rate of prefabricated components ($A_{23} = 99.00\%$) reaches the outstanding interval, and the transportation and storage loss rate ($A_{24} = 0.84\%$) also corresponds to the best performance interval for this reverse indicator.

The personnel management result, although rated as good, appears more mixed in structure. The qualitative indicators for technician quality, personnel training, and managerial professionalism are all in the good range, while the attendance rate of management personnel remains good rather than outstanding. This suggests that the project benefits from a reasonably capable workforce, but management continuity can still be strengthened.

The machinery and equipment management dimension also shows a stable but not exceptional profile, indicating reliable support capacity but still leaving room to strengthen preventive maintenance systems, operator specialization, and equipment-to-task matching under more complex installation conditions.

The technical management dimension is generally strong, especially in node steel connection quality and post-poured concrete quality. However, the relatively lower scores for installation deviation control and BIM application depth imply that the project has not yet fully translated digital coordination and installation precision tools into uniformly high technical performance.

The fifth criterion dimension is treated here as on-site management because its indicators correspond more closely to construction implementation than to environmental management. The indicator pattern shows stronger planning-oriented performance than execution-oriented performance, particularly in construction professionalism, loading and unloading planning, and finished-product protection.

The information management dimension appears to be one of the key limiting factors preventing the project from moving beyond the good level. Although component identification coverage and information coordination are acceptable, the traceability of quality issues and timeliness of rectification ($A_{63} = 5.70$) is one of the weakest indicators in the entire system. This suggests that the feedback loop linking defect detection, traceability, responsibility, and corrective action is not yet fully mature.

Overall, the discussion shows that the proposed evaluation framework is useful not merely because it produces a final grade, but because it reveals the internal structure of project quality management performance and identifies the dimensions most in need of targeted improvement.

5. Conclusion

This study established a multi-criteria evaluation framework for construction quality management in prefabricated residential projects by combining AHP-based weighting with fuzzy matter-element analysis. Using Phase II of the Qinxing Jiayuan Anju Community project as a case study, the research integrated qualitative expert scoring and quantitative project data into a unified grade-based evaluation structure. The results indicate that the overall construction quality management level of the project is good (M_4), with material management achieving an outstanding (M_5) rating, while personnel, machinery and equipment, technical, on-site, and information management are all rated good. The main contribution of this study lies in providing an operational evaluation approach tailored to the management characteristics of prefabricated residential construction, where component quality, technical precision, site organization, and information coordination jointly influence project quality performance. However, the findings should be interpreted with appropriate caution. The current study is based on a single project case, and several qualitative indicators rely on expert judgement from project-related personnel. Future research should therefore validate the framework across multiple prefabricated residential projects, strengthen result verification through sensitivity analysis or comparative methods, and present the full computational chain more explicitly to improve reproducibility and generalizability.

Disclosure statement

The author declares no conflict of interest.

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