Risk Assessment of Green Renovation Projects for Aging Residential Communities Based on Fuzzy Bayesian Networks

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Abstract. In response to the characteristics of green renovation projects in old residential communities, such as multiple participants and phased and dynamic risk transmission, this paper constructs a risk assessment system with 16 indicators in four stages of the entire life cycle. It integrates combined weighting, triangular fuzzy numbers and Bayesian networks to establish an assessment model, and introduces the Noisy-or model to simplify the parameters. Using a project in a city in East China as an empirical case, the results show that the project is generally at a medium-to-high risk level (posterior probability 0.62), with the most prominent risks in the decision-making and construction stages; financing difficulties, lack of cooperation from residents, and insufficient experience in green property management are the key risk factors.

Keywords: Aging Residential Communities; Green Renovation; Risk Assessment; Fuzzy Bayesian Networks; Noisy-OR Model

1 Introduction

1.1 Research Background

Green renovation of old residential communities is an important way to achieve urban renewal and sustainable building development, with multiple benefits such as energy conservation, emission reduction and improved livability. However, compared to new construction projects, renovation projects involve a wide range of stakeholders, with intertwined and dynamically evolving risk factors, resulting in extremely high uncertainty. Therefore, scientifically identifying key risks, establishing a systematic assessment framework, and developing response strategies are crucial to promoting the high-quality development of green renovation of old residential communities.

1.2 Literature Review

Existing studies on the green renovation of aging residential communities mainly focus on sustainability evaluation [1], collaborative decision-making [2], investment strategies [3], and project governance [6]. In project risk management, commonly

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used methods include AHP, fuzzy comprehensive evaluation, entropy weighting, and combined weighting [4,9]. Although these methods are effective for static ranking and prioritization, they are less capable of revealing causal dependence and staged transmission among interacting risks.

To address dynamic risks, Bayesian networks have been increasingly used in engineering risk analysis because they support causal reasoning and dynamic updating [5, 7, 10]. Furthermore, triangular fuzzy numbers are suitable for quantifying expert linguistic evaluations under uncertainty [8], while the Noisy-or model can simplify conditional probability estimation in multi-factor systems [11].

In summary, existing studies mainly emphasize macro-level implementation pathways and static risk assessment, but fail to capture the causal relationships and cross-stage transmission of risks. To fill this gap, this paper constructs a full-lifecycle risk assessment framework covering decision-making, design, construction, and operation and maintenance. By integrating combined weighting, triangular fuzzy numbers, and Bayesian networks, it establishes a lifecycle-oriented risk identification system, improves dynamic risk reasoning under small-sample conditions, and identifies key risk factors and their transmission characteristics for stage-specific risk control.

2 Risk Identification for Green Renovation Projects in Aging Residential Communities

To ensure scientific rigor and practical applicability, risk identification follows the principles of systematicity, specificity, lifecycle coverage, and operability.

Based on literature review, expert interviews, and case adaptation, 16 risk indicators are identified and classified into four stages: decision-making, design, construction, and operation and maintenance, as detailed in Table 1.

Table 1. Risk Indicator System for Green Renovation Projects in Aging Residential Communities

stage	Code	Risk Indicators
Decision-making Phase	A11	Changes in Incentive Policies and Related Standards
	A12	Residents are uncooperative.
	A13	The objectives and positioning of green retrofitting are unclear.
	A14	Financing difficulties
	A15	There is a lack of comparable engineering materials, and the costs and benefits are difficult to estimate.
Design Phase	A21	Designers lack experience in green renovation design.
	A22	Inadequate site investigation; poor constructability of the design.

stage	Code	Risk Indicators
Construction Phase	A23	Cost Overrun of New Technologies and Materials
	A31	Lack of Contractor Experience
	A32	New materials and equipment are not being supplied in a timely manner.
	A33	The prices of green building materials fluctuate significantly.
	A34	The renovation work is impacting surrounding buildings and the daily lives of residents.
Operations and Maintenance Phase	A41	Lack of Green Management of Company
	A42	Residents Improperly Use Modified Equipment
	A43	The performance of the renovated building is unstable.
	A44	The performance evaluation and feedback mechanisms for the transformation process are inadequate.

3 Methodology

3.1 Combined Weighting

The 16 risk indicators (Table 1) are grouped into four life-cycle stages: decision-making, design, construction, and operation. Six experts scored these indicators using a five-level linguistic scale. These scores were transformed into triangular fuzzy numbers$\tilde{A} = (l, m, r)$ and defuzzified via the centroid method to obtain prior probabilities: $P = (l + m + r) / 3$.To reduce bias, a combined weighting approach balances subjective($W^{(s)}$)and objective ($W^{(o)}$) weight is: $W = \alpha W^{(s)} + \beta W^{(o)}$($, \alpha + \beta = 1, \alpha, \beta \geq 0$).

The BN comprises three layers (Fig. 1): 16 indicators as root nodes, 4 stage risks as intermediate nodes, and R_Overall as target. Edges follow expert consensus (≥5/6 agreement). Noisy-OR gates assume independent parent contributions with causal strength p_i from expert ratings (0.3=weak, 0.7=strong).

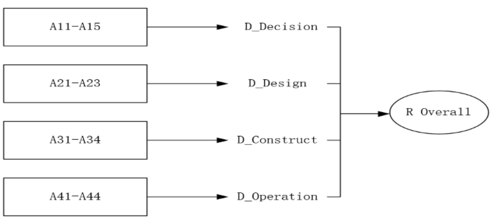

Fig. 1. Three-layer BN structure

$$P(Y = 1 \mid X_1, X_2, \ldots, X_n) = 1 - \prod_{i:\, xi=1}(1 - p_i)$$

where p_i is expert-rated causal strength (0.3=weak, 0.6=medium, 0.9=strong) for each parent-child edge.

Finally, Bayesian diagnostic inference is applied to identify critical factors : $P(X_i \mid Y) = P(Y \mid X_i)P(X_i) / P(Y)$.

4 Case Study and Results

4.1 Case Overview and Parameter Setting

The empirical case is an 18-month, RMB 32 million green renovation project in East China (12 buildings, 42,000 m²). To ensure reliability, a panel of six experts was selected to evaluate the model parameters, comprising two senior project managers, two green building design engineers, and two academic researchers in construction management, all with over 10 years of experience. They provided the linguistic scores, which were processed into prior probabilities and Noisy-OR parameters to populate the Bayesian network.The evaluation yields the comprehensive weights for the following relevant risk factors (Fig. 2).

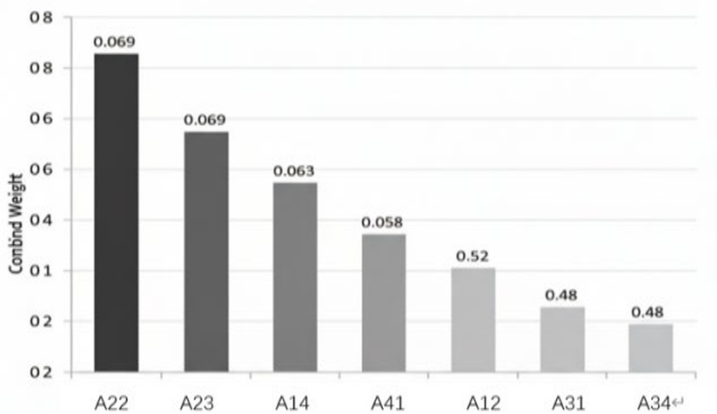

Fig. 2. Combined Weight of Key Risk Factors

4.2 Overall Risk Assessment

Based on causal reasoning in the BN, the posterior probability of the overall project risk is calculated at 0.62, indicating a medium-to-high risk level. Diagnostic reasoning (Table 2) reveals clear stage-transmission characteristics. Financing difficulties (A14) and resident non-cooperation (A12) show the highest posterior probabilities and act as key transmission nodes in early stages. Inadequate contractor experience (A31) and lack of green management (A41) further highlight vulnerabilities in project implementation and operation.

4.3 Model Validation and Sensitivity Analysis

Sensitivity analysis tests three critical nodes. Increasing A14 (financing) prior by 10% raises overall risk by 6.8%, versus 5.2% for A12 (resident) and 4.1% for A31 (contractor), while A43 (building performance) shows minimal impact (1.3%). This confirms early-stage risks dominate. For validation, AHP produces static ranking (A14>A12>A31) without probability values or transmission paths. Pure fuzzy logic yields crisp scores (0.58, 0.61) but cannot update dynamically. The FBN uniquely identifies A12's amplification via A34 (construction disturbance) when evidence enters, demonstrating causal inference unavailable to static methods.

Table 2. Key Risk Diagnosis Results

Ranking	Risk Factors	Prior probability	Posterior probability	Risk Explanation
1	Financing difficulties	0.62	0.71	High probability of occurrence, significant impact.
2	Residents are uncooperative.	0.58	0.68	Directly impacts the progress of renovation and construction organization
3	Lack of Green Management of Company	0.54	0.65	Affects the sustainability of renovation results
4	Lack of Contractor Experience	0.56	0.63	Compromises construction quality and safety
5	Cost Overrun of New Technologies and Materials	0.52	0.61	Leads to cost overruns and schedule delays

5 Practical Implications and Conclusions

5.1 Actionable Risk-Control Measures

Control measures specify responsibilities, timelines, and KPIs. Months 1-3 (decision): Developers and governments secure green loans for A14 (KPI: approval by Month 3); community committees obtain ≥80% resident consent for A12. Months 4-18 (construction): Contractors enforce noise <55dB for A34 (KPI: ≤5 complaints/month).

Month 19+ (operation): Property companies hire certified green managers for A41 (KPI: ≥15% energy savings).

5.2 Conclusions and Limitations

This Bayesian network-based framework effectively captures causal risk transmission in green renovations. However, this study has clear limitations: (1) Parameter learning relies on a small expert sample, making the fuzzy scoring inherently subjective; (2) Single-case validation limits broad generalizability. Future research will integrate measured, multi-project data to train network parameters via machine learning, thereby reducing subjectivity and improving model robustness.

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