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Enhancing Strategies for Improving Safety Risk Management in Fabricated Residential Construction: A Neutrosophic Approach to Minimize Hazards and Ensure Efficiency

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Abstract: Safety risk management in fabricated residential construction persists as an important yet challenging task because of the inherent uncertainties, ambiguities, and complexities associated with construction projects. Traditional risk management approaches often struggle to adequately capture these uncertainties, leading to suboptimal decision-making. In response to this gap, this paper proposes a novel Interval-Valued Fermatean Neutrosophic Set (IVFNS)-based ELECTRE II method for improving safety risk management. The proposed method integrates the strengths of IVFNS, which effectively models uncertainty, indeterminacy, and inconsistency, with the ELECTRE II outranking approach, which provides a structured framework for ranking alternatives based on pairwise comparisons. A public case study from a real construction company is introduced, involving five fabricated residential construction projects, to demonstrate and analyze the applicability of different safety techniques under different choice factors. The quantitative and qualitative analysis demonstrate that our methodology can offer a new solution to advance risk management in fabricated residential construction.

Keywords: Neutrosophic theory, Integrated circuits, Teaching Quality, Decision making

1. Introduction

The construction industry, particularly the residential sector, is one of the most hazardous industries worldwide, with safety risks pose significant challenges to project success and worker well-being [1]. Despite advancements in construction technologis and safety protocols, the dynamic and complex nature of fabricated residential construction projects often leads to uncertainties, ambiguities, and incomplete information in risk assessment and management [2]. Conventional risk management approaches, which rely on deterministic mechanisms, usually falls short in addressing these uncertainties, which can result in insufficient safety procedure and increasing vulnerability to accidents [3].

In recent years, the adoption of prefabricated as well as modular construction technique had been gaining momentum becuase of potential to improved efficiency, reducing waste, and enhancd quality control. However, these methods also present unique safety risks, such as those related to the transportation, assembly, and integration of prefabricated components [2], [3], [4]. These risks are often influenced by a combination of human, technical, and environmental factors, making them difficult to quantify using conventional risk management frameworks [4].

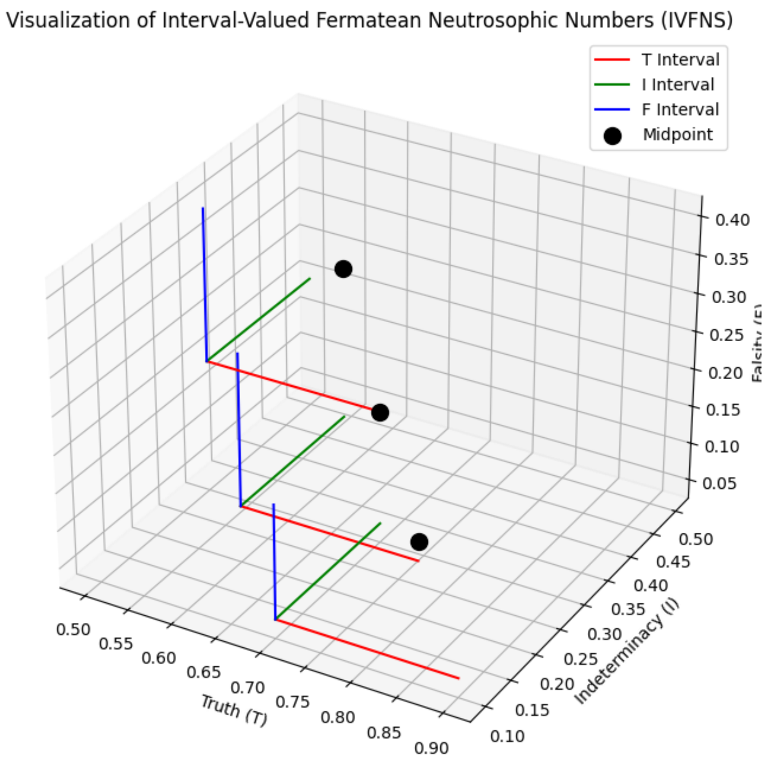

Figure 1. Visualization of Interval-Valued Fermatean Neutrosophic Numbers

For modeling uncertainty in such dynamic environment, Smarandache [5] presented an extension to standard theory of fuzzy logic by developing neutrosophic sets (NSs), which is a theoretical approach for representing information with three membership components: truth ($\mathbb{t}$), indeterminacy ($\mathbb{i}$), and falsity ($\mathbb{f}$). This way, NSs offer an enlightening description uncertainty by simultaneously capturing degrees of truth, falsehood, and ambiguity, making it particularly effective in addressing complex and inconsistent data. According to that, the application of NSs validate valued advantages in broad-range of arena thropugh building a powerful mechanism to factually analyzes and mediates uncertainty in dynamic environments [6]. To further enhance its practicality, interval-valued neutrosophic set (IVNS) [7] was proposed to extend the traditional NSs, where exact values of truth, falsity, and indeterminacy are difficult to determine. Instead of relying on careful values, IVNS represent each component with an interval within the range [0,1].

To that end, this research aims to develop a robust neutrosophic-based framework for identifying, assessing, and mitigating safety risks in fabricated residential construction projects. We propose to integrate expert knowledge, ancient data, and real-time project information into our framework to improve the accuracy and reliability of risk valuations, thereby improve safety outcomes and reduce the likelihood of coincidences. To sum up, the contribution of this research is pointed as follows:

- A comprehensive neutrosophic framework that integrates interval-valued Fermatean neutrosophic sets (IVFNS) with an extended multi-criteria decision-making technique for safety risk management in fabricated residential construction.
- Practical insights into the prioritization of safety measures, enabling construction practitioners to allocate resources more effectively and reduce the likelihood of accidents. A quantitative case study is presented, on which proof-of-concept analysis is performed to assess and evaluate the results of the proposed approach, comparing its performance against previous approaches.

2. Fundamentals & Definitions

Definition 1. IVNS is defined as an extension of standard with three interval-based membership components $T_A(x) = [infT_A(x), supT_A(x)]$, $I_A(x) = [infI_A(x), supI_A(x)]$, and $F_A(x) = [infF_A(x), supF_A(x)] \subseteq [0,1]$.

$$A = \left\{\left\langle \begin{matrix} x, [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], \\ [infF_A(x), supF_A(x)] \end{matrix} \right\rangle \mid x \in X\right\} \quad (1)$$

where

$$0 \leq supT\_A\ (x) + supI\_A\ (x) + supF\_A\ (x) \leq 3 \quad (2)$$

Definition 2. Given two IVNs $A = \{\langle [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], [infF_A(x), supF_A(x)]\rangle\}$, and $A = \{\langle [infT_B(x), supT_B(x)], [infI_B(x), supI_B(x)], [infF_B(x), supF_B(x)]\rangle\}$, you can apply the following mathematical operations:

- Complement

$$A^c = \langle [infT_A(x), supT_A(x)], [1 - infI_A(x), 1 - supI_A(x)], [infF_A(x), supF_A(x)]\rangle \quad (3)$$

- Addition

(4)

$$A \oplus B = \langle [infT_A(x) + infT_B(x) - infT_A(x) \cdot infT_B(x), supT_A(x) + supT_B(x) - supT_A(x) \cdot supT_B(x)], [infI_A(x) \cdot infI_B(x), supI_A(x) \cdot supI_B(x)], [infF_A(x) \cdot infF_B(x), supF_A(x) \cdot supF_B(x)] \rangle$$

- Multiplication

$$A \otimes B = \langle [infT_A(x) \cdot infT_B(x), supT_A(x) \cdot supT_B(x)], [infI_A(x) + infI_B(x) - infI_A(x) \cdot infI_B(x), supI_A(x) \cdot supI_B(x) - supI_A(x) \cdot supI_B(x)], [infF_A(x) + infF_B(x) - infF_A(x) \cdot infF_B(x), supF_A(x) + supF_B(x) - supF_A(x) \cdot supF_B(x)] \rangle \quad (5)$$

Definition 3. Given two IVNS Given two IVNs $A = \{\langle [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], [infF_A(x), supF_A(x)] \rangle\}$, and $B = \{\langle [infT_B(x), supT_B(x)], [infI_B(x), supI_B(x)], [infF_B(x), supF_B(x)] \rangle\}$, the following relations apply as follows:

$$A \subseteq B \text{ } iff \text{ } infT_A(x) \leq infT_B(x), supT_A(x) \leq supT_B(x); infI_A(x) \geq infI_B(x), supI_A(x) \geq supI_B(x); infF_A(x) \geq infF_B(x), supF_A(x) \geq supF_B(x) \quad (6)$$

$$A = B \text{ } iff \text{ } A \subseteq B \text{ } and \text{ } B \subseteq A. \quad (7)$$

Definition 4. Given two IVNS Given two IVNs $A = \{\langle [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], [infF_A(x), supF_A(x)] \rangle\}$, and $B = \{\langle [infT_B(x), supT_B(x)], [infI_B(x), supI_B(x)], [infF_B(x), supF_B(x)] \rangle\}$, and $C = \{\langle [infT_C(x), supT_C(x)], [infI_C(x), supI_C(x)], [infF_C(x), supF_C(x)] \rangle\}$, the following relations apply as follows:

$$\begin{aligned} &(1) A + B = B + A, \\ &(2) A \cdot B = B \cdot A, \\ &(3) \lambda(A + B) = \lambda A + \lambda B, \lambda > 0, \\ &(4) (A \cdot B)^{\lambda} = A^{\lambda} + B^{\lambda}, \lambda > 0, \\ &(5) \lambda_1 A + \lambda_2 A = (\lambda_1 + \lambda_2) A, \lambda_1 > 0, \lambda_2 > 0 \\ &(6) A^{\lambda_1} \cdot A^{\lambda_2} = A^{(\lambda_1 + \lambda_2)}, \lambda_1 > 0, \lambda_2 > 0, \\ &(7) (A + B) + C = A + (B + C), \\ &(8) (A \cdot B) \cdot C = A \cdot (B \cdot C) \end{aligned} \quad (8)$$

Definition 5. The interval-valued fermatean neutrosophic set (IVFNs) is defined as the extension of standard IVNSs with three interval-based membership components $T_A(x) = [infT_A(x), supT_A(x)]$, $I_A(x) = [infI_A(x), supI_A(x)]$, and $F_A(x) = [infF_A(x), supF_A(x)] \subseteq [0,1]$.

$$A = \left\{\left\langle \begin{matrix} x, [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], \\ [infF_A(x), supF_A(x)] \end{matrix} \right\rangle \mid x \in X\right\} \quad (9)$$

where

$$0 \leq supT_A\,(x) + supI_A\,(x) + supF_A\,(x) \leq 3 \quad (10)$$

$$0 \leq [infT_A\,(x)]^3 + [infF_A]^3 \leq 1 \; and \; 0 \leq [infI_A\,(x)]^3 \leq 1 \quad (11)$$

$$0 \leq [infT_A\,(x)]^3 + [infI_A\,(x)]^3 + [infF_A\,(x)]^3 \leq 2 \quad (12)$$

$$0 \leq [supT_A\,(x)]^3 + [supI_A\,(x)]^3 + [supF_A\,(x)]^3 \leq 2 \quad (13)$$

Given two IVFNs $A = \{\langle [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], [infF_A(x), supF_A(x)]\rangle\}$, and $A = \{\langle [infT_B(x), supT_B(x)], [infI_B(x), supI_B(x)], [infF_B(x), supF_B(x)]\rangle\}$, you can apply the following mathematical operations:

- Complement

$$A^c = \left[\sqrt[3]{1-[1-\{infT_A(x)\}^3]^{\mu}}, \sqrt[3]{1-[1-\{supT_A(x)\}^3]^{\mu}}\right], [\{infI_A(x)\}^3, \{supI_A(x)\}^3], [\{infF_A(x)\}^3, \{infF_A(x)\}^3] \quad (14)$$

- Addition

$$A \oplus B = = \left\langle \begin{bmatrix} \sqrt[3]{\{infT_A(x)\}^3 + \{infT_B(x)\}^3 - \{infT_A(x)\}^3 \cdot \{\{infT_B(x)\}^3}, \\ \sqrt[3]{\{supT_A(x)\}^3 + \{supT_B(x)\}^3 - \{supT_A(x)\}^3 \cdot \{supT_B(x)\}^3} \end{bmatrix}, [infI_A(x) \cdot infI_B(x), supI_A(x) \cdot supI_B(x)], [infF_A(x) \cdot infF_B(x), supF_A(x) \cdot supF_B(x)] \right\rangle \quad (15)$$

- Multiplication

$$A \oplus B = \left\langle \begin{matrix} [infT_A(x) \cdot infT_B(x), supT_A(x) \cdot supT_B(x)], \\ \begin{bmatrix} \sqrt[3]{\{infI_A(x)\}^3 + \{infI_B(x)\}^3 - \{infI_A(x)\}^3 \cdot \{infI_B(x)\}^3}, \\ \sqrt[3]{\{supI_A(x)\}^3 + \{supI_B(x)\}^3 - \{supI_A(x)\}^3 \cdot \{supI_B(x)\}^3} \end{bmatrix}, \\ \begin{bmatrix} \sqrt[3]{\{infF_A(x)\}^3 + \{infF_B(x)\}^3 - \{infF_A(x)\}^3 \cdot \{infF_B(x)\}^3}, \\ \sqrt[3]{\{supF_A(x)\}^3 + \{supF_B(x)\}^3 - \{supF_A(x)\}^3 \cdot \{supF_B(x)\}^3} \end{bmatrix} \end{matrix} \right\rangle \quad (16)$$

Definition 6: The weighted averaging operator for IVNS is defined to aggregate a number of IVNS weighted by the weight vector $Y = (y_1, \dots, y_j, \dots, y_n))$ and $\sum_{j=1}^{n} y_j = 1$.

$$WA_{IVNNs}(x_1, \dots, x_j, \dots, x_n) = \sum_{j=1}^{n} y_j x_j = \left\langle \begin{matrix} \left[1 - \prod_{j=1}^{n}(1 - infT_A(x))^{y_j}, 1 - \prod_{j=1}^{n}(1 - supT_A(x))^{y_j}\right] \\ \left[\prod_{j=1}^{n}(infI_A(x))^{y_j}, \prod_{j=1}^{n}(supI_A(x))^{y_j}\right], \left[\prod_{j=1}^{n}(infF_A(x))^{y_j}, \prod_{j=1}^{n}(supF_A(x))^{y_j}\right] \end{matrix} \right\rangle \quad (17)$$

Definition 7. Given an IVNS $A = \{\langle [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], [infF_A(x), supF_A(x)] \rangle\}$, the de-neutrosophication can be calculated as given below:

$$A_{den} = \left(\frac{(infT_A(x) + supT_A(x))}{2} + \left(1 - \frac{(infI_A(x) + supI_A(x))}{2}\right)(supI_A(x)) - \left(\frac{(infF_A(x) + supF_A(x))}{2}\right)(1 - supF_A(x)) \right) \tag{18}$$

Definition 8: Given an IVFNS $A = \{\langle [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], [infF_A(x), supF_A(x)] \rangle\}$, the score function of can be computed as follows:

$$S(A) = \frac{[infT_A(x)]^3 + [supT_A(x)]^3 + [infI_A(x)]^3 + [supI_A(x)]^3 + [infF_A(x)]^3 + [supF_A(x)]^3}{2} \tag{19}$$

3. Research Method

Herein, we propose a detailed explanation of the proposed IVNS decision-making approaches for evaluating the safety risks in fabricated residential construction, generating useful insights that enable the decision makers to appropriately and efficiently manage the construction sites. Our framework begin with integration of criteria weighting approach that take into account contrast intensity (reflected by standard deviation) as well as the collaboration among criteria [8]. This pass through the following steps.

Step 1, we create IVFNS decision matrix, where the alternatives are evaluated against the criteria using the triplet

$$.D_{IVFN} = \begin{bmatrix} \begin{Bmatrix} [infT_A(x), supT_A(x)], \\ [infI_A(x), supI_A(x)], \\ [infF_A(x), supF_A(x)] \end{Bmatrix}_{11} & \cdots & \begin{Bmatrix} [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], \\ [infF_A(x), supF_A(x)] \end{Bmatrix}_{1m} \\ \vdots & \ddots & \vdots \\ \begin{Bmatrix} [infT_A(x), supT_A(x)], \\ [infI_A(x), supI_A(x)], \\ [infF_A(x), supF_A(x)] \end{Bmatrix}_{n1} & \cdots & \begin{Bmatrix} [infT_A(x), supT_A(x)], [infI_A(x), supI_A(x)], \\ [infF_A(x), supF_A(x)] \end{Bmatrix}_{nm} \end{bmatrix} \tag{20}$$

Step 2, we compute the normalized IVFNS decision matrix, D_{IVFN}^{norm}, as follows:

$$\tilde{T}_{ij} = \left[\frac{\text{inf}T_{ij}}{\max(\text{sup}T_j)}, \frac{\text{sup}T_{ij}}{\max(\text{sup}T_j)}\right], \tilde{I}_{ij} = \left[\frac{\text{inf}I_{ij}}{\max(\text{sup}I_j)}, \frac{\text{sup}I_{ij}}{\max(\text{sup}I_j)}\right]$$
$$\tilde{F}_{ij} = \left[\frac{\text{inf}F_{ij}}{\max(\text{sup}F_j)}, \frac{\text{sup}F_{ij}}{\max(\text{sup}F_j)}\right] \quad (21)$$

when it comes to cost criteria, we can use the complement of the IVFNS values:

$$\tilde{T}_{ij} = \left[1 - \frac{\text{sup}T_{ij}}{\max(\text{sup}T_j)}, 1 - \frac{\text{inf}T_{ij}}{\max(\text{sup}T_j)}\right], \tilde{I}_{ij} = \left[1 - \frac{\text{sup}I_{ij}}{\max(\text{sup}I_j)}, 1 - \frac{\text{inf}I_{ij}}{\max(\text{sup}I_j)}\right]$$
$$\tilde{F}_{ij} = \left[1 - \frac{\text{sup}F_{ij}}{\max(\text{sup}F_j)}, 1 - \frac{\text{inf}F_{ij}}{\max(\text{sup}F_j)}\right] \quad (22)$$

Step 3: we perform de-neutrosophication of each IVFNS number to obtain crisp decision matrix.

$$A_{den} = \left(\frac{(infT_A(x)+supT_A(x))}{2} + \left(1 - \frac{(infI_A(x)+supI_A(x))}{2}\right)(supI_A(x)) - \left(\frac{(infF_A(x)+supF_A(x))}{2}\right)(1 - supF_A(x))\right) \quad (23)$$

Step 4, we compute the STD associated with each criterion, S_j based on the following:

$$S_j = \sqrt{\frac{\sum_{i=1}^{m}\left([D_{IVFN}^{norm}]_{ij} - \overline{[D_{IVFN}^{norm}]_j}\right)^2}{n-1}} \quad (24)$$

Step 5, the correlation between different criteria I calculated as follows:

$$r_{bj} = \frac{\sum_{b,j=1}^{n}\left([D_{IVFN}^{norm}]_{ib} - \overline{[D_{IVFN}^{norm}]_b}\right)\left([D_{IVFN}^{norm}]_{ij} - \overline{[D_{IVFN}^{norm}]_j}\right)}{\sqrt{\sum_{b=1}^{n}([D_{IVFN}^{norm}]_{ib} - [D_{IVFN}^{norm}]_b)^2 \sum_{j=1}^{n}\left([D_{IVFN}^{norm}]_{ij} - \overline{[D_{IVFN}^{norm}]_j}\right)^2}} \quad (25)$$

Step 5, the contradictory variation foreach pair of criteria is computed as follows:

$$P_j \leftarrow \sum_{b=1}^{n}(1 - r_{bj}) \quad (26)$$

Step 5, the volume of information to be measured by $j - th$ criterion, C_j, and the corresponding weights are computed as follows:

$$C_j \leftarrow S_j P_j \quad (27)$$
$$w_j \leftarrow \frac{C_j}{\sum_{j=1}^{n} C_j} \quad (28)$$

Following, we apply IVFNS-ELECTRE-II algorithm to decide on the best construction alternatives that can provide better risk management (Refer to Algorithm 1).

Algorithm 1: pseudocode of the IVFNS-ELECTRE-II.

Input: The concordance threshold, discordance threshold, criteria weights w_j, and D_{IVFN}^{norm}

1 Make use of normalized Decision Matrix, D_{IVFN}^{norm}.

2 Apply weights to decision matrix, D_{IVFN}^{norm}: $[D_{IVFN}^{norm}]_w = [D_{IVFN}^{norm}]_{ij} \times w_j$.

3 Decide the Concordance Sets: $c_{kl} = \left\{j, D_{IVFN}^{norm}{}_{kj} \geq y_{lj}\right\}$ for J = 1,2,3, … , n.

4 Decide the Discordance Sets: $d_{kj} = \left\{j, D_{IVFN}^{norm}{}_{kj} < y_{lj}\right\}$ for J = 1,2,3, … , n

5 Build the Concordance Matrices $\mathcal{F} = \begin{pmatrix} - & \mathrm{cm}_{12} & \mathrm{cm}_{13} & \dots & \mathrm{cm}_{1n} \\ \mathrm{cm}_{21} & - & f_{23} & \dots & \mathrm{cm}_{2n} \\ \mathrm{cm}_{31} & \mathrm{cm}_{32} & - & \dots & \mathrm{cm}_{3n} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ \mathrm{cm}_{n1} & \mathrm{cm}_{n2} & \mathrm{cm}_{n3} & \dots & - \end{pmatrix}$.

6 Build the Discordance Matrices $\mathcal{G} = \begin{pmatrix} - & dd_{12} & dd_{13} & \dots & dd_{1n} \\ dd_{21} & - & dd_{23} & \dots & dd_{2n} \\ dd_{31} & dd_{32} & - & \dots & dd_{3n} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ dd_{n1} & dd_{n2} & dd_{n3} & \dots & - \end{pmatrix}$.

7 Determine the concordance based dominance matrix:

$$H = \begin{pmatrix} - & h_{12} & h_{13} & \dots & h_{1n} \\ h_{21} & - & h_{23} & \dots & h_{2n} \\ h_{31} & h_{32} & - & \dots & h_{3n} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ h_{n1} & h_{n2} & h_{n3} & \dots & - \end{pmatrix}, where\ h_{pq} = \begin{cases} 1, & \mathrm{cm}_{pq} \geq \overline{\mathrm{cm}}, \\ 0, & \mathrm{cm}_{pq} < \overline{\mathrm{cm}}. \end{cases} such\ that\ \mathrm{cm}$$

$$= \frac{1}{n(n-1)} \sum_{\substack{p=1 \\ p \neq q}}^{n} \sum_{\substack{q=1 \\ q \neq p}}^{n} \mathrm{cm}_{pq}$$

8 Determine the discordance based dominance index matrix: $L =$

$$\begin{pmatrix} - & l_{12} & l_{13} & \dots & l_{1n} \\ l_{21} & - & l_{23} & \dots & l_{2n} \\ l_{31} & l_{32} & - & \dots & l_{3n} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ l_{n1} & l_{n2} & l_{n3} & \dots & - \end{pmatrix}, where\ l_{pq} = \begin{cases} 1, & g_{pq} < \overline{dd}, \\ 0, & g_{pq} \geq \overline{dd}. \end{cases} \text{such that } \overline{dd} =$$

$$\frac{1}{n(n-1)} \sum_{\substack{p=1 \\ p \neq q}}^{n} \sum_{\substack{q=1 \\ q \neq p}}^{n} dd_{pq}$$

9 Construct the strong and weak outranking relations

4. Results and Discussions

This section introduces a quantitative case study for our work based on a construction company, which is planning to implement safety measures using either of five fabricated residential construction projects (alternatives). In Project A, the company introduce a high-rise modular residential building in an urban area. In Project B, the company emphasize Low-rise prefabricated housing development in a suburban area. In project C, the company emphasize mixed-use residential and commercial modular complex in a semi-urban area. In project D, the company emphasize affordable housing projects using prefabricated components in a rural area. In project E, the company emphasize Luxury modular villas in a coastal area with challenging environmental conditions. As shown, the project varies in many characteristics that affect the safety risks and related costs. These criteria include Implementation Cost (C1), Operational Disruption (C2), Risk Reduction Effectiveness (C3), Worker Compliance and Acceptance (C4), and Long-Term Sustainability (C5).

In Table 1, we show the results of aggregating the IVFNS decision matrices from different experts, where each cell represents the IVFNS evaluation of an alternative A_i with respect to the criterion C_j:

Table 1. Aggregated IVFNS decision matrix from different domain experts.

Alternatives	C_1	C_2	C_3	C_4	C_5
A_1	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩
A_2	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩
A_3	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩
A_4	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩
A_5	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.5], [0.2, 0.4]⟩	⟨[0.7, 0.9], [0.1, 0.3], [0.05, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.4], [0.1, 0.3]⟩
A_6	⟨[0.4,0.6],[0.3,0.5], [0.2,0.4]⟩	⟨[0.5,0.7],[0.2,0.4], [0.1,0.3]⟩	⟨[0.6,0.8],[0.1,0.3], [0.05,0.2]⟩	⟨[0.5,0.7],[0.3,0.5],[0.2,0.4]⟩	⟨[0.7,0.9],[0.1,0.3],[0.05,0.2]⟩

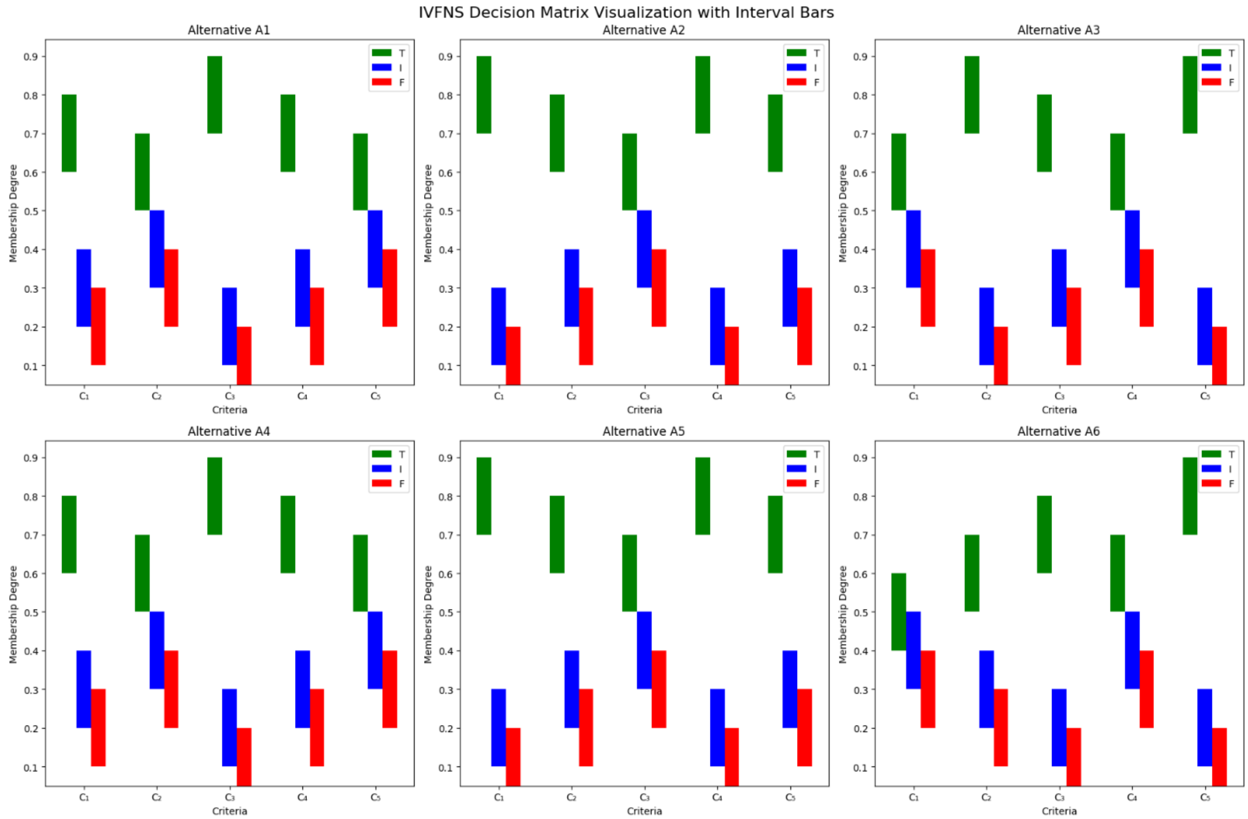

Figure 2. visual representation of IVFNS decision matrix.

Then, we convert the IVFNS decision matrix into a crisp matrix using a predefined de-neutrosophication method.

Table 2: Quantitative results of De-neutrosophication of the IVFNS Decision Matrix.

Criteria / Alternative	C1	C2	C3	C4	C5
A_1	0.84	0.72	0.94	0.84	0.72
A_2	0.94	0.84	0.72	0.94	0.84
A_3	0.72	0.94	0.84	0.72	0.94
A_4	0.84	0.72	0.94	0.84	0.72
A_5	0.94	0.84	0.72	0.94	0.84
A_6	0.62	0.74	0.84	0.72	0.94

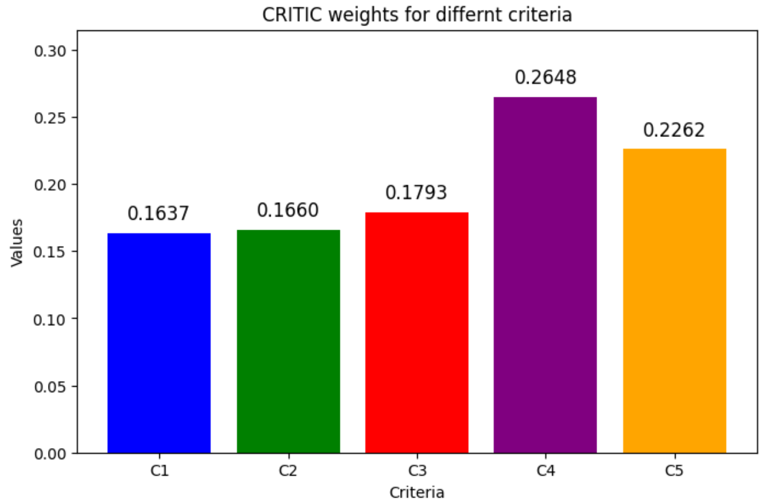

Figure 3. Qualitative representation of CRITIC weights.

Based on IVFNS-based CRITIC method, the weights of the criteria are presented in Figure 3, representing the relative importance of each construction criterion in the safety risk management

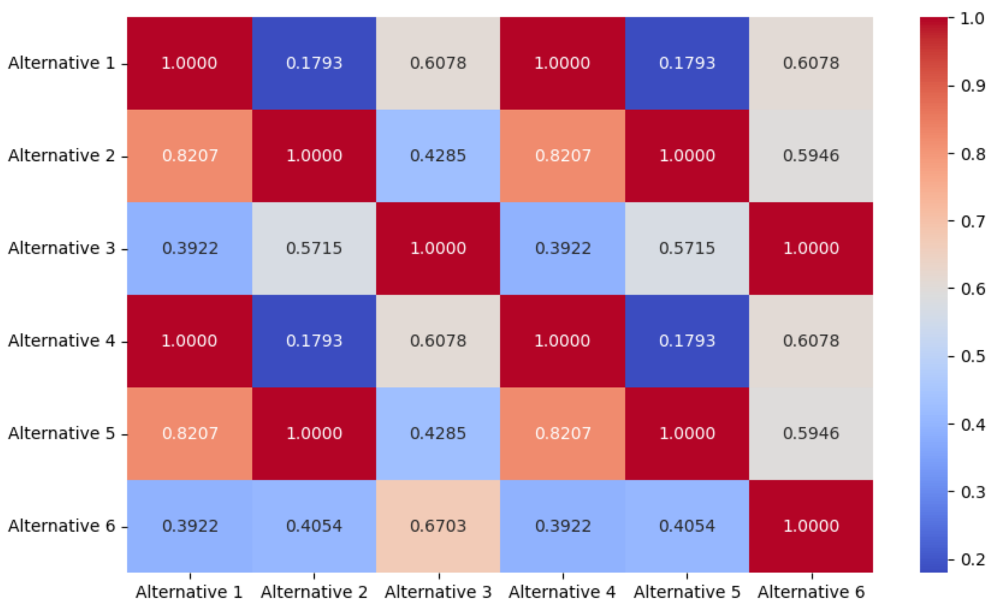

Figure 4. Concordance Matrix

process.

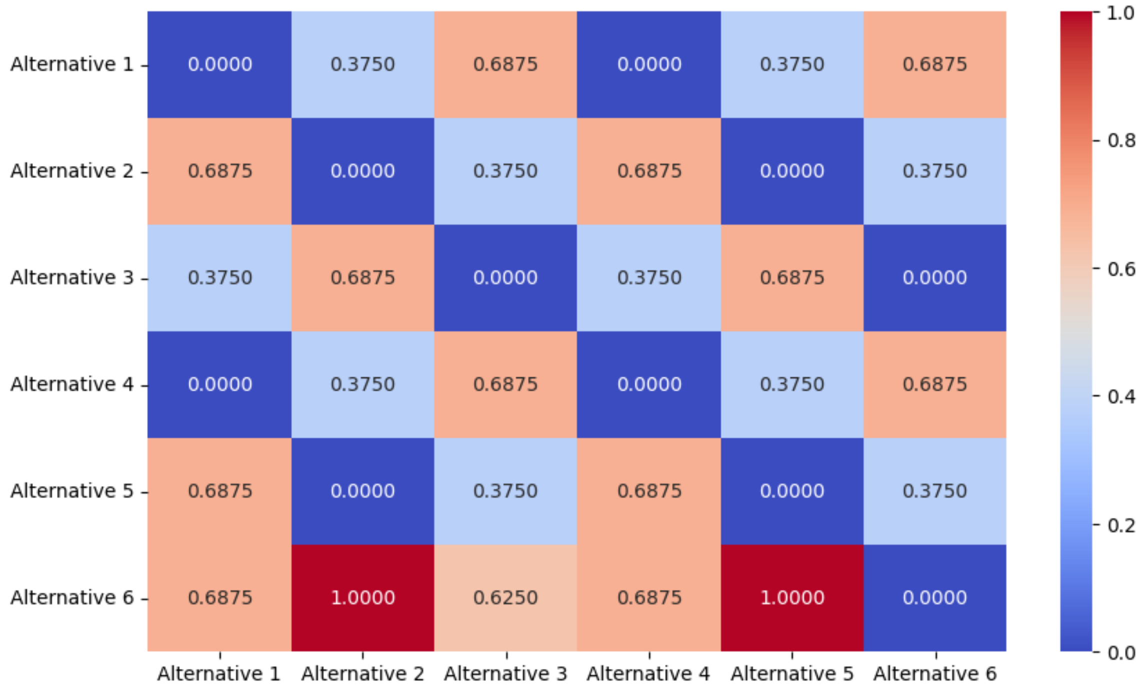

Figure 5. Discordance Matrix

To offer an informative summary of stages of arrangement between the alternatives, we present the concordance matrix are presented in Figure 4. The presented row values explain the degree to which a particular alternative being concordant with other alternatives based on the weighted upright of the different safe construction criteria. Moreover, to show the degree of divergence between alternatives, we present the discordance in Figure 5, which represent a corresponding matrix for the concordance matrix, where we could recognize the zones in which alternatives show a notable variance.

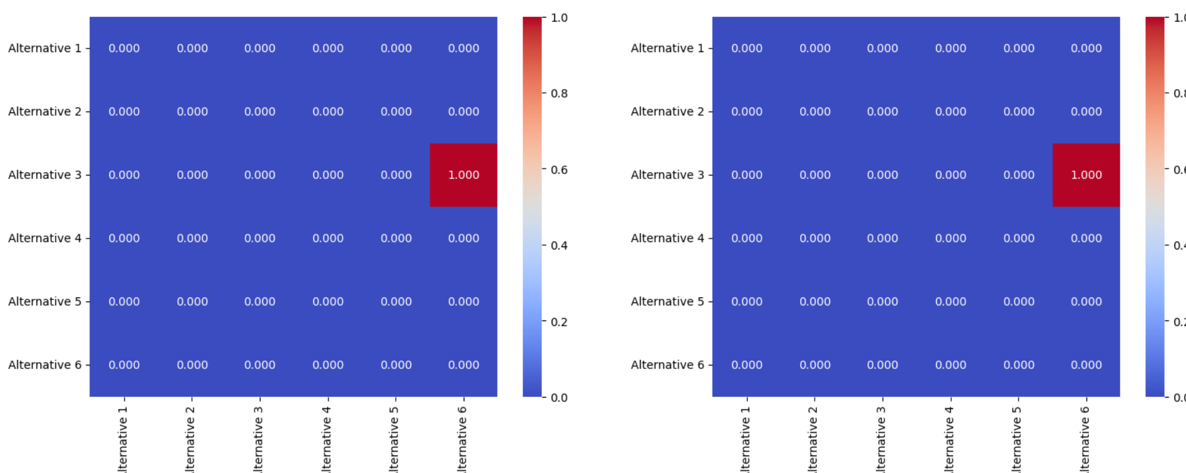

Figure 6. Strong vs weak dominance Matrix

To ascertain the dominant correlations among options, the dominance weak matrix and dominance strong matrix, displayed in Figure 6, combines the data from the concordance and discordance matrices. Depending on the combination assessment of concordance and discordance levels, every choice indicates whether one option is superior than others.

The ranking results obtained from the proposed IVFNS-based ELECTRE II method were compared with those from IVNS-ELECTRE-II, Combinative Distance-Based Assessment(CODAS) reported in [9], and TOPSIS to evaluate the consistency and robustness of our framework. As shown in Table 2, the rankings produced by all methods exhibit a high degree of agreement, particularly for the top-performing alternatives, which underscores the reliability of the proposed IVFNS-ELECTRE-II. However, minor discrepancies were observed in the middle and lower ranks, primarily because of contradictory mathematical basis. For instance, while TOPSIS relies on distance-based measures to identify the ideal and anti-ideal solutions, CODAS incorporates a threshold-based approach to assess the relative performance of alternatives. In contrast, our solution exploits outranking relations and IVFNS to capture the inherent uncertainty, in the safety decision-making process in construction sites.

Table 2. Comparative analysis

Rank	**IVFNS-ELECTRE-II**	**IVNS-ELECTRE-I**[10]	**CODAS** [9]	**TOPSIS**[11]
1	A6	A6	A6	A6
2	A1	A1	A5	A4
3	A2	A2	A2	A1
4	A4	A4	A4	A5
5	A5	A5	A1	A2
6	A3	A3	A3	A3

5. Conclusions

This study proposed a novel IVFNS-based ELECTRE-II method for improving safety risk management in fabricated residential construction. Our framework takes advantage of both IVFNS and the ELECTRE II outranking approach to build effective solution for addressing the inherent uncertainty in the task of evaluating and prioritizing safety measures. The application of our IVFNS-based ELECTRE-II method to a real-world case study demonstrated its practicality and effectiveness in ranking construction projects based on multiple cost and benefit criteria. The proof-of-concept of comparative analysis against other decision-making methods revealed a high degree of consistency in the ranking results, while also highlighting the unique advantages of the proposed approach in handling complex and ambiguous decision environments.

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