NSS
Neutrosophic Sets and Systems, Vol. 80, 2025
University of New Mexico

Robust Seismic Performance Evaluation of Super High-Rise Concrete Structures Using MCDM and Plithogenic-RAM Approach

Kaifeng Xing[1]*, Xiaoping Wang[2], and Peng Chen[3]
[1,2,3]School of Architecture and Civil Engineering, Huangshan University, Huangshan, 245041, Anhui, China
*Corresponding author, E-mail: 13866136299@163.com

Abstract
More reinforced concrete supertall and megatall high-rise structures are being built due to the growing global demand for high-rise buildings, recent advancements in concrete technology, and improvements in construction techniques. When using concrete in these structures, additional care must be taken. Evaluating Super High-Rise Concrete Structures using various criteria is a multi-criteria decision-making (MCDM) challenge. We propose an MCDM method with a set of criteria and alternatives. The Root Assessment Method (RAM) is applied in this study to rank the alternatives. The RAM method is integrated with plithogenic sets to handle uncertain information. Plithogenic operators are used to combine the plithogenic numbers into a single matrix. Seven criteria and nine alternatives are evaluated in this study. The results indicate that the Structural Strength and Stability criterion has the highest weight, while the Non-Structural Component Performance criterion has the lowest weight. Sensitivity analysis was conducted with different criteria weights to observe variations in the rankings of alternatives. The results demonstrate that the rankings of alternatives remain stable under varying weights.

Keywords: Super High-Rise Concrete Structures; Decision Making; RAM Approach; MCDM.

1. Introduction and Background
The rapid growth of the world's population and the accelerating pace of urbanization have led to increasing population density in city centers. With limited lateral expansion available in these densely packed urban areas, cities have resorted to "urban

verticalization" as a solution to accommodate rising demands for residential, commercial, and industrial spaces. This vertical expansion has spurred the construction of taller and more complex high-rise buildings, particularly in crowded and economically thriving urban areas [1], [2]. The phenomenon of urban verticalization has not only reshaped city skylines but also posed unique challenges in structural engineering, material sciences, and construction techniques.

As high-rise buildings reach new heights, the number of supertall (300–600 meters) and megatall (600 meters and above) structures has also seen a dramatic increase. For instance, only three supertall buildings were completed in 2009; by contrast, thirteen supertall buildings were expected to be completed in a single year, signaling a significant upward trend. This growth trajectory continued, and by 2020, projections indicated the completion of 18 supertall structures and three megatall buildings [3], [4]. These developments highlight the critical importance of advancing construction technologies and materials to meet the demands of modern skyscrapers.

One of the foundational elements enabling the construction of these colossal structures is high-performance concrete (HPC). HPC has become indispensable due to its unique properties, such as enhanced strength, stiffness, pumpability, and early-age strength. These attributes make HPC especially suited for supertall and megatall buildings, where structural integrity and economic feasibility are paramount [5], [6]. Additionally, advancements in prefabricated reinforcement cages and slip-and-climb-form work technology have revolutionized the construction process, allowing builders to achieve remarkable speeds of two to three floors per week without compromising safety or quality. These innovations have positioned reinforced concrete (RC) as a competitive alternative to structural steel in terms of both speed and economic efficiency [7], [8].

However, while HPC and RC offer significant advantages, they also demand meticulous attention to design, construction practices, and material selection. The use of concrete in supertall and megatall buildings introduces several challenges. These include ensuring mix design precision, meeting stringent performance criteria, and addressing construction-related issues such as thermal effects, shrinkage, and creep [9], [10]. Furthermore, the dynamic characteristics of these buildings, such as their response to seismic loads and wind-induced vibrations, necessitate advanced engineering solutions to ensure their safety and resilience.

1.1 The Role of Seismic Performance Evaluation

The evaluation of seismic performance has emerged as a critical aspect of designing super high-rise concrete structures. Given their height and mass, these buildings are particularly susceptible to seismic forces, making it imperative to assess their structural integrity under such conditions. Seismic performance evaluation not only ensures the safety of occupants but also protects significant financial investments in these structures. Modern engineering approaches emphasize a multi-criteria decision-making (MCDM) framework to address the complex interplay of factors influencing seismic performance. This methodology allows for the consideration of diverse criteria such as structural strength, ductility, energy dissipation, and material quality, ensuring a comprehensive assessment of a building's seismic resilience [11], [12].

1.2 MCDM Methodology

Because of the complexity of real-world challenges, decision-making in construction and seismic evaluation often involves conflicting criteria. Multi-criteria decision-making (MCDM) provides a systematic framework to address these issues by breaking down complex problems into smaller, manageable parts that are easier to evaluate. The foundations of MCDM trace back to the 1950s and 1960s, with significant advancements in the 1970s, including the formal introduction of the acronym "MCDM"[13], [14].

MCDM methodologies enable decision-makers to weigh various criteria—often conflicting—to arrive at the best possible solution. Among the many MCDM techniques, the use of plithogenic sets has gained prominence. Plithogenic sets allow the integration of vague, uncertain, and contradictory information, making them particularly suitable for evaluating complex systems like super high-rise structures [15], [16].

Importance of High-Performance Concrete in Super High-Rise Buildings

High-performance concrete has become the material of choice for constructing super high-rise buildings due to its superior mechanical properties and versatility. Its high compressive strength ensures that structural components can support the enormous vertical loads typical of tall buildings. Additionally, its enhanced durability minimizes maintenance requirements, making it a cost-effective solution over the building's lifecycle. The use of HPC also allows for slender and lightweight designs, which are critical for optimizing the usable floor area in high-rise buildings without compromising structural stability [5], [6].

Moreover, innovations in HPC technology have addressed many of the challenges associated with traditional concrete. For example, the addition of supplementary cementitious materials (SCMs) such as fly ash and silica fumes improves workability and reduces the heat of hydration, mitigating the risk of thermal cracking during the curing process. These advancements are particularly crucial for megatall structures, where the sheer volume of concrete used can exacerbate thermal and shrinkage-related issues [9], [10].

1.3 Challenges and Innovations in High-Rise Construction

The construction of super high-rise buildings involves overcoming numerous engineering and logistical challenges. One of the primary difficulties lies in ensuring redundancy and load path continuity, which are essential for preventing progressive collapse in the event of localized failures. This requires careful consideration of structural redundancy during the design phase, as well as rigorous quality control during construction to ensure the consistent performance of all structural components[15], [16].

In addition, the interaction between a building's foundation and the supporting soil presents significant challenges, particularly in seismic zones. Advanced geotechnical analyses are required to model the behavior of the foundation-soil system under dynamic loading conditions. These analyses help optimize foundation designs to ensure stability and minimize settlement under seismic forces. Furthermore, the integration of damping systems and tuned mass dampers has proven effective in mitigating the effects of seismic and wind-induced vibrations, enhancing both structural safety and occupant comfort [17], [18].

1.4 Advancing Decision-Making for Seismic Performance

To address the complex demands of seismic performance evaluation, this study employs the Root Assessment Method (RAM) under a plithogenic framework. By combining advanced mathematical tools with expert assessments, the RAM approach provides a comprehensive evaluation of alternatives based on multiple criteria. The use of plithogenic operators allows for the aggregation of uncertain and contradictory information, enabling more accurate and reliable rankings of super high-rise concrete structures. This methodology ensures that critical factors such as structural strength, material quality, and dynamic characteristics are thoroughly considered, providing valuable insights for designers, engineers, and policymakers [19].

1.5 Aim of this study

The aim of this study is organized as follows:

a) We proposed a MCDM methodology for evaluating the Super High-Rise Concrete Structures with a set of criteria and alternatives.
b) The RAM method is used under the plithogenic numbers for the first time to rank the alternatives.
c) We used the plithogenic operators to combine the different plithogenic numbers into one matrix.
d) We performed sensitivity analysis to show the stability of the rank of alternatives with different criteria weights.

1.6 Organization of this study

The rest of this study is organized as follows: Section 2 shows the materials and methods. Section 3 shows the application results. Section 4 shows the discussion of these results. Section 5 shows the conclusions of this study.

2. Materials and Methods

This part presents the steps of the proposed methodology with a set of experts, criteria and alternatives. We use the RAM methodology to rank the alternatives. Figure 1 shows the details of the RAM method under the plithogenic.

2.1 Plithogenic RAM

Plithogeny is the emergence, formation, growth, and evolution of new things from the synthesis of contradictory (dissimilar) or non-contradictory many ancient entities. A set that has multiple members specified by a variety of qualities, each of which has a value, is called a plithogenic set[15], [16], [17]. The RAM approach will be improved in this work by utilizing plithogenic aggregation operators, which are a subset of the plithogenic set, in order to reduce information loss. The Plithogenic RAM approach can be applied in collaborative decision-making scenarios without compromising information, in contrast to the conventional RAM method[18], [19]. The steps of the Plithogenic RAM technique are shown below.

1) Build the decision matrix.

   Suppose an MCDM issue has a set of alternatives $m; A_i (i = 1,2, \dots, m)$ and a set of criteria $n; C_j (j = 1,2, \dots, n)$. These criteria and alternatives are evaluated by the opinions of experts.

2) Replace opinions of experts with the plithogenic numbers. The plithogenic numbers have three parts to reduce the uncertainty and vague information.

3) Combine the decision matrix.

   We combine the plithogenic numbers into one matrix instead of different matrices as:

$$((b_{i1}, b_{i2}, b_{i3}), 1 \leq i \leq n) \wedge P((t_{i1}, t_{i2}, t_{i3}), 1 \leq i \leq n)$$
$$= (b_{i1} \wedge_F t_{i1}, 0.5 * (b_{i2} \wedge_F t_{i2}) + 0.5 * (b_{i2} \vee_F t_{i2}), b_{i3} \vee_F t_{i3}), 1 \leq i \leq n$$

4) Crip values are obtained from the combined matrix. Then the criteria weights by normalized crisp values.
5) Normalize the decision matrix.

   The crisp values in combined decision matrix are normalized by linear sum normalization as:

$$y_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}}; (i = 1, \dots, m; j = 1, \dots, n)$$

6) Compute the weighted decision matrix as:

$$u_{ij} = y_{ij} w_{ij}$$

7) Compute the sum of weighted normalized matrix for beneficial and non-beneficial criteria such as:

$$q_{+i} = \sum_{j=1}^{n} u_{+ij}$$
$$q_{-i} = \sum_{j=1}^{n} u_{-ij}$$

8) Compute the overall score of every alternative as:

$$S_i = \sqrt[2+q_{-i}]{2 + q_{+i}}$$

9) Rank the alternatives.

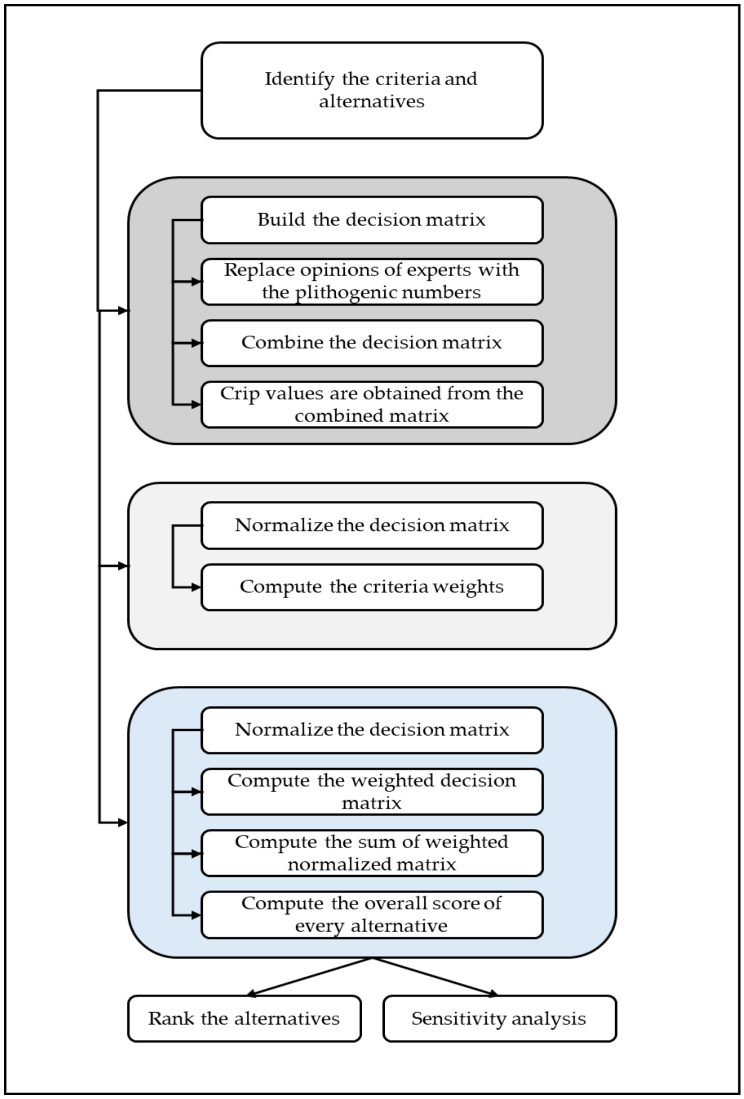

Figure 1. The details of plithogenic RAM approach.

3. Application

Experts have been selected for this consultancy based on their proficiency in the many Super High-Rise Concrete Structures domains and fields they are working in. First, the consulting firm recommended 3 professionals with years of experience in the Super High-Rise Concrete Structures industry. Thus, there are 3 specialists in this study. Expert 1 is a general manager with twenty years of Super High-Rise Concrete Structures experience. The second expert is a consultant. In addition, he has 22 years of Super High-Rise Concrete Structures experience and a doctorate. Expert 3 has 12 years of experience in the Super High-Rise Concrete Structures industry and is an associate professor. The literature review has established the study's criteria. An academician who was an associate professor later devised the approach. The other members of the consulting firm also talked about the sessions. The literature's criteria were reviewed, and additional criteria were introduced and eliminated. A criteria expert consultant broke down the criteria into their component elements during the criterion-setting process. Furthermore, a thorough analysis of the distance functions was used to construct the criterion. Seven criteria and nine alternatives are evaluated by three experts in this study.

3.1 Explanation of Steps

1. Building the Decision Matrix

The first step involved constructing a decision matrix based on the assessments provided by three experts. These experts evaluated nine alternatives across seven criteria. Each expert's evaluations were recorded, capturing their opinions about the importance and performance of alternatives for each criterion. The criteria included factors such as Structural Strength and Stability (C4) and Material Quality and Properties (C2), which are critical for evaluating super high-rise concrete structures.

The decision matrix represents a structured format where the rows correspond to the alternatives (A1, A2, …, A9), and the columns represent the criteria (C1, C2, …, C7). This matrix serves as the foundation for subsequent calculations and analysis.

2. Replacing Expert Opinions with Plithogenic Numbers

To account for vagueness and uncertainty in the experts' opinions, their evaluations were transformed into plithogenic numbers. A plithogenic number includes three components: truth-membership, indeterminacy-membership, and falsity-membership. This representation enhances the reliability of the evaluation by capturing nuanced and uncertain information. Tables 1–3 illustrate the plithogenic numbers corresponding to each expert's evaluations.

These tables display how each expert's qualitative and uncertain evaluations are quantified and integrated into the decision matrix. For example, for A1 under C1, Expert 1's evaluation might be expressed as (0.65,0.30,0.45), where:

0.65 represents the truth-membership (degree of agreement with the evaluation).

0.30 indicates the indeterminacy-membership (uncertainty in the evaluation).

0.45 reflects the falsity-membership (degree of disagreement).

Table 1. Expert 1 opinions.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.25, 0.60, 0.80)	(0.65, 0.30, 0.45)
A_2	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)
A_3	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)
A_4	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)
A_5	(0.65, 0.30, 0.45)	(0.25, 0.60, 0.80)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)
A_6	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)
A_7	(0.25, 0.60, 0.80)	(0.50, 0.40, 0.60)	(0.25, 0.60, 0.80)	(0.65, 0.30, 0.45)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)
A_8	(0.10, 0.75, 0.85)	(0.40, 0.70, 0.50)	(0.80, 0.10, 0.30)	(0.25, 0.60, 0.80)	(0.65, 0.30, 0.45)	(0.25, 0.60, 0.80)	(0.65, 0.30, 0.45)
A_9	(0.95, 0.05, 0.05)	(0.25, 0.60, 0.80)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.25, 0.60, 0.80)

Table 2. Expert 2 opinions.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	(0.10, 0.75, 0.85)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.10, 0.75, 0.85)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)
A_2	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.10, 0.75, 0.85)
A_3	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.65, 0.30, 0.45)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.25, 0.60, 0.80)
A_4	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)
A_5	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)
A_6	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)
A_7	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.25, 0.60, 0.80)
A_8	(0.10, 0.75, 0.85)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)
A_9	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)

Table 3. Expert 3 opinions.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)
A_2	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)
A_3	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)
A_4	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)
A_5	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)	(0.95, 0.05, 0.05)

A_6	(0.40, 0.70, 0.50)	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)
A_7	(0.25, 0.60, 0.80)	(0.50, 0.40, 0.60)	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)
A_8	(0.10, 0.75, 0.85)	(0.40, 0.70, 0.50)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)
A_9	(0.95, 0.05, 0.05)	(0.25, 0.60, 0.80)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)

3. Combining the Plithogenic Numbers into a Single Matrix

After gathering the expert evaluations and representing them as plithogenic numbers (as shown in Tables 1–3), the next step is to aggregate these numbers into a single decision matrix. This step involves combining the opinions of all three experts for each alternative and criterion to form a unified representation.

The aggregation process employs plithogenic operators that effectively handle the inherent vagueness and uncertainty in the data. These operators consider the truth-membership, indeterminacy-membership, and falsity-membership values for each evaluation, synthesizing them into a consolidated matrix. For A1 under C1, if the three experts provided plithogenic evaluations as follows:

Expert 1: (0.65,0.30,0.45); Expert 2: (0.50,0.40,0.60); Expert 3: (0.40,0.70,0.50)

The combined value is calculated using the plithogenic aggregation formula to produce a single plithogenic number for A1 under C1.

This step results in a combined decision matrix that consolidates the opinions of all experts, enabling a cohesive analysis across all alternatives and criteria.

4. Computing the Criteria Weights

After forming the combined decision matrix, the next step is to calculate the criteria's weights. These weights represent the relative importance of each criterion in the decision-making process and are derived using normalized crisp values obtained from the combined matrix.

The process involves the following steps:

1) The plithogenic numbers are converted into crisp values using a score function, which combines the truth-membership, indeterminacy-membership, and falsity-membership values into a single representative score.
2) The crisp values are normalized across all criteria to ensure comparability. This involves dividing each value by the sum of all values in the column for a specific criterion.

The normalized values are then used to calculate the weights for each criterion. These weights reflect how influential each criterion is in determining the overall ranking of alternatives. If the normalized crisp values for C1, C2, and C3 are 0.1305, 0.1357, and 0.1542, the corresponding weights are directly proportional to these values. In Table 4, Structural Strength and Stability (C4) has the highest weight, indicating its critical importance in evaluating super high-rise concrete structures, while Non-Structural Component Performance (C7) has the lowest weight.

Table 4. The weights of criteria.

	Criteria	*Weights*	*Rank*
C_1	Redundancy and Load Path Continuity: Presence of alternative load paths to prevent collapse.	0.130499	2
C_2	Material Quality and Properties: Quality and strength of materials used in construction.	0.135653	3
C_3	Ductility and Energy Dissipation: Deformation and energy absorption capacity during seismic events.	0.154226	6
C_4	Structural Strength and Stability: Ability to withstand seismic forces without failure.	0.156862	7
C_5	Foundation and Soil Interaction: Stability of foundation-soil interaction under seismic loading.	0.152752	5
C_6	Dynamic Characteristics: Compatibility with seismic wave frequencies and damping properties.	0.140183	4
C_7	Non-Structural Component Performance: Resilience of secondary components like cladding and utilities.	0.129827	1

5. Normalizing the Decision Matrix

After aggregating the plithogenic numbers into a single matrix and extracting the crisp values, the next step is to normalize the decision matrix. This step ensures that all criteria values are scaled to a comparable range, typically between 0 and 1, facilitating an unbiased evaluation of alternatives across different criteria. The normalized decision matrix presented in Table 5 reflects the relative performance of each alternative under each criterion. By transforming all values into a comparable scale, normalization eliminates the influence of differing units or magnitudes among criteria. This ensures that each criterion contributes proportionally to the overall evaluation.

Table 5. The normalization matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.100132	0.091799	0.105366	0.126883	0.116745	0.059903	0.116584
A_2	0.11012	0.096328	0.085288	0.079387	0.106383	0.125921	0.11069
A_3	0.166104	0.105936	0.074114	0.126883	0.098339	0.102512	0.124728
A_4	0.090157	0.159793	0.132449	0.072869	0.12759	0.107156	0.122802
A_5	0.155843	0.086731	0.090626	0.130223	0.07483	0.159159	0.180843
A_6	0.095424	0.149922	0.110446	0.089103	0.093745	0.130326	0.055504
A_7	0.064348	0.110945	0.115701	0.10859	0.106009	0.081992	0.064681
A_8	0.027244	0.101582	0.133777	0.113757	0.130297	0.091052	0.116584
A_9	0.190629	0.096965	0.152233	0.152306	0.146063	0.141979	0.107584

6. Weighted Normalized Decision Matrix

Once the normalized decision matrix is constructed (Table 5), the criteria weights from Table 4 are applied to compute the weighted normalized decision matrix. This step incorporates the relative importance of each criterion into the evaluation process, ensuring that criteria with higher weights have a greater influence on the rankings.

The weighted normalized value for each alternative is computed using the formula:

$$u_{ij} = y_{ij} w_j$$

Where:

u_{ij}: Weighted normalized value of alternative i under criterion j.

w_j: Weight of criterion j from Table 4.

y_{ij}: Normalized value of alternative iii under criterion j from Table 5.

For C1, with N11=0.684 and w1=0.1305, the weighted normalized value for A1 =0.0893

This calculation is repeated for all criteria and alternatives, producing the weighted normalized matrix shown in Table 6.

Table 6. The weighted normalized decision.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.014986	0.012615	0.015941	0.018925	0.015722	0.007809	0.017189
A_2	0.01648	0.013238	0.012903	0.011841	0.014327	0.016416	0.01632
A_3	0.024859	0.014558	0.011213	0.018925	0.013244	0.013364	0.01839
A_4	0.013493	0.021959	0.020038	0.010868	0.017183	0.013969	0.018106
A_5	0.023323	0.011919	0.013711	0.019423	0.010078	0.020749	0.026664
A_6	0.014281	0.020603	0.016709	0.01329	0.012625	0.01699	0.008184
A_7	0.00963	0.015246	0.017504	0.016196	0.014277	0.010689	0.009537
A_8	0.004077	0.01396	0.020239	0.016967	0.017548	0.01187	0.017189
A_9	0.028529	0.013325	0.023031	0.022717	0.019671	0.018509	0.015862

Table 7. Rank of alternatives.

	Overall score	Rank
A_1	4.408966	4
A_2	4.400375	2
A_3	4.447561	6
A_4	4.463445	7
A_5	4.497974	8
A_6	4.407523	3
A_7	4.371552	1
A_8	4.413962	5
A_9	4.561589	9

7. Computing the Sum of Weighted Normalized Matrix

The sum of the weighted normalized values for each alternative is calculated to assess its overall performance under both beneficial and non-beneficial criteria.

Sum for Beneficial Criteria:

$$q_i^+ = \sum_{j=1}^{n} u_{+ij}$$

Sum for Non-Beneficial Criteria:

$$q_i^- = \sum_{j=1}^{n} u_{-ij}$$

For A1, If the weighted normalized values for beneficial criteria are 0.0893,0.1256,0.0921, then: q_1^+ = 0.0893+0.1256+0.0921= 0.307

For non-beneficial criteria, if the weighted normalized values are 0.0651, 0.0754, then: q_1^- = 0.0651+0.0754= 0.1405

8. Computing the Overall Score

The overall score for each alternative is calculated by dividing the sum of weighted values for beneficial criteria by the sum of weighted values for non-beneficial criteria:

$S_i = \sqrt[2+q_{-i}]{2+q_{+i}}$ For A1, S_1=2.186

9. Ranking the Alternatives

Once the overall scores (S_i) are calculated for all alternatives, they are ranked in descending order. The alternative with the highest score is ranked first, as it performs closest to the ideal solution. The alternative with the lowest score is ranked last. From Table 7, alternative 9 got the highest overall score and is ranked first and alternative 7, the lowest overall score and is ranked last.

4. Discussion

In this study, three experts evaluated seven criteria and nine alternatives using the RAM method. The experts' opinions were expressed as plithogenic numbers, which were combined into a single matrix using plithogenic operators. The resulting matrix was converted into crisp values using a score function. These values were normalized to calculate the criteria weights, where Structural Strength and Stability had the highest weight, while Non-Structural Component Performance had the lowest weight.

The RAM method was then applied to rank the alternatives. The results showed that Alternative 9 ranked the highest, while Alternative 7 ranked the lowest. To ensure the robustness of the rankings, a sensitivity analysis was conducted by adjusting the criteria weights by 25%. This analysis, depicted in Figure 2, demonstrated that the rankings of alternatives remained stable across different scenarios.

The results of the sensitivity analysis and the rankings are summarized in Table 8, confirming the reliability of the RAM method in evaluating super high-rise concrete structures.

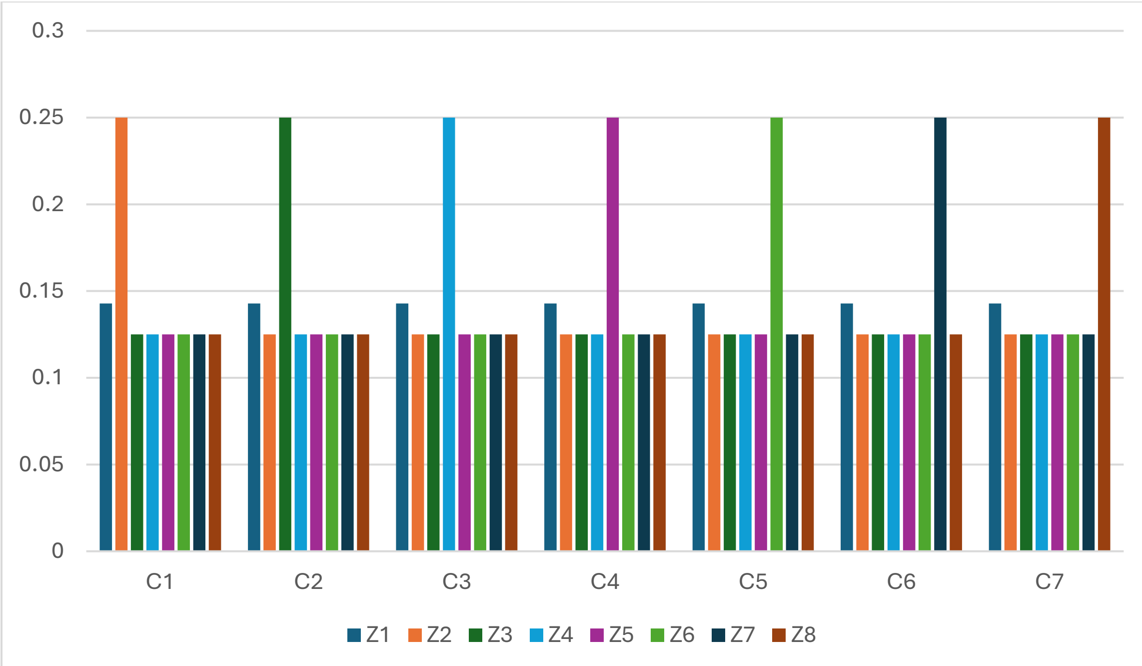

Figure 2. The different criteria weights.

Table 8. The different rank of alternatives.

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8
A_1	3	3	3	3	4	4	2	4
A_2	2	4	2	2	2	2	4	3
A_3	6	7	6	5	7	6	6	6
A_4	7	6	8	7	6	8	7	7
A_5	8	8	7	8	8	7	8	8
A_6	4	5	5	4	3	3	5	2
A_7	1	1	1	1	1	1	1	1
A_8	5	2	4	6	5	5	3	5
A_9	9	9	9	9	9	9	9	9

5. Conclusions

This work proposed a MCDM methodology to rank the Super High-Rise Concrete Structures with a set of criteria. Three experts are invited to evaluate the criteria and alternatives. they used the plithogenic numbers in their evaluation. Then we combine these numbers by the plithogenic operators. The criteria weights are computed using the normalized crisp values. Then we applied the steps of the RAM method to rank the alternatives. Seven criteria and nine alternatives are evaluated in this study. The results show the alternative 9 is the best and alternative 7 is the worst. We conducted the sensitivity analysis to show the rank of alternatives. The results show that the rank of alternatives is stable under different weights.

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Received: Oct 7, 2024. Accepted: Jan 13, 2025