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

Comprehensive Evaluation of Green Construction in Building Projects Using an Integrated MCDM and Plithogenic Set Approach

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Abstract: Green construction aims to minimize the overall negative impact of the built environment on both human health and the environment by efficiently using energy, water, and other resources. It helps reduce waste, pollution, and environmental impact while enhancing worker productivity and protecting occupant health. This study introduces a multi-criteria decision-making (MCDM) approach to evaluate green construction in building projects. The MCDM approach is integrated into the plithogenic set framework to address uncertainty and vague information. The simple additive weighting (SAW) method is employed to rank the alternatives. Three experts evaluated nine criteria and eight alternatives to determine the criteria weights and rank the alternatives. Sensitivity analysis was conducted to assess the stability of the rankings, with results showing that the ranks of the alternatives remain stable under varying criteria weights.

Keywords: Sustainability; Green construction; building projects; Decision-making; MCDM Approach.

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1. Introduction

Depending on the expert, different people have different ideas about green building. It denotes clean construction made of natural materials for eco-builders. They believe that a building's ability to accommodate people must come first, with the welfare of its residents serving as its most valuable asset. These proponents of green building denounce the industrial production of building materials using hazardous ingredients. Using cutting-edge technologies, energy conservation experts seek to minimize the adverse environmental effects of human habitation and lower the energy consumption of homes, buildings, and flats. They advise using cutting-edge building methods and improved thermal insulation. Eco-builders take a building's lifespan into account. In addition to including energy conservation, they also examine the source of the materials[1], [2].

Eco-construction, sometimes known as green building or sustainable construction, suggests several ways to lessen the influence that buildings have on the environment. Green building is not a single construction methodology; rather, it is a collection of methods, materials, and technologies that, when properly applied to a project, help to improve its environmental performance[3], [4]. In a perfect scenario, eco-construction maximizes the use of recyclable, non-toxic, and recycled materials while minimizing water usage and energy consumption. Additionally, it produces as little waste as feasible both during building and after it is occupied[5], [6].

The procedures used to create the structural elements of a green building are resource-efficient and environmentally conscious. This approach is becoming more popular and supports the traditional goals of creating comfortable, sustainable, and energy-efficient buildings. A green building is a sustainable, clean structure that is easy to maintain, made of natural materials, uses little energy—and renewable energy—and is reasonably priced [7].

A green building can effectively use sustainable materials (recycled, recyclable, repurposed, or derived from renewable resources) in its construction, provide a healthy interior environment with minimal pollutants, and have a water-efficient landscape design that uses native vegetation that grows well without extra watering[7], [8]. Evaluating green construction is a multi-criteria decision-making (MCDM) approach. However the evaluation of this problem contains uncertainty.

Uncertain, ambiguous, and incomplete information is a flaw that can result in a less-than-ideal choice, as is the case with many assessments and decision-making issues. Therefore, more accurate evaluation findings should be obtained by combining the plithogenic set with the triple components of the neutrosophic set (truth-membership, falsity-membership, and indeterminacy-membership). Plithogenic sets improve decision-making efficiency and accuracy. Smarandache developed plithogeny, which is a generalization of neutrosophy[9], [10].

The plithogenic set is a collection of elements where each element x is distinguished by an appurtenance degree d(x, v) of element x to the plithogenic set and attribute values v that have a matching contradiction degree c(v, D) between them and a dominant attribute value D[11], [12].

MCDM focuses on organizing and resolving planning and decision-making issues that involve several criteria. Some prevalent features of MCDM difficulties include the existence of disparate alternatives, multiple non-commensurable and competing criteria, and differing units of measurement among the criteria. The MCDM problem's criteria can all be divided into two groups. Benefit criteria are those that should be maximized. On the other hand, the cost criteria group includes factors that should be minimized. An example of an MCDM problem with m alternatives[13], [14].

The most straightforward, well-known, and widely applied MCDM technique is most likely the SAW approach. The weighted total of all attribute values determines a candidate solution's overall score in SAW. The three main processes of the SAW technique are determining the overall score for each alternative, assigning the weight vector W, and normalizing the decision matrix X[15].

2. Methods

In this work, the MCDM approach is applied to compute the criteria weights and rank the alternatives. The MCDM approach is applied under the plithogenic sets. The plithogenic set is used to solve the uncertainty in the MCDM approach to evaluate the alternatives.

2.1 Basic concepts of the plithogenic set

Plithogeny is a generalization of neutrosophy established by Smarandache that refers to the creation, improvement, and advancement of new items from syntheses of competing or nonconflicting multiple old ones. Plithogenic intersection (∧p), plithogenic union (∨p), plithogenic complement (¬p), plithogenic inclusion (→), and plithogenic equality (↔) are the operations on plithogenic sets[16], [17].

Because of its two primary characteristics, the degree of appurtenance and the degree of contradiction, the plithogenic set offers a high consideration of information uncertainty to produce more accurate findings. Each attribute value is distinguished from the dominant (most desired) attribute value using the contradiction (dissimilarity) degree function c(v,D). The following axioms are maintained by the attribute value contradiction degree function c(v1, v2), which is c: V×V → [0, 1][18], [19].

Let two plithogenic numbers such as $a = (a_1, a_2, a_3)$ and $b = (b_1, b_2, b_3)$ and plithogenic operators can be computed as:

$$\left((a_{i1}, a_{i2}, a_{i3}), 1 \le i \le n\right) \wedge p \left((b_{i1}, b_{i2}, b_{i3}), 1 \le i \le n\right)$$

$$= \left(\left(a_{i1} \wedge_F b_{i1}, 0.5 * (a_{i2} \wedge_F b_{i2}) + 0.5(a_{i2} \vee_F b_{i2}), a_{i3} \vee_F b_{i3}\right)\right), 1 \le i < n$$

$$\left((a_{i1}, a_{i2}, a_{i3}), 1 \le i \le n\right) \vee p \left((b_{i1}, b_{i2}, b_{i3}), 1 \le i \le n\right)$$

$$= \left(\left(a_{i1} \vee_F b_{i1}, 0.5 * (a_{i2} \wedge_F b_{i2}) + 0.5(a_{i2} \vee_F b_{i2}), a_{i3} \wedge_F b_{i3}\right)\right), 1 \le i < n$$

2.2 SAW Approach

SAW is the MCDM approach and the simplest approach. The overall score can be computed by the weighted normalized matrix. The SAW approach has three main stages:

normalizing the decision matrix, assigning the weight vector, and computing the overall score[15]. The steps of the SAW approach are detailed such as:

Step 1. Build the decision matrix.

The decision matrix is constructed between the criteria and alternatives by the opinions of experts.

Step 2. Normalize the decision matrix.

A normalization process should be used to convert the original data into equivalent values. Many different normalizing algorithms have been devised for the SAW approach. The most used normalizing technique is most likely the Max approach. It is necessary to convert cost criteria into benefit criteria during normalization. The following is the normalization process:

$$r_{ij} = \frac{x_{ij}}{\max x_{ij}}$$

$$r_{ij} = \frac{\min x_{ij}}{x_{ij}}$$

Step 3. Assign weight to each criterion.

Step 4. Compute the final rank.

$$S_i = \sum_{j=}^{n} w_j x_{ij}$$

Where r_{ij} is the ith alternative's normalized performance concerning the jth criterion, wj is the weight of the jth criterion, and Si is the ith alternative's ranking score. The ranking score Si in the SAW method indicates the overall performance of the ith alternative, and the option with the highest Si value is the one that is rated highest.

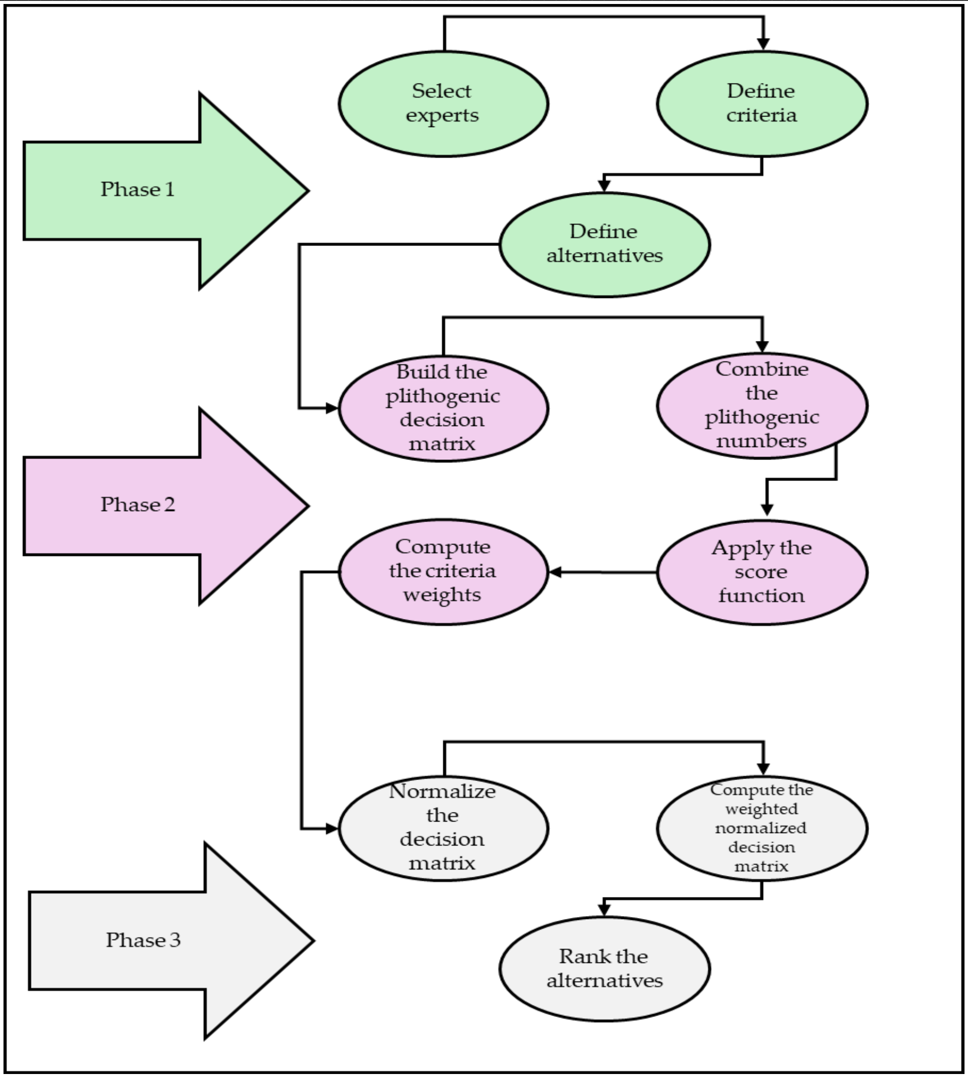

Figure 1. Phases of proposed method.

3. Proposed Framework

This study proposed a combined framework to evaluate the performance of Green Construction in building projects under the uncertainty environment. We compute the criteria weights to affect the rank of alternatives. Then we applied the SAW approach to rank the alternatives.

This strategy is crucial for managing the significant degree of uncertainty brought on by the lack of subject-matter expertise. By considering the truth-membership function, falsity-membership function, and indeterminacy-membership function, Plithogenic makes it effective at managing ambiguous judgments. Furthermore, the plithogenic set operations' properties yield more precise outcomes. To provide a more accurate assessment, this framework makes use of the benefits of the SAW technique and plithogenic set operation. The steps of the suggested framework are shown in Figure 1 and explained below:

Phase 1: A panel of decision makers is established to obtain valuable information on evaluation issues. We define a set of criteria to measure the performance of Green Construction in building projects and the alternatives to evaluate a set of projects.

In this study, the proposed approach examines the performance of Green Construction in building projects based on nine criteria and eight alternatives as shown in Figure 2.

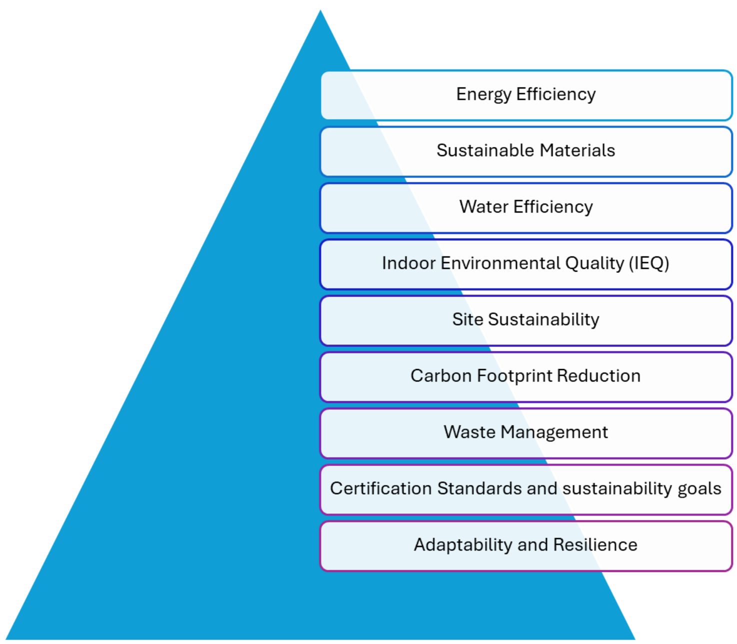

Figure 2. Assessment criteria of Green Construction in building projects.

Phase 2: Compute the criteria weights.

- Step 1. Build the plithogenic decision matrix between the criteria. Experts use the plithogenic terms to evaluate the criteria and alternatives.

- Step 2. Combine the plithogenic numbers into one matrix using the plithogenic operators.
- Step 3. Apply the score function to obtain the crisp values between the criteria and alternatives.
- Step 4. Compute the criteria weights by normalizing the crisp values.

Phase 3: rank the alternatives using the SAW approach.

- Step 1: Normalize the decision matrix between the criteria and alternatives.
- Step 2: Compute the weighted normalized decision matrix.
- Step 3: Rank the alternatives.

4. Case Study

The comprehensive evaluation of green construction in building projects focuses on assessing the overall implementation of sustainable practices during the construction process. It aims to ensure that the project aligns with environmental protection goals, resource efficiency, and sustainable development principles. Green construction emphasizes reducing environmental impact, promoting innovation, and adopting energy-saving technologies to create environmentally friendly and efficient construction processes. This evaluation serves as a systematic approach to reviewing the integration of green practices, ensuring the project meets sustainability requirements. It highlights the importance of minimizing waste, conserving natural resources, and protecting the surrounding ecosystem. Additionally, the evaluation encourages the adoption of advanced construction methods and technologies that align with long-term environmental and economic goals. By conducting a comprehensive evaluation, stakeholders can ensure that green construction principles are effectively implemented, contributing to sustainable urban development and eco-friendly building practices. The proposed approach based on plithogenic set is used to measure the green construction in building projects performance. The evaluation matrix is obtained by three experts and decision-makers.

Phase 1: The performance of Green Construction in building projects is based on nine criteria and eight alternatives. Evaluate eight projects based on their performance.

Phase 2: To compute the criteria weights, three experts have evaluated the criteria and alternatives. Then we evaluate these criteria and alternatives using the plithogenic numbers as shown in Table 1. Then we combine these numbers using the plithogenic operators. Then we apply the score function to obtain crisp values. Then we compute the criteria weights as shown in Figure 3.

Table 1. The decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	(0.25, 0.60, 0.80)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)
A_2	(0.80, 0.10, 0.30)	(0.25, 0.60, 0.80)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.25, 0.60, 0.80)	(0.25, 0.60, 0.80)	(0.80, 0.10, 0.30)	(0.25, 0.60, 0.80)
A_3	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.25, 0.60, 0.80)	(0.50, 0.40, 0.60)	(0.25, 0.60, 0.80)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)
A_4	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.25, 0.60, 0.80)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)
A_5	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)
A_6	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)
A_7	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(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)
A_8	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)
A_2	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)
A_3	(0.95, 0.05, 0.05)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.50, 0.40, 0.60)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)	(0.10, 0.75, 0.85)
A_4	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)
A_5	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.10, 0.75, 0.85)	(0.80, 0.10, 0.30)
A_6	(0.65, 0.30, 0.45)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)
A_7	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.40, 0.70, 0.50)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.80, 0.10, 0.30)	(0.10, 0.75, 0.85)
A_8	(0.95, 0.05, 0.05)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(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)	(0.95, 0.05, 0.05)
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.95, 0.05, 0.05)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)
A_2	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.80, 0.10, 0.30)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.65, 0.30, 0.45)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)
A_3	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)	(0.80, 0.10, 0.30)
A_4	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.65, 0.30, 0.45)
A_5	(0.40, 0.70, 0.50)	(0.65, 0.30, 0.45)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)
A_6	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)
A_7	(0.80, 0.10, 0.30)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)	(0.50, 0.40, 0.60)
A_8	(0.95, 0.05, 0.05)	(0.50, 0.40, 0.60)	(0.50, 0.40, 0.60)	(0.40, 0.70, 0.50)	(0.25, 0.60, 0.80)	(0.10, 0.75, 0.85)	(0.95, 0.05, 0.05)	(0.40, 0.70, 0.50)	(0.40, 0.70, 0.50)

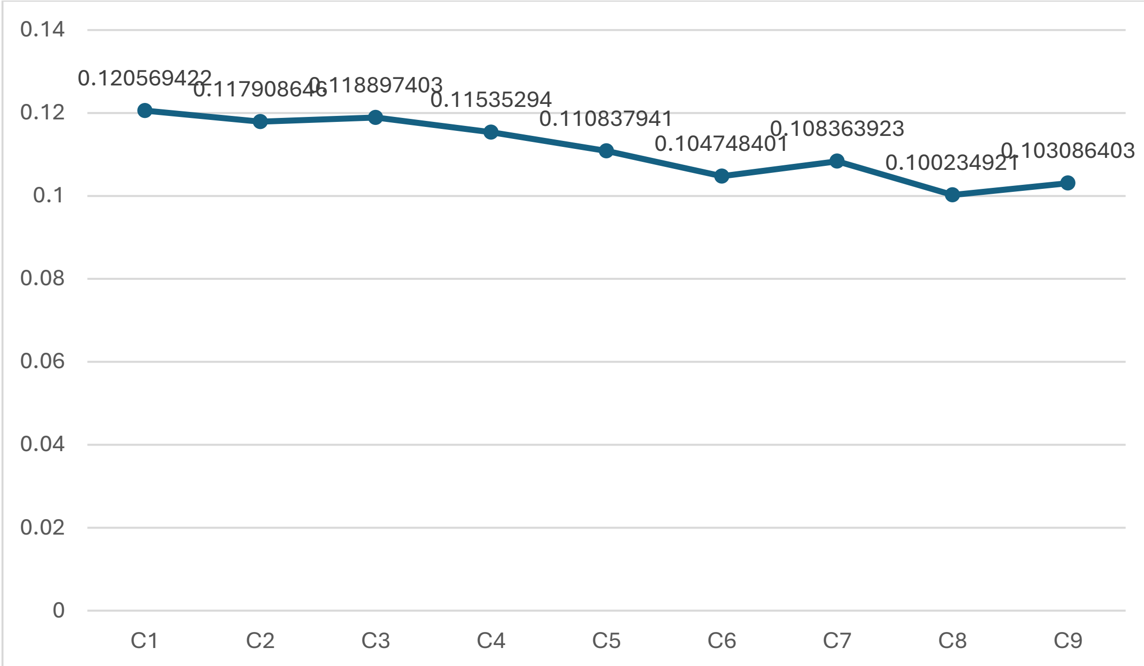

Figure 3. The criteria weights.

Phase 3: In this study, we used the SAW approach to rank the alternatives. We normalize the decision matrix between the criteria and alternatives as shown in Table 2. Then we compute the weighted normalized decision matrix. Then we compute the overall score values for each alternative as shown in Table 3.

Table 2. Normalization matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.744448	0.958415	1	1	0.870142	0.692136	0.530394	0.375488	0.150534
A_2	0.609572	0.416999	0.947288	0.844584	0.770544	0.58486	0.49574	0.577873	0.952107
A_3	0.874474	0.926567	0.744448	0.689572	0.734245	0.889986	0.926635	0.712359	0.721315
A_4	0.898979	0.926635	0.609572	0.676368	0.611119	0.926635	0.595375	1	1
A_5	0.741959	0.902123	0.874474	0.643492	1	0.628981	1	0.660325	0.946898
A_6	0.517645	1	0.898979	0.923134	0.933336	1	0.909291	0.742954	0.903912
A_7	0.947288	0.6303	0.676803	0.905922	0.942983	0.6303	0.6303	0.86626	0.352625
A_8	1	0.802556	0.494959	0.714464	0.47078	0.478109	0.944536	0.922553	0.677153

Table 3. The rank of alternatives.

	Score	Rank
A_1	0.716589	2
A_2	0.68918	1
A_3	0.803524	6
A_4	0.800782	5
A_5	0.822914	7
A_6	0.868076	8
A_7	0.735526	4
A_8	0.723355	3

To show the stability of the proposed approach we performed the sensitivity analysis by changing criteria weights and then ranking the alternatives. We proposed ten cases in changing the criteria weights as shown in Figure 4. Then we apply the SAW approach to these ten cases. Then we rank the alternatives based on these cases as shown in Table 4. The results show that alternative 6 is the best and alternative 2 is the worst.

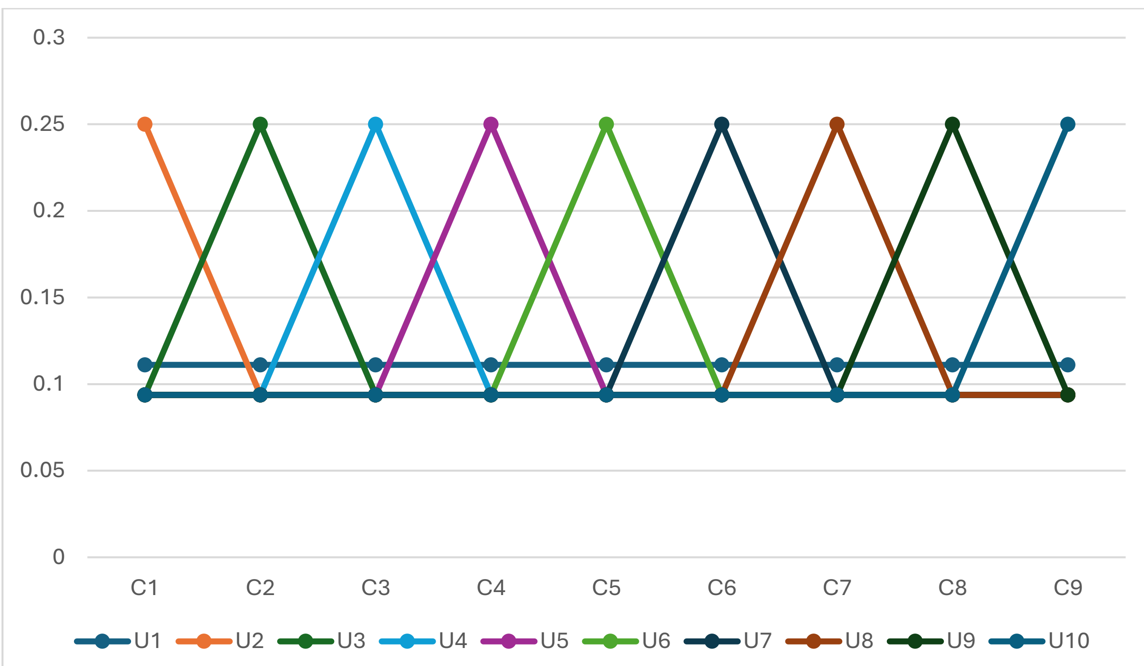

Figure 4. The change in criteria weights.

Table 4. The results of sensitivity analysis.

	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}
A_1	2	2	4	4	3	3	3	2	1	1
A_2	1	1	1	3	1	2	1	1	2	4
A_3	5	6	5	6	5	6	6	6	5	5
A_4	6	8	6	5	6	5	7	5	7	6
A_5	7	5	7	7	7	7	5	7	6	7
A_6	8	7	8	8	8	8	8	8	8	8
A_7	4	3	2	2	4	4	4	3	3	2
A_8	3	4	3	1	2	1	2	4	4	3

5. Conclusions

This study uses a hybrid SAW approach to formulate the problem of performance evaluation of green construction as an MCDM. The majority of evaluation difficulties have shortcomings because there are disparate decision-makers, options, and standards. For this reason, the plithogenic set serves as the foundation for the suggested structure. The plithogenic hypothesis yields extremely accurate answers for information that is ambiguous, ambiguous, inconsistent, and lacking in real-world assessments. In the meantime, it considers each evaluation's degrees of truth, indeterminacy, and falsity.

Three experts have evaluated the criteria and alternatives. They used plithogenic numbers to evaluate the decision matrix. Eight alternatives and nine criteria are used to build the decision matrix. The SAW approach is a MCDM approach used to rank alternatives. The results show that alternative 6 is the best and alternative 2 is the worst.

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Received: Oct 3, 2024. Accepted: Jan 14, 2025