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Harmonizing Aesthetics and Sustainability through the Evaluation of Environmental Art Design in Green Architecture using the Triangular UnderNorm

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Abstract: Environmental art design has emerged as a crucial element in enhancing the aesthetic and ecological value of green architecture. This study develops a multi-criteria evaluation framework to assess the effectiveness of environmental art design within sustainable architectural spaces. By integrating both visual and environmental aspects, this framework enables a comprehensive assessment based on six carefully selected criteria and ten alternative design projects. The research contributes to bridge the gap between artistic expression and ecological responsibility in modern architectural practices. We use the RAFSI methodology to rank alternatives. The average methodology is used to compute the criteria weights. This methodology is used under the Triangular UnderNorm to deal with interval values in the decision matrix. The case study is shown to show the validation of the proposed approach. The sensitivity analysis is provided to show the stability of the ranks.

Keywords: Triangular UnderNorm; Harmonizing Aesthetics and Sustainability; Harmonizing Aesthetics and Sustainability; Green Architecture.

1. Introduction

The design of environmental art is becoming more and more important in relation to sustainable development. The need for architectural solutions that combine aesthetic appeal and ecological integrity is only increasing as urban surroundings become more complicated[1], [2]. Energy efficiency, the use of sustainable materials, and environmental harmony are all highlighted in green architecture. In this regard, environmental art is essential for raising ecological consciousness and human well-being. In green architectural projects, artistic components serve as more than just ornaments; they are means of communication that convey environmental principles and raise community awareness[3], [4]. The incorporation of ecological and artistic design aspects is frequently evaluated subjectively, despite their significance. This emphasizes the necessity of a methodical and impartial assessment framework[5], [6].

To assist architects, urban planners, and decision-makers, this study suggests a criteria-based evaluation framework for assessing the caliber of environmental art design from the standpoint of green architecture. Six essential criteria that encompass sustainability and aesthetics are adopted by the study. These are used in ten different architectural designs that are evaluated for their impact and inventiveness[7].

A comparative and scalable examination is made possible by the distinct ways that each alternative integrates environmental art into green building environments. The study supports more comprehensive and ecologically conscious urban development plans by fusing sustainable architecture with creative design[8], [9].

The most common usage of MCDM approaches is in the structuring and resolution of multi-criteria planning and decision problems. Methodologies used to address these issues are typically organized according to the steps. In the first step, needs and objectives are established to characterize the problem. The identification of decision variables is the second step. Along with the criteria that will serve as the basis for that comparison, it also covers the choice of possibilities to be contrasted[10], [11].

Step three involves choosing the best context-dependent MCDM technique, which is a needs-specific model that is only concerned with the pertinent variables and the unique situation. Data collection and tool definition (usually a test, questionnaire, rubric, etc.) are the focus of the fourth step. Data collection is necessary for step five after this tool is ready. The comparison is carried out in the last phase using the MCDM model, which yields an ordered list of options[12], [13].

This entails choosing a suitable MCDM technique, developing a data aggregation tool, and defining pertinent decision-making factors and criteria. It should be completed first because deciding on the criteria and decision variables is essential to the other activities. An efficient method for collecting data is a specially designed rubric, which makes it possible to evaluate scores objectively. Choosing the best MCDM approach guarantees that the strategy fits the issue[14].

It is first required to select the most suitable MCDM technique for Evaluating Environmental Art Design in Green Architecture, since the rubric must allow for the selected MCDM. The RAFSI technique is widely utilized in MCDM to address issues pertaining to engineering system design. By measuring its proximity to fictitious ideal solutions, this method determines the best design option. The weights of the various criteria and the value of each alternative for each criterion are the two primary kinds of data needed to implement RAFSI[15], [16].

One of the most important input parameters in multivariate decision-making is the weight of attributes. There are several methods for determining each criterion's weight. The most basic of these entails assigning subjective weights according to decision-makers' preferences while making sure the sum of the coefficients equals unity. On the other hand, there are alternatives when employing mathematical methods[17].

To calculate weighting, hybrid approaches—like the average method technique—combine mathematical principles with decision-maker inclinations. Additionally, the MCDM literature shows that algorithms from average method-based RAFSI have been widely used. Because it allows specialists to scale the value of criteria, average method typically gives a higher degree of sensitivity[18], [19].

The study chooses average method and RAFSI as appropriate MCDM techniques despite certain drawbacks, such as reliance on expert selection, because of their shown efficacy in managing complex decisions with numerous conflicting criteria in a variety of scenarios. The order of convergence to the optimal solution can be unilaterally determined by using the organized framework that average method offers for methodically weighing various factors. RAFSI enhances this by using mathematical ranking techniques to make excellent decisions and providing a simple ranking system based on how close alternatives are to optimal answers. As a result, combining these two approaches can produce more reliable and efficient results[17], [20].

To create a strong foundation for decision-making, the suggested hybridization is implemented utilizing the convergence values derived from average method as the weights in the RAFSI model. By combining many assessments and doing a thorough sensitivity analysis to examine the resilience of results against changes in criteria weights, it also reduces inherent subjectivity.

2. Definitions

The uncertain Set was extended by Smarandache [21] in 2007 to uncertain OverSet (when some component is > 1), since he observed that, for example, an employee working overtime deserves a degree of membership > 1, with respect to an employee that only works regular full-time and whose degree of membership = 1; and to uncertain UnderSet (when some neutrosophic component is < 0), since, for example, an employee making more damage than benefit to his company deserves a degree of membership < 0, with respect to an employee that produces benefit to the company and has the degree of membership > 0; and to and to uncertain OffSet (when some neutrosophic components are off the interval [0, 1], i.e. some neutrosophic component > 1 and some neutrosophic component<0). Then, similarly, the uncertain Logic/Measure/Probability/Statistics etc. were extended to respectively uncertain Over-/Under-/Off- Logic / Measure / Probability / Statistics etc [22].

This section shows the definitions of triangular UnderNorm [23].

The triangular UnderNorm include in interval $[\mu, 1]$; $\mu < 0$

$$T_{underNorm}: [\mu, 1] \times [\mu, 1] \rightarrow [\mu, 1] \; and \; \mu > 0 \tag{1}$$

For any $(E, F) \in [\mu, 1] \times [\mu, 1]$ (2)

$$T_{underNorm}(E, F) = T_{underNorm}(F, E) \text{ commutativity} \tag{3}$$

$$T_{underNorm}\big(E, T_{underNorm}(F, D)\big) = T_{underNorm}(T_{underNorm}(E, F), D) \text{ associativity} \tag{4}$$

$$if\ F \leq D\ then\ T_{underNorm}(E,F) \leq T_{underNorm}(E,Z) \text{ monotonicity} \tag{5}$$

$$T_{underNorm}(E,1) = E \text{ or the neutral element is 1.} \tag{6}$$

$$T_{underNorm}(E,F) = \min(E,F) \tag{7}$$

We show the steps of the RAFSI to rank the options. Create the decision matrix between the criteria and alternatives. Then we combine the decision matrix using the $T_{underNorm}$.

Compute the criteria weights using the average method.

Compute the ideal $(D_j)^A$ and non-ideal $(D_j)^C$ numbers.

Compute the interval of each criterion. $D_1 = 0.1, D_2 = 0.9$.

$$H_m(y_{ij}) = \frac{D_{2_C} - D_1}{(D_j)^A - (D_j)^C} y_{ij} + \frac{(D_j)^A D_1 - D_{2_C}(D_j)^C}{(D_j)^A - (D_j)^C} \tag{7}$$

Compute the harmonic and arithmetic means

$$Q = \frac{2}{\frac{1}{D_1} + \frac{1}{D_{2_C}}} \tag{8}$$

$$Q = \frac{D_1 + D_{2_C}}{2} \tag{9}$$

Compute the normalized the decision matrix

$$U_{ij} = \frac{y_{ij}}{2Q} \tag{10}$$

$$U_{ij} = \frac{Q}{2y_{ij}} \tag{11}$$

Compute the criteria function

$$K(D_i) = \sum_{j=1}^{n} w_j U_{ij} \tag{12}$$

Rank the alternatives.

3. Case Study

This section shows the implementation of the proposed approach. We use six criteria and ten alternatives such as:

Visual Integration (C1): The degree to which art complements the building's architectural form and spatial arrangement.

Material Sustainability (C2): Use of recycled, locally sourced, or renewable materials in artistic features.

Energy Interaction (C3): Functional contributions of art design to energy efficiency (e.g., shading, daylighting).

Environmental Messaging (C4): The effectiveness of conveying ecological values through artistic representation.

User Engagement (C5): The extent to which users interact with and are influenced by the art in their behavior or perception.

Durability and Maintenance (C6): Longevity of the art installations and the ease and cost of maintenance over time.

A1: Solar Sculpture Plaza, A2: Eco-Wall Installation in Urban Park, A3: Recycled Glass Facade Mural, A4: Living Roof Mosaic, A5: Wind-Activated Light Totems, A6: Biophilic Interactive Tunnel, A7: Bamboo Art Walkway, A8: Rainwater Reflection Garden, A9: Earth-Tone Relief Panels, A10: Community-Painted Recycled Canopy.

Table 1 shows the decision matrix between the criteria and alternatives. Three experts created the decision matrix. We use the $T_{underNorm}$ to combine the decision matrix. We use the average method to compute the criteria weights.

C1= 0.1719: Visual Impact and Aesthetic Value — This criterion holds significant weight, indicating that the visual and aesthetic integration of the design is crucial. It suggests that how the design appears to the public or users is a key factor in the evaluation process.

C2= 0.1656: Sustainability of Materials — Slightly less than C1, this weight shows a strong emphasis on the ecological sustainability and environmental friendliness of the materials used in the design.

C3= 0.1497: Functionality and Utility — This weight reflects moderate importance. It assesses whether the design elements serve a functional role beyond visual appeal (e.g., providing shade, ventilation, or energy generation).

C4= 0.1592: Symbolism and Conceptual Depth — This value suggests moderate to high emphasis on the narrative or symbolic message that the art or design conveys, especially in terms of cultural or environmental awareness.

C5= 0.1752: User Engagement and Interaction — With one of the highest weights, this indicates a major priority on how users or viewers engage with and experience the design. Interactivity, accessibility, and emotional impact are key factors here.

C6= 0.1783: Durability and Maintenance — The highest weighted criterion, showing strong concern for the long-term feasibility of the design. This includes resistance to weathering, ease of upkeep, and lifecycle cost-effectiveness.

The distribution of weights suggests a well-balanced but slightly utility-leaning evaluation model, with Durability (C6) and User Engagement (C5) taking top priority, followed closely by Visual Appeal (C1) and Sustainability (C2). The smallest weight still reflects considerable importance, emphasizing a comprehensive and holistic approach.

Table 1. The decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	[-0.2,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]	[-0.6,1]	[-0.9,1]
A_2	[-0.9,1]	[-0.1,1]	[-0.2,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]
A_3	[-0.6,1]	[-0.1,1]	[-0.4,1]	[-0.5,1]	[-0.6,1]	[-0.6,1]
A_4	[-0.5,1]	[-0.2,1]	[-0.3,1]	[-0.2,1]	[-0.1,1]	[-0.2,1]
A_5	[-0.4,1]	[-0.1,1]	[-0.5,1]	[-0.6,1]	[-0.9,1]	[-0.6,1]
A_6	[-0.3,1]	[-0.5,1]	[-0.4,1]	[-0.2,1]	[-0.9,1]	[-0.2,1]
A_7	[-0.9,1]	[-0.4,1]	[-0.5,1]	[-0.1,1]	[-0.3,1]	[-0.3,1]
A_8	[-0.1,1]	[-0.3,1]	[-0.1,1]	[-0.5,1]	[-0.4,1]	[-0.4,1]
A_8	[-0.2,1]	[-0.9,1]	[-0.9,1]	[-0.9,1]	[-0.5,1]	[-0.5,1]
A_{10}	[-0.6,1]	[-0.5,1]	[-0.4,1]	[-0.3,1]	[-0.9,1]	[-0.6,1]
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	[-0.1,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]	[-0.6,1]	[-0.2,1]
A_2	[-0.2,1]	[-0.6,1]	[-0.2,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]
A_3	[-0.3,1]	[-0.6,1]	[-0.4,1]	[-0.5,1]	[-0.6,1]	[-0.1,1]
A_4	[-0.4,1]	[-0.2,1]	[-0.3,1]	[-0.9,1]	[-0.1,1]	[-0.9,1]
A_5	[-0.5,1]	[-0.6,1]	[-0.5,1]	[-0.1,1]	[-0.2,1]	[-0.3,1]
A_6	[-0.3,1]	[-0.9,1]	[-0.1,1]	[-0.2,1]	[-0.3,1]	[-0.4,1]
A_7	[-0.9,1]	[-0.3,1]	[-0.2,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]
A_8	[-0.1,1]	[-0.4,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]	[-0.4,1]
A_8	[-0.2,1]	[-0.5,1]	[-0.4,1]	[-0.5,1]	[-0.5,1]	[-0.5,1]
A_{10}	[-0.6,1]	[-0.5,1]	[-0.5,1]	[-0.3,1]	[-0.2,1]	[-0.6,1]
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	[-0.9,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]	[-0.5,1]	[-0.2,1]
A_2	[-0.9,1]	[-0.5,1]	[-0.2,1]	[-0.3,1]	[-0.4,1]	[-0.5,1]
A_3	[-0.1,1]	[-0.4,1]	[-0.4,1]	[-0.5,1]	[-0.3,1]	[-0.4,1]
A_4	[-0.5,1]	[-0.3,1]	[-0.5,1]	[-0.2,1]	[-0.2,1]	[-0.3,1]
A_5	[-0.4,1]	[-0.9,1]	[-0.4,1]	[-0.5,1]	[-0.5,1]	[-0.2,1]
A_6	[-0.3,1]	[-0.5,1]	[-0.3,1]	[-0.4,1]	[-0.4,1]	[-0.5,1]
A_7	[-0.2,1]	[-0.4,1]	[-0.2,1]	[-0.3,1]	[-0.3,1]	[-0.4,1]
A_8	[-0.6,1]	[-0.3,1]	[-0.6,1]	[-0.9,1]	[-0.9,1]	[-0.3,1]
A_8	[-0.2,1]	[-0.2,1]	[-0.2,1]	[-0.2,1]	[-0.5,1]	[-0.2,1]
A_{10}	[-0.1,1]	[-0.5,1]	[-0.4,1]	[-0.3,1]	[-0.2,1]	[-0.6,1]

We compute the ideal $(D_j)^A$ and non-ideal $(D_j)^C$ numbers.

We compute the interval of each criterion using eq. (7) as shown in Fig 1.

We compute the harmonic and arithmetic means using eq. (8) as shown in Fig 2.

We compute the normalized decision matrix using eq. (10) as shown in Fig 3.

We compute the criteria function using eq. (12) as shown in Fig 4.

Rank the alternatives as shown in Fig 5.

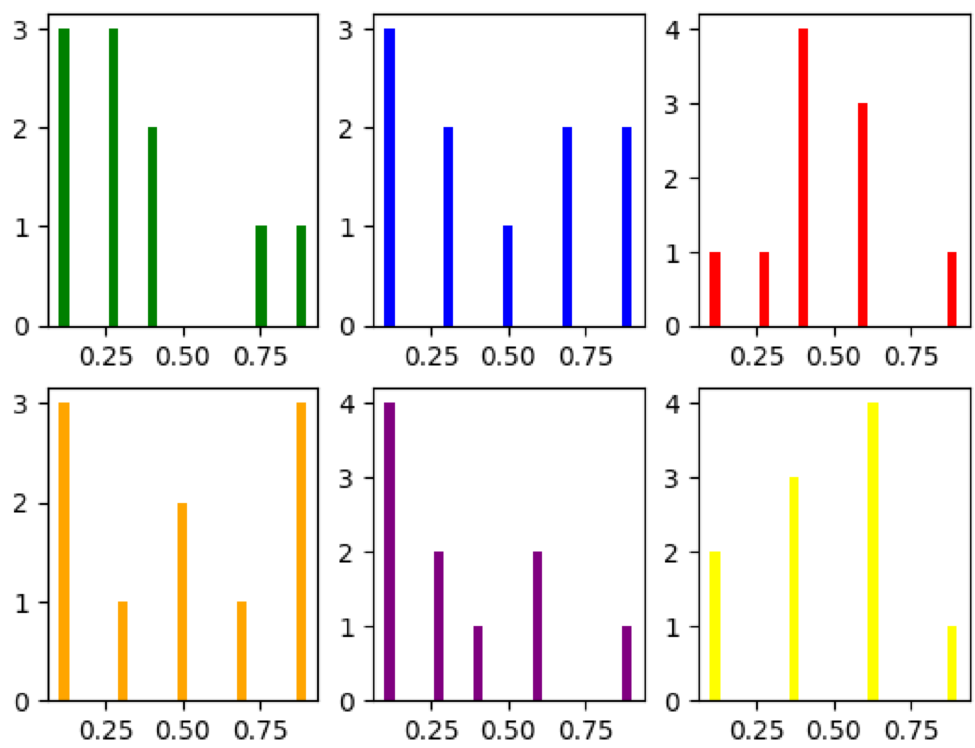

Fig 1. The interval of each criterion.

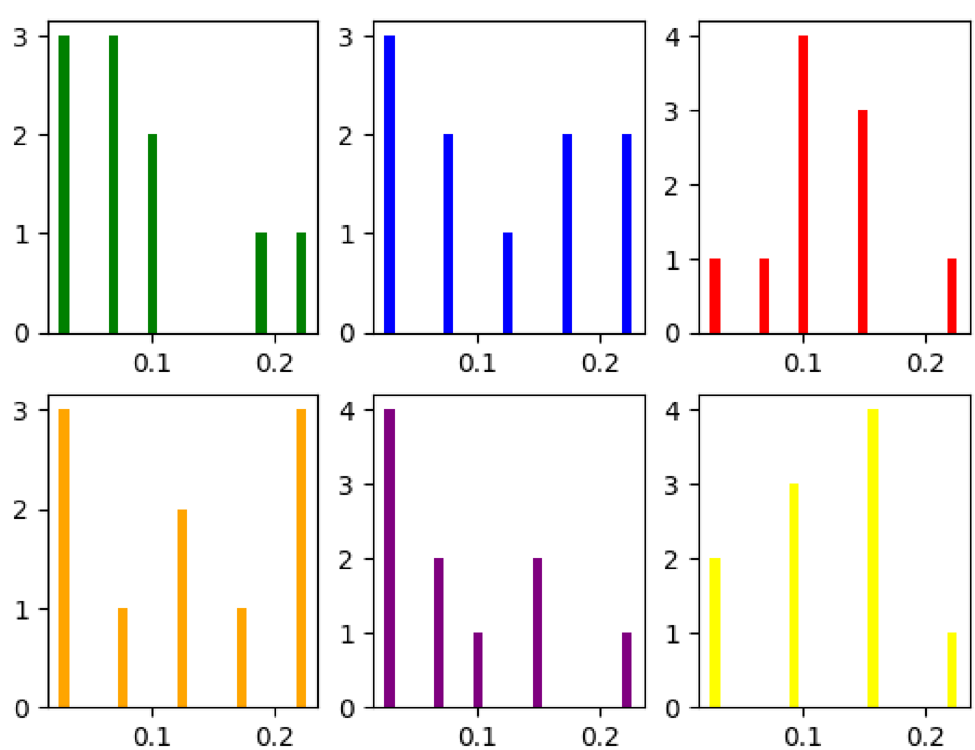

Fig 2. The harmonic and arithmetic means.

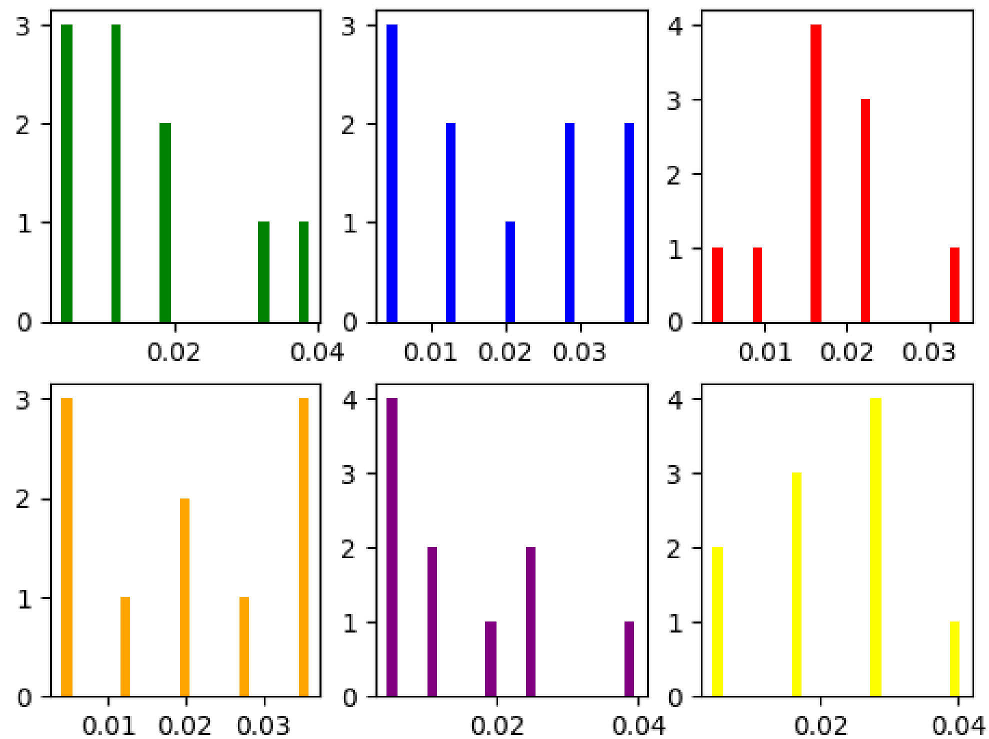

Fig 3. The normalized decision matrix.

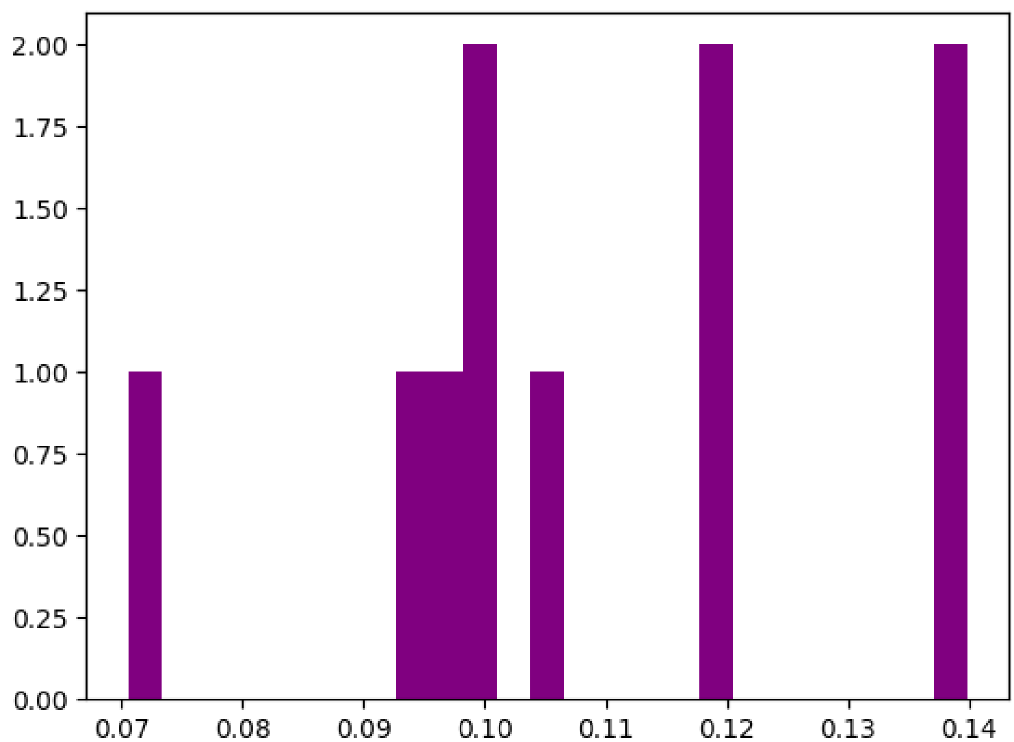

Fig 4. The criteria function.

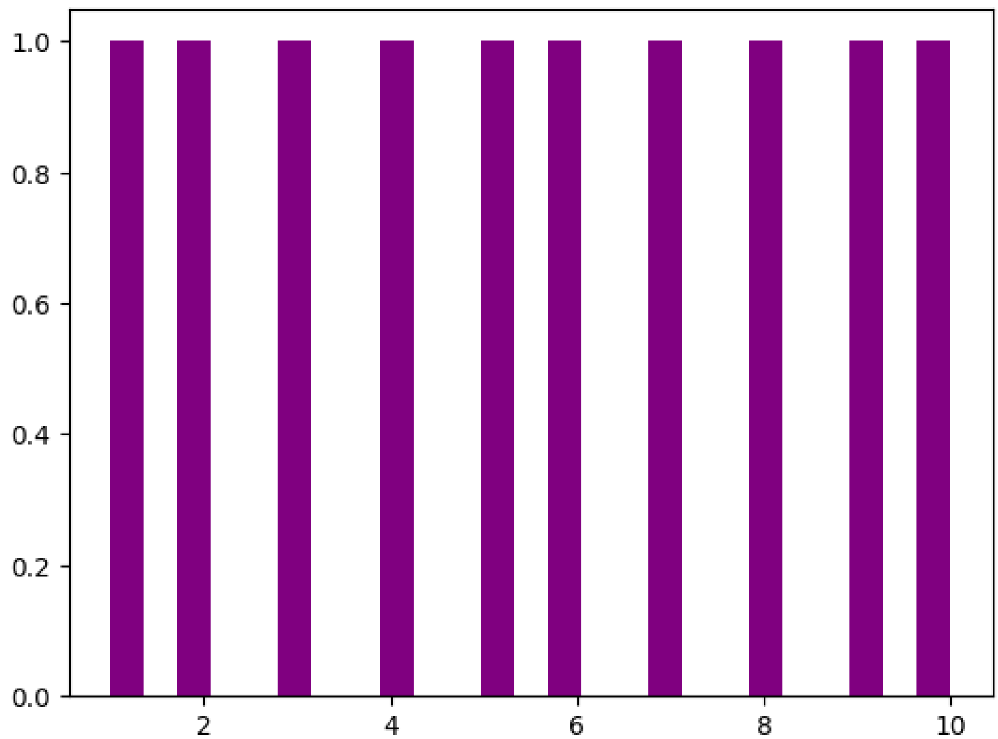

Fig 5. The ranks of alternatives.

4. Sensitivity Analysis

This section shows the results of sensitivity analysis. We change the criteria weights by 20% of each criterion as shown in Fig 6. Then we apply the proposed approach to show the ranks of alternatives. Fig 7 shows the criteria function of each alternative. Fig 8 shows the ranks of alternatives.

Fig 6 shows criteria weights across six different cases (Case 1 to Case 6) for a decision-making or evaluation model (e.g., MCDM framework for evaluating Environmental Art Design in Green Architecture. Values: Represent the relative weight of each criterion in each case. These weights usually sum up to 1 in each column (or nearly so), indicating a normalized priority distribution.

C1: Shows very low weight (≈ 0.04) in Case 1, but very high and stable weight (≈ 0.20) in Cases 2 to 6. This implies C1 was nearly unimportant in Case 1 but becomes a top priority in the other scenarios.

C2: Starts very strong in Case 1 (~0.19), drops dramatically in Case 2 (~0.038), then returns to high importance across Cases 3 to 6.

C3: Maintains consistent medium-high values (~0.17) in most cases, except in Case 3 where its importance is minimal (≈ 0.034). This suggests Case 3 emphasizes other factors.

C4: Like C3, it is stable in most cases (~0.18), but in Case 4 its weight drops significantly to ~0.036.

C5: Holds the highest weight in most cases, especially Case 6 (~0.204), but is given very little weight in Case 5 (~0.0407), which might indicate a different objective or constraint in that case.

C6: Very important across most cases (~0.20) but sharply deprioritized in Case 6 (≈ 0.0416), possibly due to competing priorities.

Each case has one criterion heavily deprioritized (very low value ~0.03–0.04), possibly to simulate different decision environments or stakeholder perspectives.

C5 and C6 are among the most dominant in most scenarios, suggesting structural or practical concerns (e.g., durability or usability) may weigh heavily in this model.

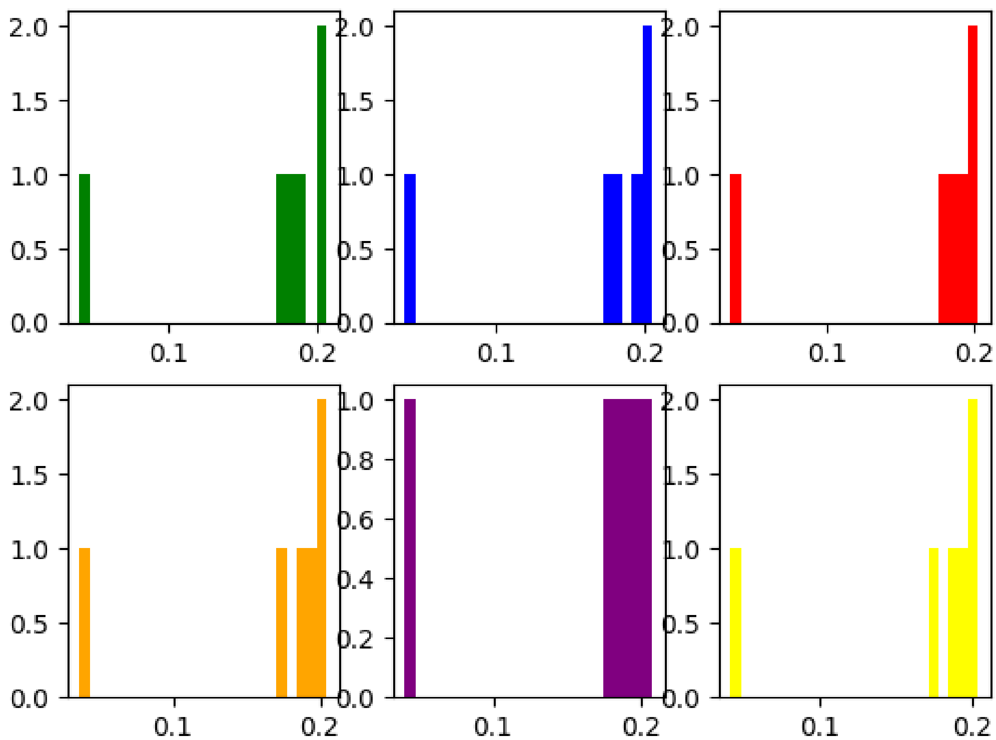

Fig 6. The different criteria weights.

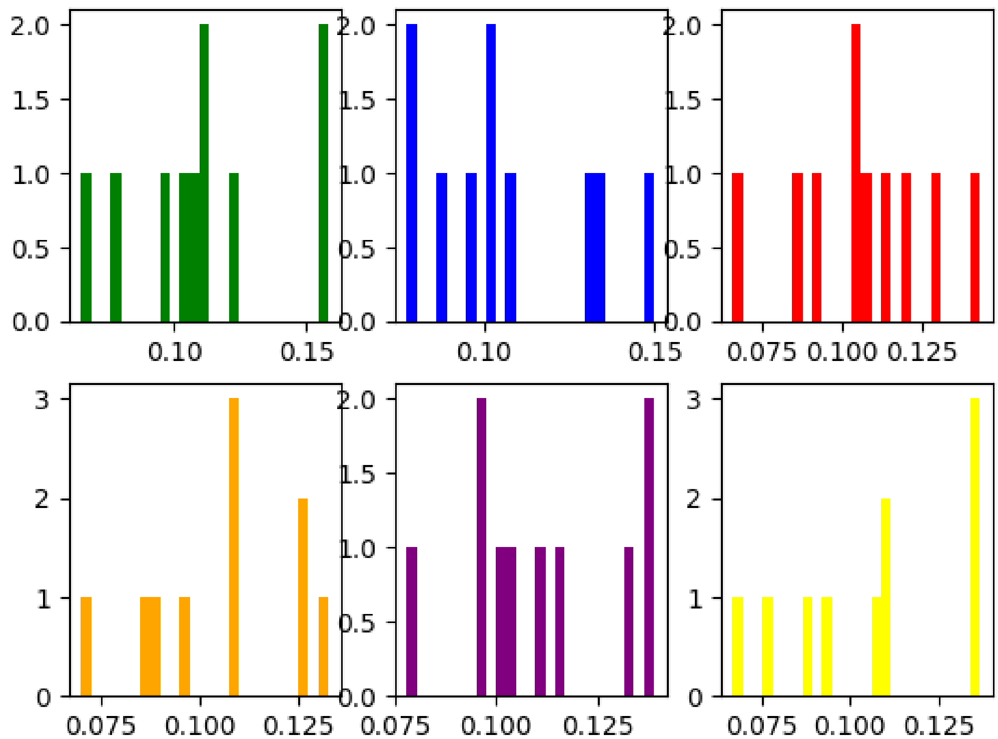

Fig 7. The different criteria function.

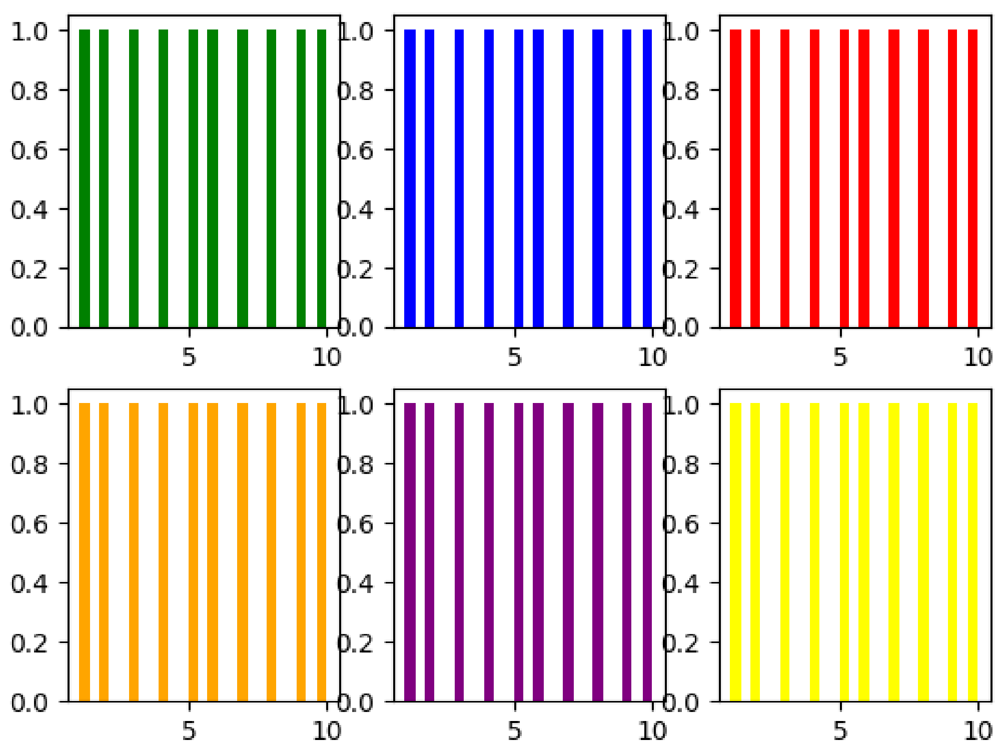

Fig 8. The different ranks of alternatives.

A1: Mixed rankings, starting low in Case 1 (Rank 7), but improves in Cases 2 to 4. Slight decline in Cases 5 and 6 (Ranks 5 and 6). Suggests inconsistent performance.

A2: Consistently ranked worst (Rank 10) in all cases except Case 3 (Rank 9). Indicates it consistently underperforms across all evaluation scenarios.

A3: Maintains strong ranks (Ranks 2 to 4) in all cases, especially Case 3 (Rank 2). Demonstrates steady and strong performance.

A4: Highly variable. Performs better in Case 5 (Rank 4), but drops sharply in Case 4 (Rank 10). Indicates unstable or scenario-dependent performance.

A5: Top performer in all cases (Rank 1) — consistently ranked first. This indicates exceptional performance and universal preference across all scenarios.

A6: Moderate performer. Ranges from Rank 5 to Rank 8. Not a leader, but relatively stable in the middle range.

A7: Poor performer. Typically ranked 9 or 10, except Case 4 (Rank 8). Consistently among the bottom-ranked.

A8: Fairly strong and improving in Case 6 (Rank 2). Usually ranked between 3 and 6, showing moderate to strong performance.

A9: Starts strong (Rank 2), with mid-level ranks elsewhere. Notably drops in Case 2 (Rank 7). A strong contender, though performance varies.

A10: Mid-range performer, ranked between 2 and 7. Notably better in Case 4 (Rank 2). Shows balanced but not exceptional performance.

Case 1: A5 and A9 lead (Ranks 1 & 2), while A2 and A7 perform worst.

Case 2: A5, A1, and A8 lead. A2 and A9 drop.

Case 3: A5 and A3 are top. A4 and A7 fall.

Case 4: A10 and A3 shine. A4 performs worst.

Case 5: A5 remains best, with A9, A3, and A4 close. A2 and A7 continue to struggle.

Case 6: A5 and A8 lead. A2 and A4 are weak.

5. Conclusions

This research underscores the significance of evaluating environmental art design through a structured framework that values both aesthetics and sustainability. The proposed criteria allow for an objective analysis of how well artistic features are integrated into green architectural practices. Through the comparative analysis of ten diverse alternatives, this study offers insights into the current trends and future directions of environmentally conscious design. The findings aim to inform architects, planners, and policymakers on best practices for harmonizing artistic creativity with ecological stewardship. We used the MCDM approach to show the criteria weights and ranking the alternatives using the RAFSI method. Six criteria and ten alternatives are used to show the validation of the proposed approach. The results of sensitivity analysis show the ranks of alternatives are stable under six different cases.

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