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Fuzzy Framework for Evaluation Strategies of Climate Change Adaptation on Constructing

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Abstract

This study proposes a decision-making model for ranking strategies to eliminate climate change in construction. The triangular fuzzy set deals with uncertain information in the ranking process. Various criteria are used in this study, so the multi-criteria decision-making (MCDM) methodology is used to deal with these criteria. The TOPSIS method is an MCDM methodology used to rank the alternatives. The TOPSIS method is integrated with triangular fuzzy numbers. The criteria weights are computed by using the average method. The application is applied with 12 criteria and 8 options. The results show that alternative 7 is the best and alternative 3 is the worst. The results are tested with sensitivity analysis to show their stability. The sensitivity analysis was conducted with 13 cases of changing the criteria weights. Then, the TOPSIS method is applied under 13 cases in criteria weights. The results show that the ranking is stable in different cases.

Keywords: Climate Change; Multi-Criteria Decision Making; Fuzzy Sets; TOPSIS Method; Decision Analysis.

1 | Introduction

The land surface air temperature would climb by approximately 1.53 °C, or nearly twice as much, as the world average temperature increases between 1990 and 2100, according to the Intergovernmental Panel on Climate Change (IPCC) research. The land, ocean, cryosphere, and our living environment have all been impacted by climate change. To meet the aim of 1.5–2.0 °C of global warming, around 9 Gt of CO2 emissions have to be cut [1-3]. The building sector in the construction industry is responsible for 39% of the world's CO2 emissions; moreover, HVAC (heating, ventilation, and air conditioning) systems use between 40% and 50% of the energy used in the building sector. As a result, several studies have demonstrated the significant influence that climate change has on structures [4].

The massive effects of climate change on buildings have prompted the creation and optimization of several mitigation techniques to identify the best one [5-7]. When considering various harsh climate circumstances, the long projection balcony, enormous openable windows, sun shading, and lower-solar-gain windows proved more effective than other tactics (e.g., window solar heat gain coefficient (SHGC), U value of walls).

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Furthermore, several proactive initiatives have shown to be highly effective in reducing the negative effects of climate change on energy usage [8, 9]. Photovoltaic (PV) panels, more energy-efficient HVAC systems, effective lighting schemes, and practical building energy control systems are examples of active techniques [10-12].

Generally speaking, the Multi-Criteria Decision-Making (MCDM) problem entails selecting the best alternative among potential solutions based on various quantitative and qualitative considerations. Because of the great accuracy and reliability of MCDM variants in addressing real-world problems, researchers have used them in multiple applications [13]. In real life, one rarely has enough knowledge to solve a problem precisely because ambiguity complicates decision-making. Lotfi Zadeh invented fuzzy set theory to address the ambiguity and uncertainty inherent in complex systems but often overlooked. Fuzzy MCDM (F-MCDM) helps address such complicated issues by fusing fuzzy set theory with MCDM [14, 15].

It is feasible to consider a subset of the numerous MCDM compensating procedures that consider costs and benefits. Among these is the TOPSIS method, which stands for Technique for Order Performance by Similarity to Ideal Solution. There are four key reasons why this method is used [16, 17]s:

The reasoning behind TOPSIS is logical and clear; the calculation methods are simple; the idea enables the search for the best options for every criterion represented in an easy-to-understand mathematical format; and the comparison processes take the necessary weights into account [18, 19].

The contributions of this study are:

i. It is the first study to rank the strategies to eliminate climate change in the constructions using triangular fuzzy sets.

ii. The triangular fuzzy sets are integrated with the MCDM methodology for uncertain information.

iii. The TOPSIS method is used to rank the alternatives.

iv. The sensitivity analysis is conducted to show the stability of the rank.

The rest of this paper is organized as follows: section 2 introduces the materials and method of this study. Section 3 presents the results of the suggested methodology. Section 4 introduces the sensitivity analysis.

2 | Materials and Methods

This section introduces the integrated triangular fuzzy sets (TFSs) with the TOPSIS method for ranking strategies to eliminate climate change on construction. This section is divided into two parts. In the first part, we compute the criteria weights by the average method. In the second part, we rank the alternatives under the TOPSIS method. Figure 1 shows the research framework.

Step 1. Build the fuzzy decision matrix. This matrix consists of the number of criteria n and the number of alternatives m.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{n1} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Experts and decision-makers use fuzzy triangular numbers (FTNs) [20] to build the decision matrix between criteria and alternatives.

Step 2. Obtain the crisp values [20].

$$S(x) = \frac{l+4m+u}{6} \tag{2}$$

Where l, m, u are memberships of FTNS.

Step 3. Aggregate the decision matrix. The decision matrices are aggregated into one matrix by the average method.

Step 4. Normalize the decision matrix

$$n_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m}(x_{ij})^2} \quad (3)$$

Step 5. Compute the weighted normalized decision matrix.

$$r_{ij} = n_{ij}\, w_{ij} \quad (4)$$

Step 6. Compute the positive and negative ideal solution.

$$B^{+} = \{r_1^{+}, \dots, r_n^{+}\} = \left\{\left(\max_i r_{ij}, j \in J\right)\left(\min_i r_{ij}\, j \in J^{-}\right)\right\}; i = 1,2, \dots m \quad (5)$$

$$B^{-} = \{r_1^{-}, \dots, r_n^{-}\} = \left\{\left(\min_i r_{ij}, j \in J\right)\left(\max_i r_{ij}\, j \in J^{-}\right)\right\}; i = 1,2, \dots m \quad (6)$$

Where J refers to the beneficial criteria and J^{-} refers to non-beneficial criteria.

Step 7. Compute the separation measures.

$$y_i^{+} = \left\{\sum_{j=1}^{n}\left(r_{ij} - b_j^{+}\right)^2\right\}^{\frac{1}{2}} \quad (7)$$

$$y_i^{-} = \left\{\sum_{j=1}^{n}\left(r_{ij} - b_j^{-}\right)^2\right\}^{\frac{1}{2}} \quad (8)$$

Step 8. Compute the closeness value.

$$U_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad (9)$$

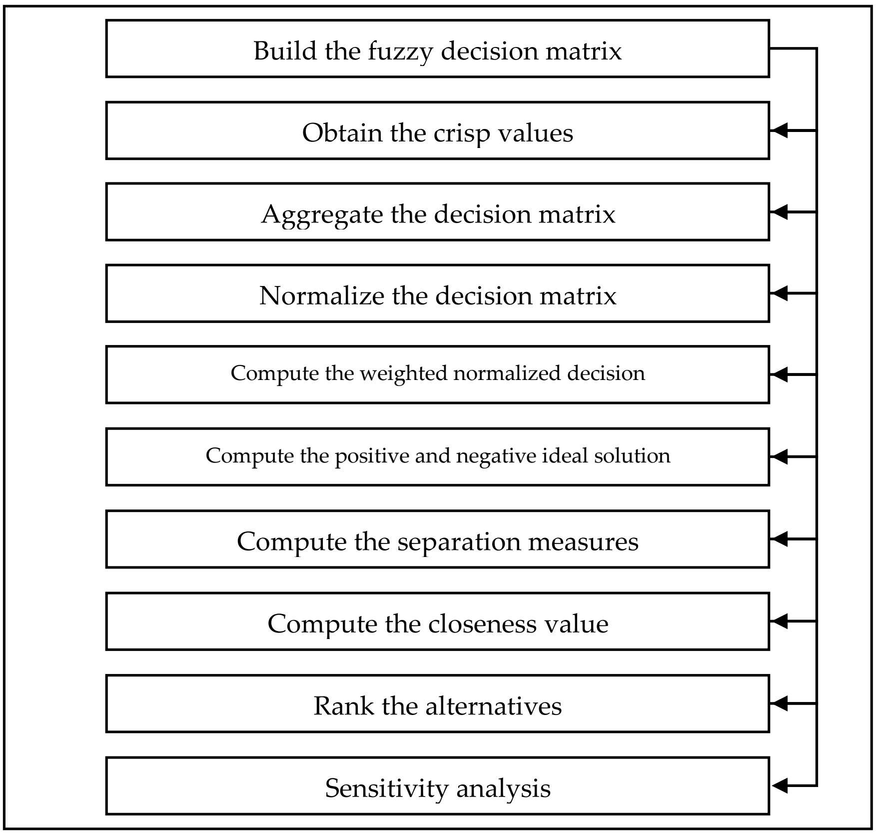

Figure 1. The research framework.

3 | Results and Discussion

This section introduces the results of the F-TOPSIS method to rank the alternatives. This study invited three experts and decision-makers to evaluate the criteria and alternatives. These experts have expertise more than 20 years in climate change and construction. These experts collected 12 criteria and 8 alternatives in this study as shown in Figure 2. We replaced their opinions by using the FTNs.

Step 1. Build the fuzzy decision matrix by opinions of experts and decision-makers between criteria and alternatives as shown in Tables A-1 and A-2.

Step 2. Obtain the crisp values by using Eq. (2) to obtain one value instead of three values.

Step 3. Then we aggregated the decision matrix by using Eq. (3) as shown in Table A-3. Then we compute the criteria weights by the average method as shown in Figure 3. We show criterion 5 has the highest weight and criterion 11 has the lowest weight.

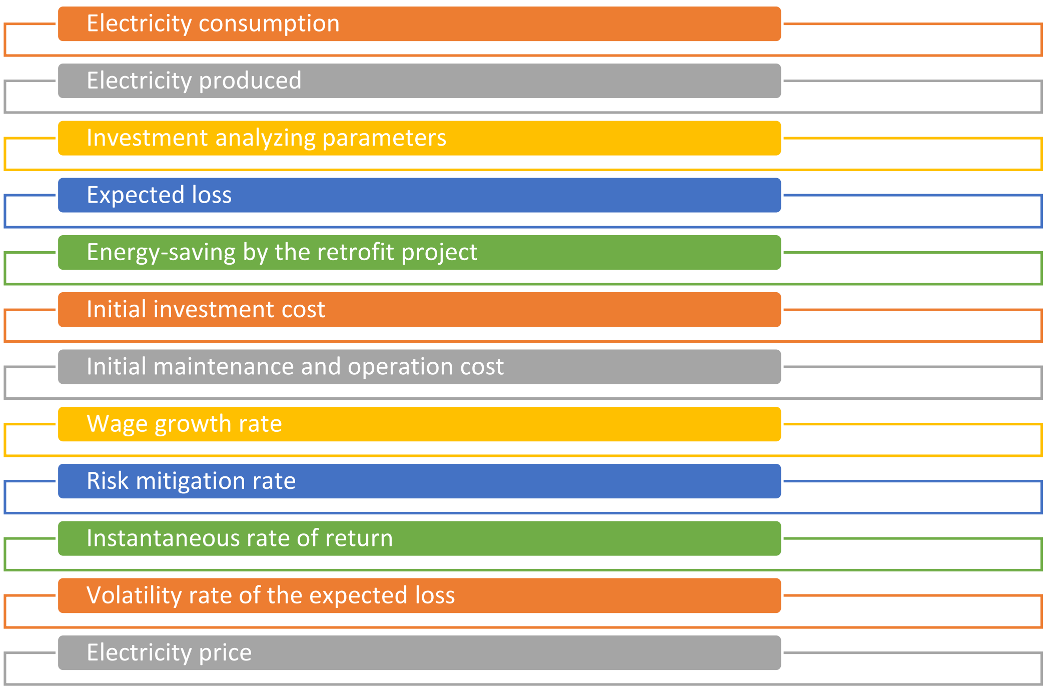

Figure 2. List of criteria.

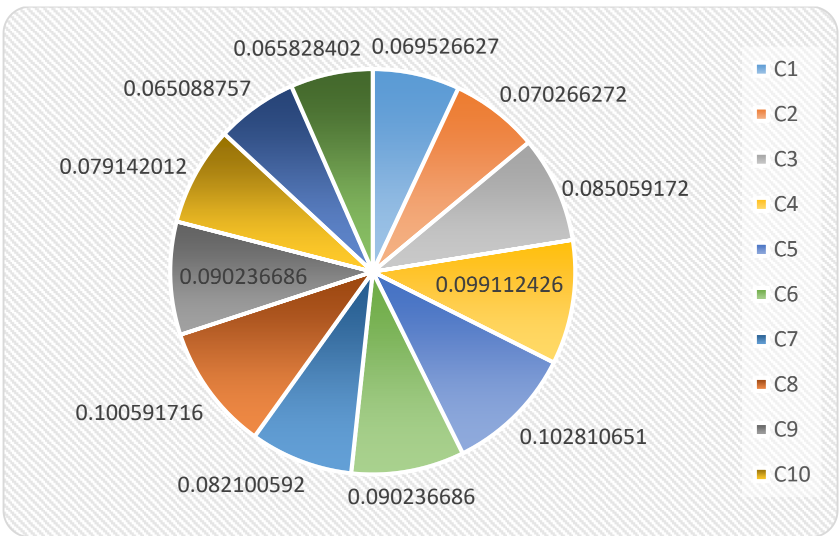

Figure 3. The criteria weights.

Step 4. Normalize the decision matrix by using Eq. (3) as shown in Table 1.

Step 5. Compute the weighted normalized decision matrix by using Eq. (4) as shown in Table 2.

Step 6. Compute the positive and negative ideal solution by using Eqs. (5) and (6).

Step 7. Compute the separation measures by using Eq. (7) and (8).

Step 8. Compute the closeness value by using Eq. (9) as shown in Figure 4. We show that alternative 7 is the best and alternative 3 is the worst.

Table 1. The normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.33609	0.307454	0.293448	0.354863	0.487258	0.296754	0.380711	0.407439	0.233419	0.268594	0.251648	0.264989
A_2	0.29655	0.276708	0.23793	0.422456	0.316717	0.331666	0.390229	0.424415	0.518708	0.298437	0.24326	0.264989
A_3	0.29655	0.389442	0.380689	0.354863	0.324838	0.436403	0.285533	0.322556	0.30258	0.497395	0.24326	0.256156
A_4	0.494251	0.307454	0.229999	0.278821	0.276113	0.366578	0.34264	0.331044	0.345806	0.288489	0.251648	0.247323
A_5	0.415171	0.389442	0.222068	0.245025	0.397927	0.427674	0.437817	0.297091	0.259354	0.338229	0.360696	0.247323
A_6	0.375631	0.307454	0.396551	0.29572	0.332959	0.322938	0.276015	0.331044	0.389031	0.348177	0.343919	0.459314
A_7	0.286665	0.491926	0.475861	0.506948	0.389806	0.366578	0.276015	0.339532	0.423612	0.447656	0.503296	0.423983
A_9	0.266895	0.307454	0.475861	0.29572	0.243629	0.235657	0.399746	0.356509	0.259354	0.268594	0.503296	0.529978

Table 2. The weighted normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.023367	0.021604	0.02496	0.035171	0.050095	0.026778	0.031257	0.040985	0.021063	0.021257	0.016379	0.017444
A_2	0.020618	0.019443	0.020238	0.041871	0.032562	0.029928	0.032038	0.042693	0.046807	0.023619	0.015833	0.017444
A_3	0.020618	0.027365	0.032381	0.035171	0.033397	0.03938	0.023442	0.032446	0.027304	0.039365	0.015833	0.016862
A_4	0.034364	0.021604	0.019564	0.027635	0.028387	0.033079	0.028131	0.0333	0.031204	0.022832	0.016379	0.016281
A_5	0.028865	0.027365	0.018889	0.024285	0.040911	0.038592	0.035945	0.029885	0.023403	0.026768	0.023477	0.016281
A_6	0.026116	0.021604	0.03373	0.029309	0.034232	0.029141	0.022661	0.0333	0.035105	0.027555	0.022385	0.030236
A_7	0.019931	0.034566	0.040476	0.050245	0.040076	0.033079	0.022661	0.034154	0.038225	0.035428	0.032759	0.02791
A_9	0.018556	0.021604	0.040476	0.029309	0.025048	0.021265	0.032819	0.035862	0.023403	0.021257	0.032759	0.034888

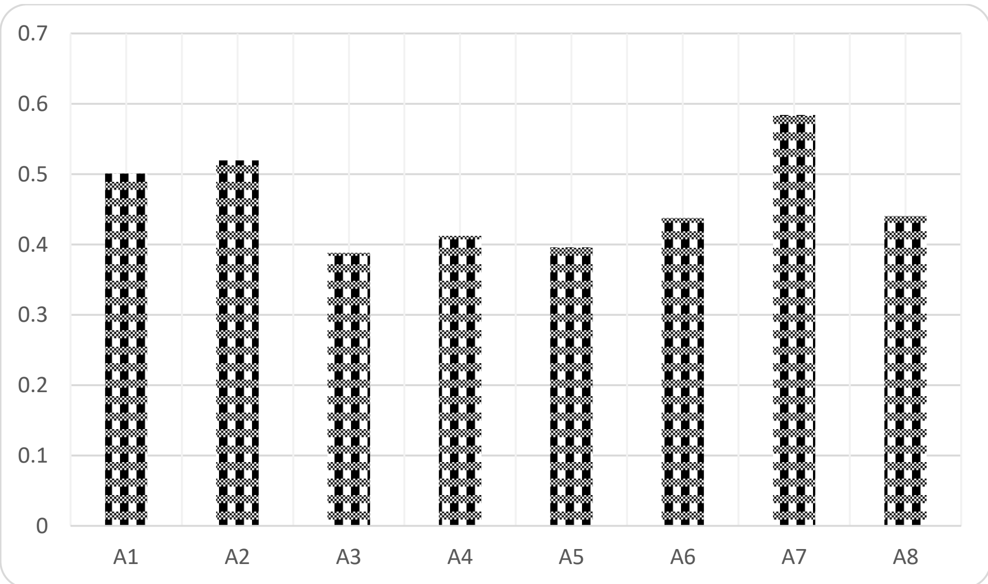

Figure 4. The closeness values.

4 | Sensitivity Analysis

This section changes the criteria weights and ranks the alternatives to show the stability of the results. We suggested 13 cases in criteria weights, as shown in Figure 5. In the first case, we put all criteria with equal weights, then in the second case, we put the first criterion with 0.1 weights and others with equal weights. We put the second criterion in the third case with 0.1 weight; the others are equal weights.

Then, we applied the F-TOPSIS method to the 13 case weights to show the rank of alternatives. We computed the closeness values of each case, as shown in Figure 6. Then, we ranked the other options, as shown in Figure 7. We show that alternative 7 is the best of all alternatives, alternative 2 is the worst except case 4, and alternative 5 is the worst.

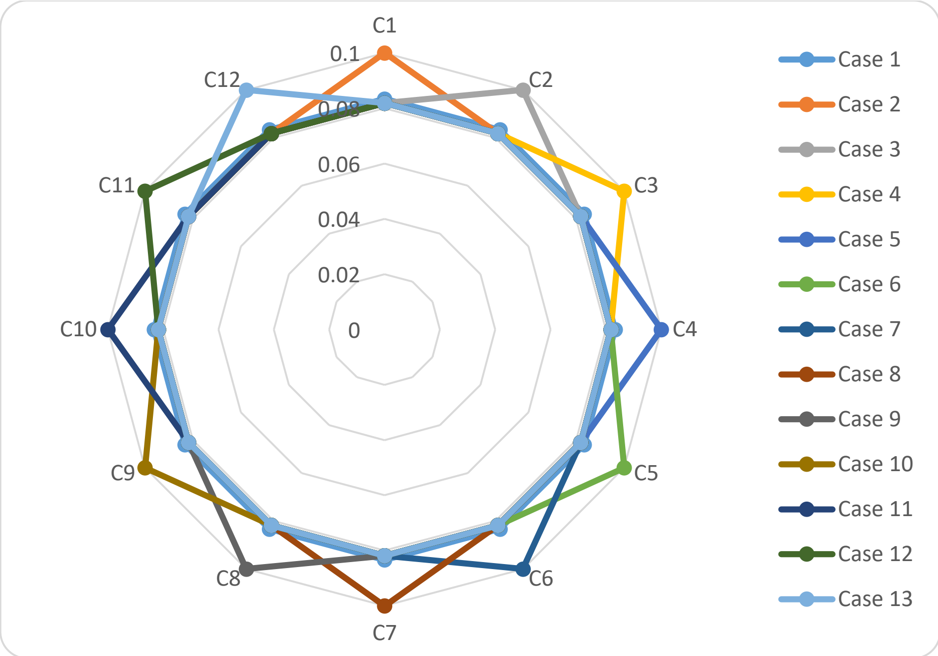

Figure 5. The criteria weights under sensitivity analysis.

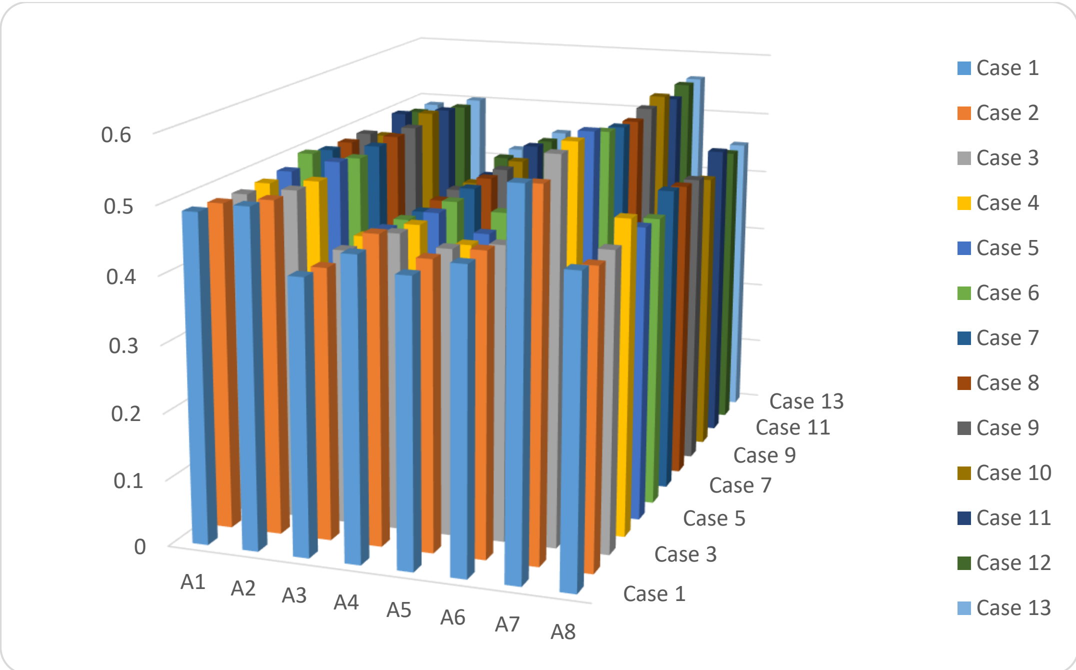

Figure 6. The closeness values under sensitivity analysis.

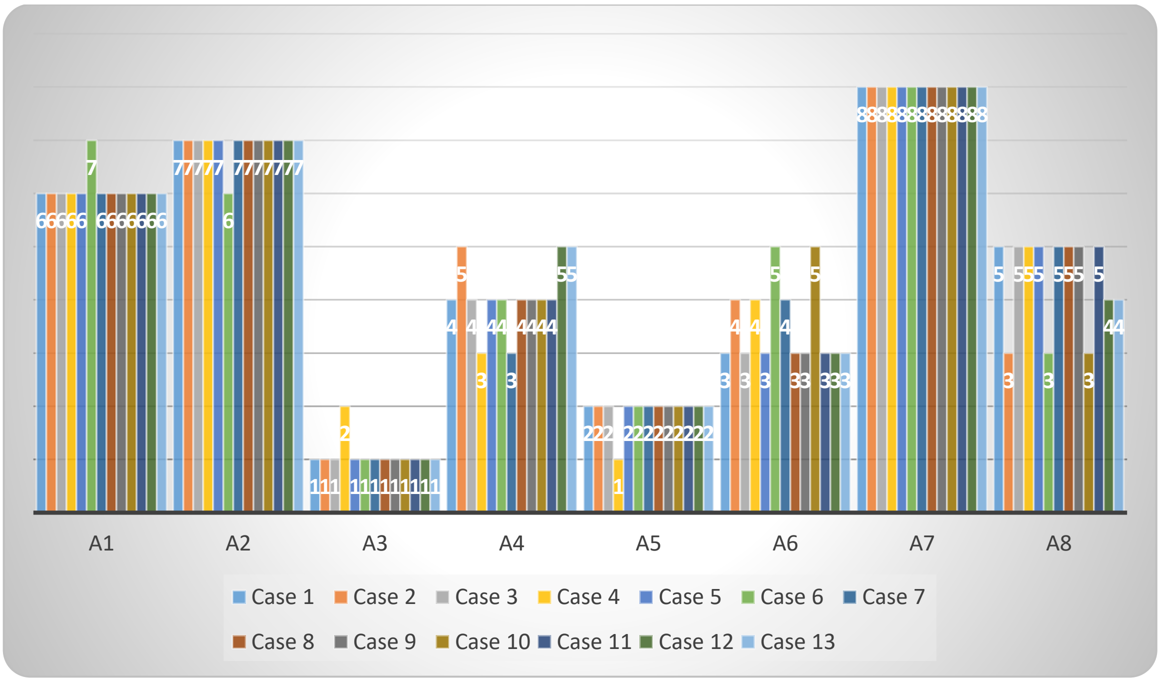

Figure 7. The rank of alternatives under sensitivity analysis.

5 | Conclusions

This study proposed an MCDM methodology to select the best strategy to eliminate climate change in construction. The MCDM methodology deals with various criteria in the ranking process. The TOPSIS method is used to rank the strategies. The TOPSIS method was integrated with triangular fuzzy numbers to deal with uncertain and vague information. Three experts used the terms of triangular fuzzy numbers to evaluate the criteria and alternatives. Then, we replace their opinions to build the decision matrix with fuzzy triangular numbers. Then, we computed the score function to obtain the crisp values. Then, we aggregated these matrices into one decision matrix. Then, we computed the closeness values of each alternative. We show that alternative 7 is the best and alternative 3 is the worst. We applied the sensitivity analysis to show the stability of the ranks with 13 cases.

The proposed methodology can be applied in the future to various decision-making problems, such as those in energy, healthcare, medicine, etc. Various MCDM methods, such as VIKOR, MARCOS, AHP, and DEMATEL, can be applied to this problem. The fuzzy extension can be integrated with the TOPSIS method, such as spherical fuzzy sets and neutrosophic sets.

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Author Contribution

All authors contributed equally to this work.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Appendix

Table A-1. The first decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	(1, 3, 5)	(3, 3, 5)	(3, 5, 5)	(5, 5, 7)	(5, 7, 7)	(1, 3, 5)	(3, 3, 5)	(3, 5, 5)	(1, 3, 5)	(1, 3, 5)	(3, 3, 5)	(3, 3, 5)
A_2	(3, 3, 5)	(1, 3, 5)	(3, 3, 5)	(5, 7, 7)	(5, 7, 7)	(3, 5, 5)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(3, 3, 5)
A_3	(3, 3, 5)	(3, 5, 5)	(5, 5, 7)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(3, 3, 5)	(3, 5, 5)	(5, 5, 7)	(5, 7, 7)	(1, 3, 5)	(3, 3, 5)
A_4	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(3, 5, 5)	(3, 5, 5)	(5, 5, 7)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(1, 3, 5)
A_5	(5, 5, 7)	(1, 3, 5)	(1, 3, 5)	(3, 3, 5)	(5, 7, 7)	(5, 7, 7)	(5, 5, 7)	(5, 5, 7)	(3, 3, 5)	(3, 5, 5)	(3, 5, 5)	(1, 3, 5)
A_6	(3, 5, 5)	(3, 3, 5)	(5, 7, 7)	(5, 5, 7)	(5, 5, 7)	(3, 5, 5)	(3, 3, 5)	(5, 7, 7)	(5, 5, 7)	(5, 5, 7)	(5, 5, 7)	(5, 5, 7)
A_7	(3, 3, 5)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(5, 5, 7)	(3, 5, 5)	(3, 3, 5)	(3, 3, 5)	(5, 7, 7)	(5, 5, 7)	(5, 7, 7)	(5, 5, 7)
A_9	(1, 3, 5)	(3, 3, 5)	(5, 7, 7)	(1, 3, 5)	(3, 3, 5)	(1, 3, 5)	(3, 5, 5)	(3, 5, 5)	(3, 3, 5)	(1, 3, 5)	(5, 7, 7)	(5, 7, 7)

Table A-2. The second decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	(1, 3, 5)	(3, 3, 5)	(3, 5, 5)	(5, 5, 7)	(5, 7, 7)	(1, 3, 5)	(3, 3, 5)	(3, 5, 5)	(1, 3, 5)	(1, 3, 5)	(3, 3, 5)	(3, 3, 5)
A_2	(3, 3, 5)	(1, 3, 5)	(3, 3, 5)	(5, 7, 7)	(1, 3, 5)	(3, 5, 5)	(1, 3, 5)	(5, 7, 7)	(5, 7, 7)	(3, 3, 5)	(1, 3, 5)	(3, 3, 5)
A_3	(3, 3, 5)	(3, 3, 5)	(5, 5, 7)	(5, 5, 7)	(3, 3, 5)	(5, 7, 7)	(3, 3, 5)	(3, 5, 5)	(1, 3, 5)	(5, 7, 7)	(3, 3, 5)	(1, 3, 5)
A_4	(5, 7, 7)	(3, 3, 5)	(1, 3, 5)	(1, 3, 5)	(3, 3, 5)	(5, 5, 7)	(3, 3, 5)	(1, 3, 5)	(3, 3, 5)	(1, 3, 5)	(3, 3, 5)	(3, 3, 5)
A_5	(5, 5, 7)	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(5, 7, 7)	(5, 7, 7)	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(3, 3, 5)	(5, 7, 7)	(3, 3, 5)
A_6	(3, 5, 5)	(3, 3, 5)	(3, 3, 5)	(3, 3, 5)	(5, 5, 7)	(3, 5, 5)	(3, 3, 5)	(3, 3, 5)	(5, 7, 7)	(3, 3, 5)	(5, 5, 7)	(5, 7, 7)
A_7	(3, 3, 5)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(5, 5, 7)	(3, 5, 5)	(3, 3, 5)	(5, 7, 7)	(5, 7, 7)	(5, 7, 7)	(5, 7, 7)	(5, 5, 7)
A_9	(1, 3, 5)	(3, 3, 5)	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(1, 3, 5)	(3, 5, 5)	(3, 5, 5)	(3, 3, 5)	(1, 3, 5)	(5, 7, 7)	(5, 7, 7)

Table A-3. The aggregated decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	3.777778	3.333333	4.111111	4.666667	6.666667	3.777778	4.444444	5.333333	3	3	3.333333	3.333333
A_2	3.333333	3	3.333333	5.555556	4.333333	4.222222	4.555556	5.555556	6.666667	3.333333	3.222222	3.333333
A_3	3.333333	4.222222	5.333333	4.666667	4.444444	5.555556	3.333333	4.222222	3.888889	5.555556	3.222222	3.222222
A_4	5.555556	3.333333	3.222222	3.666667	3.777778	4.666667	4	4.333333	4.444444	3.222222	3.333333	3.111111
A_5	4.666667	4.222222	3.111111	3.222222	5.444444	5.444444	5.111111	3.888889	3.333333	3.777778	4.777778	3.111111
A_6	4.222222	3.333333	5.555556	3.888889	4.555556	4.111111	3.222222	4.333333	5	3.888889	4.555556	5.777778
A_7	3.222222	5.333333	6.666667	6.666667	5.333333	4.666667	3.222222	4.444444	5.444444	5	6.666667	5.333333
A_9	3	3.333333	6.666667	3.888889	3.333333	3	4.666667	4.666667	3.333333	3	6.666667	6.666667