Neutrosophic Sets and Systems, Vol. 63, 2024
University of New Mexico

Comprehensive Review MEREC weighting method for Smart Building Selection for New Capital using neutrosophic theory

Asmaa Elsayed [1,*]

Faculty of computers and informatics, Zagazig University, Egypt; aa.ahmed023@eng.zu.edu.eg

Abstract

Population growth has become a serious problem in many countries, especially Egypt. Which leads to an increase in the population area and an increase in buildings, which then leads to several problems, including large energy consumption, increased pollution, traffic congestion, and others. Therefore, many governments have resorted to using technology and applying it to build smart buildings to help save energy by using renewable energy to improve its impact on the environment, improve the quality of life of citizens, provide security and safety, and so on. The selection of smart buildings depends on many criteria. Since this problem is described as a multi-criteria decision-making (MCDM) problem, MCDM methods will be used in this paper. A hybrid method is presented to evaluate smart buildings. The first method, MEREC, was used to calculate the weights of criteria, and the VIKOR model was used for ranking alternatives. Then applying those weights to the CoCoSo, COPRAS, and TOPSIS methods for making comparisons using Spearman`s correlation coefficients for ranking these four methods. All methods used are applied in the T2NN environment.

Keywords: Multi-Criteria Decision Making; Smart Building; Neutrosophic Theory; MEREC, VIKOR, TOPSIS, COPRAS, CoCoSo.

1. Introduction

The smart city has gained a lot of attention in recent years because it promises benefits such as high quality of life, economic prosperity, and environmental sustainability through advanced technologies [1]. Smart cities are a dynamic, integrated ecosystem that uses advanced technology such as integration of information and communication technologies (ICT), internet of things (IoT) devices, software solutions, user interfaces (UI), AI, data analysis and communication networks.

Smart cities use data analysis to collect and analyze data from various sources, and this data is processed to enable decision makers to take the necessary measures to create a sustainable environment, facilitate citizens' lives, improve energy efficiency, and improve quality of life in general, such as transportation, energy, public safety, water resources, etc. Smart cities use this technology to be applied in different parts of the city, such as the smart traffic system, to improve traffic, avoid congestion, save time, and maintain citizen safety. Smart lighting system to save energy and reduce costs. Waste management and recycling systems, and water management systems to preserve materials. These applications result in improving energy consumption, generating clean energy, and enhancing the efficiency of its use.

Smart cities are characterized by several features like, connectivity, data collection and analysis, infrastructure, sustainability, public services, citizen engagement, security, innovation, ecosystem, efficient transportation, see Figure 1.

With the rapid development of artificial intelligence, the concept of smart building has been proposed to improve the performance and efficiency in the life cycle of a building [2]. the whole world is starting to realize the important of data and technology to improve citizens' quality of life, enhance sustainability, and optimize urban infrastructure. The whole world is seeking to build smart cities to help leaders make decisions that contribute to improving the quality of life for citizens, enhance efficiency, safety, and overall performance. Smart Buildings play a crucial role in transforming urban landscapes by incorporating advanced technologies and intelligent systems contributes to sustainability goals by reducing energy consumption and environmental impact, optimize resource utilization, and enhance overall building performance.

In smart buildings, technology and some advanced algorithms are used to monitor air quality, temperature, energy levels, humidity, the extent of pollution produced, and water consumption to enable officials to take the necessary measures to maintain a sustainable environment. Systems have also been built that can evaluate risk and emergency situations and respond quickly to them, such as natural disasters, accidents, and terrorist attacks, and provide means of safety and preservation of citizens, such as providing immediate evacuation methods or providing first aid.

Here are key features and components of smart buildings:

- Energy Efficiency: Smart buildings using advanced sensors, automation systems, and real-time data analytics to detect energy consumption and adjust lighting and HVAC systems to improve efficiency, reduce costs, reduce dependence on non-renewable energies, and use renewable energies.

- Building Automation Systems (BAS): BAS It is an integrated system that includes the building's various systems, such as heating, ventilation, air conditioning (HVAC), lighting, security, and so on, to facilitate the process of managing and controlling the building and improving its maintenance.
- Smart Infrastructure: Smart Buildings are part of an interconnected ecosystem within Smart Cities. Using networked devices, cloud-based platforms, and interoperable technologies we can share data with other systems, such as transportation, water management, and public safety, enabling better coordination and resource allocation for improved management of building ensuring optimal building performance and reducing maintenance costs.
- Enhanced Connectivity: Smart buildings are equipped with sensors that monitor ambient conditions, occupancy, and other parameters, allowing monitoring and control of building performance, occupancy patterns, and energy use.
- Advanced Security Systems: Smart buildings are equipped with security systems such as surveillance cameras and intrusion detection devices to detect and prevent threats and risks such as fires and burglaries.
- Resilience and Adaptability: Technology is used in smart buildings to monitor environmental conditions to make buildings have the ability to adapt to conditions as well as respond to them dynamically, adjust energy usage during peak demand, and integrate with renewable energy sources for increased resilience.
- Economic Benefits: Smart Buildings attract businesses and stimulate economic growth in smart cities. Their energy-efficient features and advanced infrastructure make them attractive to companies seeking sustainable and technologically advanced spaces.
- Predictive Maintenance: Sensors and data analytics enable predictive maintenance by monitoring the condition of building equipment. This helps identify potential issues before they lead to failures, reducing downtime and maintenance costs.

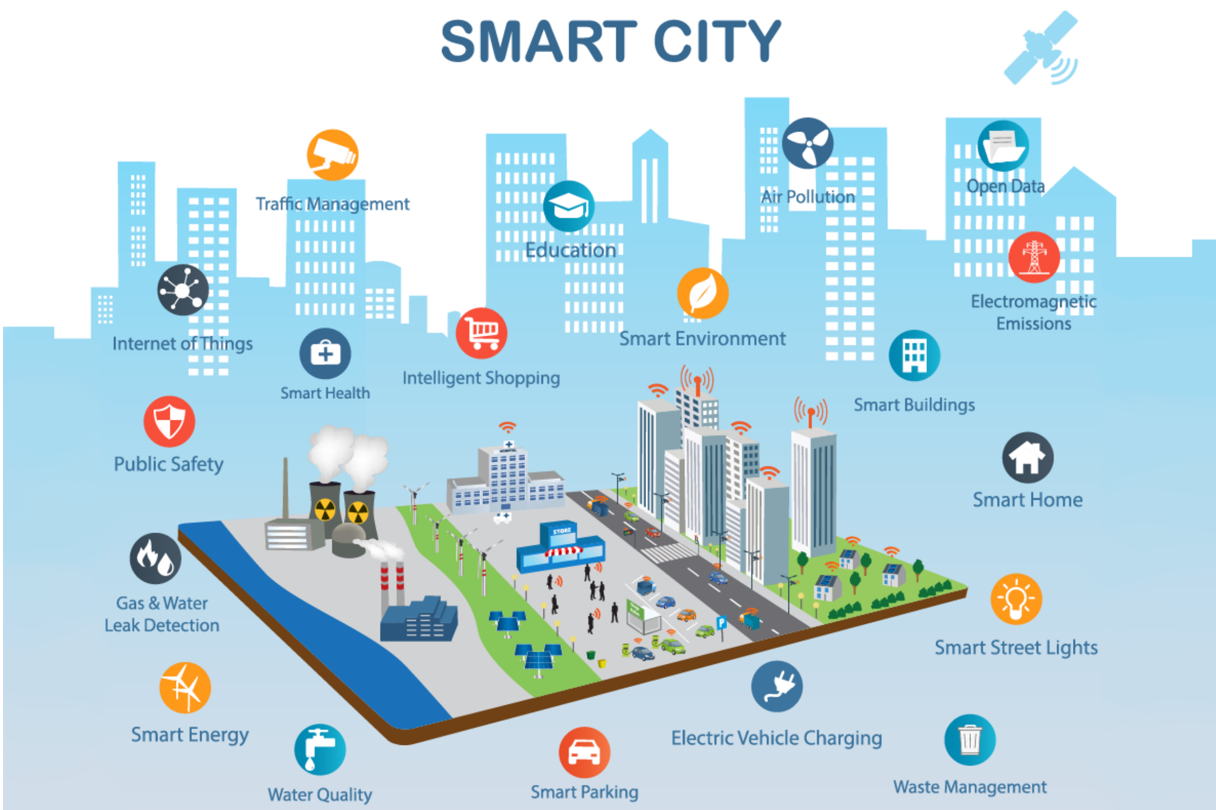

Figure 1. Smart city.

Egypt aim to build new administrative capital and intend to make it smart city. The Egyptian government has planned to build many smart cities recently, and they are currently being built, with the new administrative capital on top of these cities. The New Administrative Capital is one of the most important smart cities that Egypt is building according to the standards of fourth generation cities, as it was designed to become one of the largest capitals in the world. Its total area is about 170 thousand acres, which is larger than the area of Singapore, to accommodate 18 to 40 million people by 2025. President Abdel Fattah El-Sisi decided to build the Administrative Capital to relieve congestion in Cairo, so that the new capital will be the new headquarters for Egypt's government. Among the most important features of the city are the elegance of architectural design, the electricity generation system, ease of transportation, a smart waste collection system, and a security command and control center in the capital. One of the most important features of smart cities is smart buildings, so the government seeks to make the capital's buildings smart buildings.

Multi-criteria decision-making (MCDM) problem has many methods that can assess each criterion. To choose the most suitable smart building solution, MCDM approach are applied.

MCDM is a problem-solving technique that incorporates decision-makers' preferences to identify the best alternative. By assigning weights to each criterion based on the decision-makers' preferences and using suitable evaluation methods, such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) or the Simple Additive Weighting (SAW) method, you can identify the smart building solution that best aligns with your organization's needs and priorities. The weights of criteria are very crucial and imperative to the problem as they influence the outcome of the decision- making process and may lead to unpredictable results [3]. weights show the importance for each criteria in the problem. Weighting methods can be divided into three categories: subjective, objective and combinative. Subjective methods require DMs to take responsibility for assigning weights to the criteria depending on their preference, subjective methods like (Direct Ranking, Point allocation, Pairwise Comparisons, SMART) but this type of method is not efficient enough when the number of criteria increase. In contrast, objective methods do not involve DMs in determining the relative importance of the criteria but instead use mathematical algorithms based on initial data or decision matrix like Entropy, CRITI. The combinative approach involves a blend of both subjective and objective methods [4]. This paper aim to show a new hybrid method to help decision makers to select best city. First MEREC method (Method based on the Removal Effects of Criteria), for determining criteria weights [5], The VIKOR method used to solve various decision-making issues based on multi-criteria. Additionally, the proposed approach is presented in the type-2 neutrosophic number (T2NN). Hence, the T2NN-MEREC method is used to calculate the weight of each criterion then T2NN-VIKOR method is used to evaluate and rank alternatives.

Finally, this paper including a comparative between four methods VIKOR, COPRAS, TOPSIS and COCOSO and rank disagreements are expressed using spearman`s correlation coefficients.

1.1 Contributions of this study

The primary contribution of this study are summarized below: This paper development of a new approach MEREC method with VIKOR method based on T2NN. The proposed approach T2NN-MEREC-VIKOR improve performance of decision making problems. This study provides a suggestion for the government for selecting best smart city and proposed a comparative analysis between MCDM methods for evaluating alternatives. Finally, sensitivity analysis and a comparative analysis are presented to prove the robustness, and stability of the proposed approach.

1.2 Organization of the paper

This paper is organized as follows: In section 2, a literature review the studies used in this paper. Section 3, introduce the concept and methodology for the suggested approach T2NN-MEREC-VIKOR. Section4, introduce case study for this method. Finally, Section5, proposed the sensitivity and comparative analysis between some of MCDM methods using spearman`s correlation coefficients. Section 6 display the conclusion of this study.

2. Literature Review

In this section, simple explanation will be given contain literature associated with this study. This part consists of three sub-parts. the first one present studies related to smart building. second part introduce the studies that explain the neutrosophic numbers T2NN. Third part present some literature about MEREC, VIKOR, COCOSO, COPRAS, and TOPSIS methods.

2.1 Smart Building

Building performance optimization is a multidisciplinary field that encompasses various aspects, including building rating systems, energy simulation algorithms, AI and ML technologies, and project delivery methodologies. As the global energy crisis continues to exert pressure on the construction industry, there is an increasing need for innovative solutions to ensure the efficient and sustainable operation of buildings. Given the importance of building performance, developing an innovative MCDM method is necessary to promote the Efficiency and effectiveness in building performance-based design [6].

The goal of optimization in building performance design is to identify the best design solution for a specific building application, considering factors such as energy efficiency, indoor environmental quality, cost, and other criteria specified by the client or the regulatory requirements. MCDM can be applied to evaluate and select the final optimization solution among several alternative solutions. This process involves assigning weights to the criteria, forming decision matrices, and calculating the normalized decision matrix to determine the relative preference for each solution. Building performance optimization is a critical issue in the AEC field, which requires the development and implementation of innovative algorithms and methodologies. By applying MCDM and other evaluation techniques, the optimal solution for a specific building performance optimization problem can be determined, leading to the design and construction of more efficient, sustainable, and cost-effective buildings. MCDM or Multi-Criteria Decision

Analysis (MCDA), is one of the most accurate methods of decision-making, and it can be known as a revolution in this field [7].

2.2 T2NN Environment

Type-1 neutrosophic number (T1NNS) is a mathematical concept introduced by Florentin Smarandache in early 1990s as a generalization of fuzzy numbers to capture the nature of human judgments and beliefs, which can be expressed as true, false, or indeterminate. It has been successfully applied in various fields, including building performance optimization, to improve the accuracy and robustness of decision-making processes. The concept of T1NNS is based on three levels of truth: True, False, and Indeterminate. The True level represents beliefs that are confirmed, the false level represents beliefs that are refuted, and the indeterminate level represents beliefs that are uncertain or have not been evaluated yet. Smarandache proposed the neutrosophic sets in [8-9, 23]. Type-2 neutrosophic number (T2NNS) is an extension of the concept of a T1NN to a higher level of indeterminacy [24]. This extension enables a more comprehensive representation of the beliefs of decision-makers and their degree of confidence in the beliefs. The neutrosophic sets proved to be a valid workspace in describing incompatible and indefinite information. z(T, I, F) is a Type-1 Neutrosophic Number. But z((T_t, T_i,T_f), (I_t, I_i,I_f), (F_t, F_i, F_f)) is a Type-2 Neutrosophic Number, which means that each neutrosophic component T, I, and F is split into its truth, indeterminacy, and falsehood subparts [10]. Then, T2NN has become a preferred tool by scholar and researchers in recent time.

2.3 MCDM Methods

MCDM methods are used in many fields [11, 12]. These methods help to compare alternatives and find the best one [13]. There are various MCDM technique that have been employed to deal with several real-world decision making issues. Keshavarz-Ghorabaee et al. [5] a new Method based on the Removal Effects of Criteria (MEREC). This method used for determining criteria weights. Saidin et al. [14] mention that MEREC can solve fuzzy MCDM problems. Shanmugasundar et al. [15] introduce application of MEREC in multi-criteria selection. MEREC focuses on the change in the total criteria weight by disabling that criterion when determining the weight of a criterion.

Also, VIKOR method has been utilizes in several literatures. VIKOR used to prioritize and rank different alternatives. It is based on the concept of stochastic dominance, which considers both the strength and the number of attributes that exceed a particular threshold. VIKOR (Vise

Kriterijumska Optimizajica I Kompromisno Resenje) was first introduced by Serafim Opricovic in 1998. VIKOR aims to complete decision-making on existing alternatives by ranking and choosing sample sets with conflicting criteria [16]. Sayadi et al. [17] introduce extension of VIKOR method for decision making problem with interval numbers. Shumaiza et al. [18] present VIKOR method with trapezoidal bipolar fuzzy information. Yazdani et al. [19] proposed a technique called the combined compromise solution (CoCoSo) for an MCDM problem which is based on integrated simple additive weighing and an exponentially weighted product model. TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method, which is one of the most widely used MCDM methods [20]. TOPSIS is one of the fundamental methods in MADM domain and has been immensely popular in applications and as foundation to numerous method development [21, 22].

3. Methodology

This section introduces the methodology for each study in this paper. this section also divided into three parts. First, some basic concept and definitions about T2NN. Second MEREC method to determine the weights for each criterion, then the MCDM methods proposed for ranking best alternatives form smart buildings.

Four steps to evaluate process using MCDM approaches:

- Defining alternatives and criteria related to problem.
- Determine weights of each criteria using one of the MCDM methods.
- Assigning individual performance to each option.
- Evaluate alternatives based on the aggregate performance of them on all criteria.

3.1 Preliminaries

In this part definitions and some concepts and operations associated with T2NN are given below:

Definition 1 [10]. We consider that Z is limited universe of discourse and F[0,1] is the set of all triangular neutrosophic numbers on F[0,1] .

A Type 2 neutrosophic number set (T2NNS) $\widetilde{U}$ in Z is represented by:

$$\widetilde{U} = \left\langle \left(T_{T_{\widetilde{U}}}(z), T_{I_{\widetilde{U}}}(z), T_{F_{\widetilde{U}}}(z)\right), \left(I_{T_{\widetilde{U}}}(z), I_{I_{\widetilde{U}}}(z), I_{F_{\widetilde{U}}}(z)\right), \left(F_{T_{\widetilde{U}}}(z), F_{I_{\widetilde{U}}}(z), F_{F_{\widetilde{U}}}(z)\right) \right\rangle \quad (1)$$

Where $\breve{T}_{\widetilde{U}}(z) : Z \to F[0,1]$, $\tilde{I}_{\widetilde{U}}(z) : Z \to F[0,1]$, $\breve{F}_{\widetilde{U}}(z) : Z \to F[0,1]$. The type -2 neutrosophic number set $\breve{T}_{\widetilde{U}}(z) = \left(T_{T_{\widetilde{U}}}(z), T_{I_{\widetilde{U}}}(z), T_{F_{\widetilde{U}}}(z)\right)$, $\tilde{I}_{\widetilde{U}}(z) = \left(I_{T_{\widetilde{U}}}(z), I_{I_{\widetilde{U}}}(z), I_{F_{\widetilde{U}}}(z)\right)$, $\breve{F}_{\widetilde{U}}(z) = \left(F_{T_{\widetilde{U}}}(z), F_{I_{\widetilde{U}}}(z), F_{F_{\widetilde{U}}}(z)\right)$ defined as the truth, indeterminacy and falsity member-ships of z in $\widetilde{U}$.

Definition 2 [10]. Suppose that

$\widetilde{U}_1 = \left\langle \left(T_{T_{\widetilde{U}_1}}(z), T_{I_{\widetilde{U}1}}(z), T_{F_{\widetilde{U}1}}(z)\right), \left(I_{T_{\widetilde{U}1}}(z), I_{I_{\widetilde{U}1}}(z), I_{F_{\widetilde{U}1}}(z)\right), \left(F_{T_{\widetilde{U}1}}(z), F_{I_{\widetilde{U}1}}(z), F_{F_{\widetilde{U}1}}(z)\right) \right\rangle$ and

$\widetilde{U}_2 = \left\langle \left(T_{T_{\widetilde{U}_2}}(z), T_{I_{\widetilde{U}_2}}(z), T_{F_{\widetilde{U}2}}(z)\right), \left(I_{T_{\widetilde{U}2}}(z), I_{I_{\widetilde{U}2}}(z), I_{F_{\widetilde{U}2}}(z)\right), \left(F_{T_{\widetilde{U}2}}(z), F_{I_{\widetilde{U}2}}(z), F_{F_{\widetilde{U}_2}}(z)\right) \right\rangle$

Are two T2NNs then the following equations describe some of T2NN operators.

- $$\widetilde{U}_1 \oplus \widetilde{U}_2 = \left\langle \begin{matrix} \begin{pmatrix} T_{T_{\widetilde{U}_1}}(z) + T_{T_{\widetilde{U}_2}}(z) - T_{T_{\widetilde{U}_1}}(z).T_{T_{\widetilde{U}_2}}(z),\ T_{I_{\widetilde{U}1}}(z) + T_{I_{\widetilde{U}2}}(z) - T_{I_{\widetilde{U}1}}(z).T_{I_{\widetilde{U}2}}(z), \\ T_{F_{\widetilde{U}1}}(z) + T_{F_{\widetilde{U}2}}(z) - T_{F_{\widetilde{U}1}}(z).T_{F_{\widetilde{U}2}}(z) \end{pmatrix}, \\ \left(I_{T_{\widetilde{U}1}}(z).I_{T_{\widetilde{U}2}}(z), I_{I_{\widetilde{U}1}}(z).I_{I_{\widetilde{U}2}}(z), I_{F_{\widetilde{U}1}}(z).I_{F_{\widetilde{U}2}}(z)\right), \\ \left(F_{T_{\widetilde{U}1}}(z).F_{T_{\widetilde{U}2}}(z), F_{I_{\widetilde{U}1}}(z).F_{I_{\widetilde{U}2}}(z), F_{F_{\widetilde{U}1}}(z).F_{F_2}(z)\right) \end{matrix} \right\rangle \quad (2)$$
- $$\widetilde{U}_1 \otimes \widetilde{U}_2 = \left\langle \begin{matrix} \left(\left(T_{T_{\widetilde{U}_1}}(z).T_{T_{\widetilde{U}_2}}(z), T_{I_{\widetilde{U}1}}(z).T_{I_{\widetilde{U}2}}(z), T_{F_{\widetilde{U}1}}(z).T_{F_{\widetilde{U}2}}(z)\right)\right), \\ \left(\left(I_{T_{\widetilde{U}1}}(z) + I_{T_{\widetilde{U}2}}(z) - I_{T_{\widetilde{U}1}}(z).I_{T_{\widetilde{U}2}}(z)\right), \left(I_{I_{\widetilde{U}1}}(z) + I_{I_{\widetilde{U}2}}(z) - I_{I_{\widetilde{U}1}}(z).I_{I_{\widetilde{U}2}}(z)\right), \begin{pmatrix} I_{F_{\widetilde{U}1}}(z) + I_{F_{\widetilde{U}2}}(z) - \\ I_{F_{\widetilde{U}1}}(z).I_{F_{\widetilde{U}2}}(z) \end{pmatrix}\right) \\ \left(\left(F_{T_{\widetilde{U}1}}(z) + F_{T_{\widetilde{U}2}}(z) - F_{T_{\widetilde{U}1}}(z).F_{T_{\widetilde{U}2}}(z)\right), \left(F_{I_{\widetilde{U}1}}(z) + F_{I_{\widetilde{U}2}}(z) - F_{I_{\widetilde{U}1}}(z).F_{I_{\widetilde{U}2}}(z)\right), \begin{pmatrix} F_{F_{\widetilde{U}1}}(z) + F_{F_2}(z) - \\ F_{F_{\widetilde{U}1}}(z).F_{F_2}(z) \end{pmatrix}\right) \end{matrix} \right\rangle \quad (3)$$
- Score function

$$S(\widetilde{U}) = \frac{1}{12}\left\langle 8 + \left(T_{T_{\widetilde{U}1}}(Z) + 2\left(T_{I_{\widetilde{U}1}}(Z)\right) + T_{F_{\widetilde{U}1}}(Z)\right) - \left(I_{T_{\widetilde{U}1}}(Z) + 2\left(I_{I_{\widetilde{U}1}}(Z)\right) + I_{F_{\widetilde{U}1}}(Z)\right) - \left(F_{T_{\widetilde{U}1}}(Z) + 2\left(F_{I_{\widetilde{U}1}}(Z)\right) + F_{F_{\widetilde{U}1}}(Z)\right)\right\rangle \quad (4)$$

Definition 3 [10]. To Build the evaluation matrix $A_i \times Œ_{ip}$ to assess the classification of alternatives with respect to each criterion.

$$\breve{R} = \begin{matrix} & Œ_{ip} & \cdots & Œ_{in} \\ Alt_1 & \breve{Z}_{11} & \cdots & \breve{z}_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ Alt_m & \breve{Z}_{m1} & \cdots & \breve{Z}_{mn} \end{matrix} \quad (5)$$

3.2 MEREC method

In this section, the following steps present the MEREC method that used to evaluate the weights of criteria in MCDM problems as mentioned if the Figure 2.

Step 1. Build the decision matrix which element will be x_{ij}, and matrix consist of n x m where n numbers of criteria and m numbers of alternatives , then matrix form is :

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{im} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \quad (6)$$

Step 2. Normalize this matrix using the following Eq. (7).

$$n_{ij}^{x} = \begin{cases} \frac{\min_k x_{kj}}{x_{ij}}, & if\ j \in B \\ \frac{x_{ij}}{\max_k x_{kj}}, & if\ j \in H \end{cases} \quad (7)$$

where B is the set of beneficial criteria and H is the set of non-beneficial criteria.

Step 3. The overall efficiency of the alternatives (S_i) is calculated using Eq. (8).

$$S_i = \ln\left(1 + \frac{1}{m} \sum_j \left|\ln(n_{ij}^{x})\right|\right) \quad (8)$$

Step 4. Based on method idea, calculate the performance of the alternatives by removing each criterion. So, $\grave{S_{ij}}$ denotes as the overall performance of ith alternative concerning the removal of jth criterion.

$$\grave{S_{ij}} = \ln\left(1 + \left(\frac{1}{m} \sum_{k,k\neq j} \left|\ln(n_{ik}^{x})\right|\right)\right) \quad (9)$$

Step 5. Calculating the absolute value of the deviations using Eq. (10), E_j the difference between Step 3 and Step 4.

$$E_j = \sum_i \left| \grave{S_{ij}} - S_i \right| \quad (10)$$

Step 6: The weights of criteria is computed as follow using Eq. (11).

$$W_j = \frac{E_j}{\sum_k E_k} \quad (11)$$

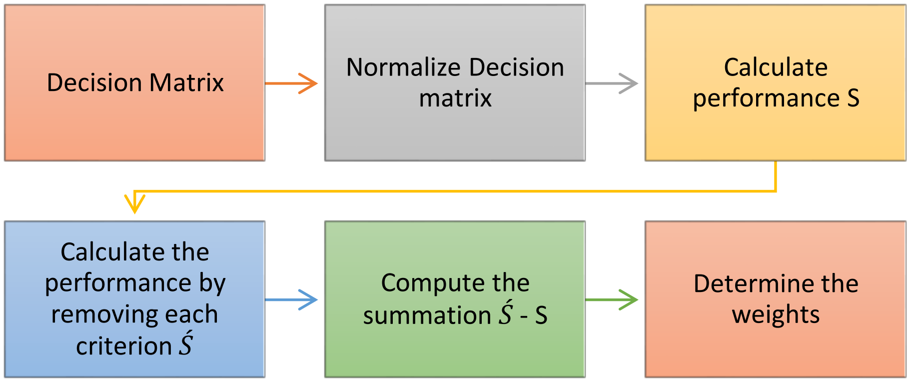

Figure 2. Steps for MEREC method.

3.3 VIKOR method

In this part VIKOR steps are introduced to rank alternatives based on weights given from MEREC method as mentioned in Figure 3.

Step 1. Define the decision matrix. This matrix is defined as follow:

$$F = \begin{matrix} & C_{x1} & C_{x2} & \cdots & C_{xn} \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_3 & x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix} \quad (12)$$

Where A_i denote alternatives as i = 1,2, 3, …., n and C_{xn} denote criteria as j = 1,2, 3, …., m

Step 2. Determining best (f_j^*) and worst (f_j^-) performance values as the ideal solution for all criteria, to normalize decision matrix as the following equations:

$$f_j^* = max_j \, f_{ij} \text{ and } f_j^- = min_j \, f_{ij} \quad (13)$$

$$f_j^* = min_j \, f_{ij} \text{ and } f_j^- = max_j \, f_{ij} \quad (14)$$

Step 3. The utility measure (S_i) and regret measures (R_i) are calculated as follow:

$$S_i = \sum_{j=1}^{n} W_j \frac{(f^* - f_{ij})}{(f_j^* - f_j^-)} \quad (15)$$

$$R_i = max_j \left[W_j \frac{(f^* - f_{ij})}{(f_j^* - f_j^-)} \right] \quad (16)$$

where W_j is the weight of each criterion with the MEREC.

Step 4. Finally, the value of Q_i is calculated known as VIKOR index using Eq. (17).

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1\text{-}\,v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \quad (17)$$

Where $S^* = min_i\, S_i$ and $S^- = max_i\, S_i$

$R^* = min_i\, R_i$ and $R^- = max_i\, R_i$

Step 5. Ranking is applied on Q_i by ascending order.

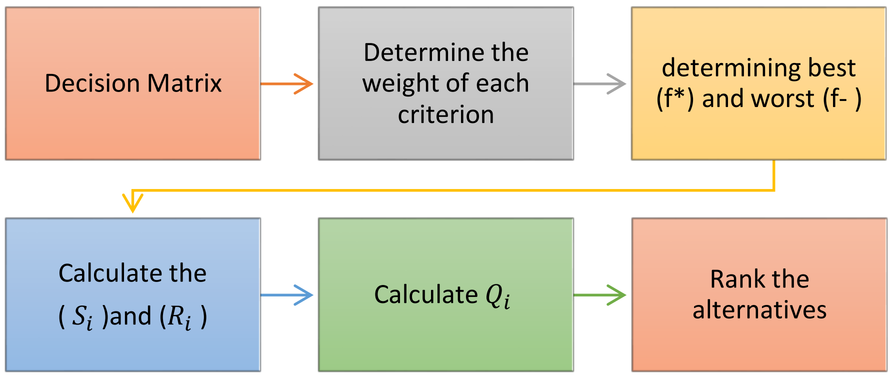

Figure 3. Steps for VIKOR method.

3.4 TOPSIS method

Here are the steps for TOPSIS method.

Step 1. Construct decision matrix same as the following above.

Step 2. Calculating the normalized matrix based on this equation:

$$\alpha_{ij} = \frac{x_{ij}}{\sqrt{\sum (X_{ij})^2}}$$

Step 3. Assigning weights to decision matrix as follow:

$$X_{ij} = \alpha_{ij} * W_j$$

Step 4. Define best and worst solution

$$X_i^b = \max x_{ij} \quad \text{as best value}$$

$$X_i^w = \min x_{ij} \quad \text{as worst value}$$

Step 5. Calculating Euclidean distance for best and worst values.

$$d_i^b = \sqrt{\sum (x_{ij} - X_j^b)^2}$$

$$d_i^w = \sqrt{\sum (x_{ij} - X_j^w)^2}$$

Step 6. Calculating Value of D_i by

$$D_i = \frac{d_i^w}{d_i^w + d_i^b}$$

Step 7. Ranking based on D_i values while the largest D_i is best alternatives.

3.5 COCOSO method

Here are the steps for COCOSO method.

Step 1. Construct decision matrix same as the following above.

Step 2. Determine the normalized matrix by the following equation:

$$r_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \quad \text{for benefit criterion}$$

$$r_{ij} = \frac{maxx_{ij} - x_{ij}}{maxx_{ij} - minx_{ij}} \quad \text{for cost criterion}$$

Step 3. As, CoCoSo method consists of the integration of methods such as the WASPAS, SAW and EWP. So, based on WASPAS method S_i ,P_i are computed as follow:

$$S_i = \sum w_i \,.\, r_{ij}$$

$$P_i = \sum (\, r_{ij})^{w_i}$$

Step 4. Three appraisal score strategies are calculated

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} P_i + S_i}$$

$$k_{ib} = \frac{S_i}{min\ S_i} + \frac{P_i}{min\ P_i}$$

$$k_{ic} = \frac{\lambda . S_i + (1-\lambda) P_i}{\lambda . \max S_i + (1-\lambda) \max P_i}$$

Where λ usually =0.5 but its range from 0 to1.

Step 5. Final step final ranking for all alternatives based on performance k_i

$$k_i = (k_{ic} + k_{ib} + k_{ic})^{\frac{1}{3}} + \frac{1}{3} (k_{ic} + k_{ib} + k_{ic})$$

3.6 COPRAS method [26]

Step 1. Same as all MCDM method first step is to construct decision matrix.

Step 2. Normalize matrix using these formula.

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

Step 3. Obtain weighted normalized matrix by:

$$\breve{r_{ij}} = r_{ij} \, . w_i$$

Step 4. Determine maximize and minimize for each alternative

$$S^{+} = \sum_{j=1}^{k} \breve{r_{ij}}$$

$$S^{-} = \sum_{j=k+1}^{k} \breve{r_{ij}}$$

Step 5. Calculate the relative weight for each alternative

$$Q_i = S^{+} + \frac{min\, S^{-} \ \sum_{i=1}^{m} S^{-}}{S^{-} \quad \sum_{i=1}^{m} \frac{min\, S^{-}}{S^{-}}}$$

Step 6: The priority order of the alternatives is ranked using the value of Qi in descending order. The highest relative weight is the most acceptable alternative.

4. Case Study

4.1 problem definition

The problem definition of smart buildings revolves around addressing challenges and inefficiencies in traditional building systems by integrating advanced technologies to enhance efficiency, sustainability, safety, and occupant comfort.

With the dense population increase, there are several problems facing traditional buildings that affect the environment and the quality of life of citizens, as well as the consumption of energy and resources in general. Traditional buildings face several problems, including overlapping buildings and an increase in shared spaces, thus increasing the risk of theft, harm to citizens, and lack of security. Therefore, smart buildings are designed to provide more privacy and security through sensors, surveillance cameras, and a security system to prevent unauthorized persons from accessing the buildings.

Among the most important problems that traditional buildings suffer from is the increase in energy costs and their increased impact on the environment resulting from increased heat. Therefore, smart buildings contain an energy management system that can track energy consumption and adjust the system settings to adapt to the results after obtaining them after collecting data and adjusting the control of heating and ventilation mechanisms. And air conditioning. There are many other problems that must be overcome, therefore, by addressing these challenges by using technology in smart buildings to improve citizens' lives, reduce energy consumption, provide safety, improve the quality of buildings, optimize the use of resources, and improve economic growth.

Smart cities seek to build a better future through advanced technology and modern technologies. One of the most important smart cities is OSLA the first smart city in the world. There are several smart cities like Barcelona, Spain, Columbus, Ohio, USA, Dubai, United Arab Emirates, Hong Kong, China, Kansas City, Missouri, USA, London, England, Melbourne, Australia. Egypt also aims to become an ideal model for cultural environmental development, and in order to choose the best solutions, the Egyptian government can use different evaluation methods. In this paper, a method is used to obtain the weights of the criteria. Smart buildings use wide rang technology and its intelligence to design building and collect data from citizen, systems and sensors and analyze these data and optimize smart building.

To get a comprehensive and balanced ranking, the government can use the T2NN algorithm, which is an Artificial Neural Network approach that considers both qualitative and quantitative factors. This approach can provide a reliable ranking of potential smart city candidates based on their overall suitability and ability to contribute to Egypt's goal of developing smart, sustainable, and environmentally friendly cities.

4.2 Description of alternatives and criteria

Several cities around the world have been implementing smart technologies, including smart buildings, to enhance urban living. So, we choose of cities that have made strides in adopting smart building technologies:

- Alt1: Singapore: has been a pioneer in the development of smart city technologies. As it depends on the use of sensors and data analytics in buildings for energy efficiency, waste management, and urban planning.
- Alt2: Barcelona, Spain: has implemented the "Smart City Barcelona" initiative, leveraging technologies for smart lighting, waste management, and transportation. Smart building solutions are integrated into the city's infrastructure to enhance energy efficiency and sustainability.

- Alt3: Seoul, South Kore: has focused on creating a smart city infrastructure with an emphasis on smart buildings. The city has implemented energy-efficient technologies, smart grids, and advanced transportation systems to improve overall urban sustainability.
- Alt4: Dubai, United Arab Emirates: has been working towards becoming a smart city with initiatives like the Smart Dubai project. The city has incorporated smart building technologies for energy management, smart lighting, and integrated data systems.

The criteria for defining a smart building can vary, but generally, they encompass the integration of intelligent systems and data-driven solutions. Here are key criteria for smart buildings:

- C1: Energy Efficiency: Integration of energy-efficient technologies, such as smart lighting systems, occupancy sensors, and energy management systems, to optimize energy consumption and reduce environmental impact.
- C2: Building Advanced Security Systems: Implementation of security systems, including access control, and intrusion detection, often integrated with other building systems.
- C3: Data Analytics and Predictive Maintenance: Use of data analytics to gain insights into building performance, enabling predictive maintenance to address potential issues before they become critical.
- C4: Resilience and Disaster preparedness: Conduct a comprehensive risk assessment to identify potential hazards and vulnerabilities specific to the building's location, such as earthquakes, floods, hurricanes, or other natural disasters.

4.3 Applying MEREC to get weights then using VIKOR method to rank alternatives

Step 1. Organize alternative and criteria based on our expert’s opinion in Table 1, according to Eq. (5).

- Experts use the linguistic terms presented in Table 7 [10].
- Aggregate the finial evaluation matrix using Eq. (4) to form the decision matrix in Table 2.

Table 1. Classification of alternatives by experts.

Expert	Alt n	C1	C2	C3	C4
$Expert_1$	Alt1	MG	G	VG	MG
$Expert_2$	Alt2	VB	VG	G	B
$Expert_3$	Alt3	B	MG	MG	M
$Expert_4$	Alt4	G	MB	VG	MG

Table 2. Decision matrix.

	Criteria	
	$C_1 \in B$	$C_2 \in B$
Alt_1	⟨(0.617,0.599,0.623); (0.013,0.001,0.014); (0.003,0.005,0.005)⟩	⟨(0.476,0.440,0.453); (0.013,0.018,0.030); (0.008,0.011,0.026)⟩
Alt_2	⟨(0.353, 0.308, 0.358); (0.043, 0.042, 0.064); (0.024, 0.032, 0.063)⟩	⟨(0.640, 0.613, 0.637); (0.002, 0.003, 0.007); (0.004, 0.007, 0.006)⟩
Alt_3	⟨(0.245, 0.245, 0.099); (0.070, 0.160, 0.193); (0.034, 0.160, 0.106)⟩	⟨(0.475, 0.393, 0.358); (0.006, 0.006, 0.017); (0.002, 0.016, 0.005)⟩
Alt_4	⟨(0.589, 0.588, 0.591); (0.006, 0.005, 0.003); (0.008, 0.005, 0.002)⟩	⟨(0.383, 0.261, 0.358); (0.054, 0.003, 0.057); (0.030, 0.024, 0.084)⟩
	Criteria	
	$C_3 \in H$	$C_4 \in H$
Alt_1	⟨(0.650,0.619,0.650); (0.003,0.004,0.004); (0.001,0.008,0.005)⟩	⟨(0.653,0.629,0.650); (0.006, 0.005,0.006); (0.008, 0.006,0.001)⟩
Alt_2	⟨(0.552, 0.544, 0.593); (0.004, 0.005, 0.009); (0.002, 0.002, 0.008)⟩	⟨(0.393, 0.351, 0.358); (0.033, 0.039, 0.060); (0.026, 0.030, 0.059)⟩
Alt_3	⟨(0.603, 0.539, 0.571); (0.001, 0.008, 0.001); (0.001, 0.001, 0.004)⟩	⟨(0.485, 0.420, 0.458); (0.005, 0.003, 0.011); (0.001, 0.008, 0.003)⟩
Alt_4	⟨(0.664, 0.657, 0.664); (0.003, 0.003, 0.004); (0.004, 0.004, 0.004)⟩	⟨(0.588, 0.510, 0.571); (0.003, 0.001, 0.002); (0.008, 0.001, 0.002)⟩

Here we have two beneficial criteria C1, C2 and two non-beneficial criteria C3, C4.

Step 2. Use Eq. (4) to modify type 2 neutrosophic numbers to the crisp represented in Table 3.

Table 3. Crisp numbers.

Alternatives	$C1$	$C2$	$C3$	$C4$
Alt1	0.8659	0.8061	0.8765	0.8598
Alt2	0.7488	0.8720	0.8497	0.7614
Alt3	0.6493	0.7954	0.8523	0.8118
Alt4	0.8597	0.7487	0.8844	0.8467

Step 3. Applying MEREC method to get weight, use Eq. (7) to get normalized decision matrix as shown in Table 4.

Table 4. Normalized decision matrix

Alternatives	$C1$	$C2$	$C3$	$C4$
Alt1	0.75	0.93	0.99	1

Alt2	0.87	0.86	0.96	0.89
Alt3	1	0.94	0.96	0.94
Alt4	0.75	1	1	0.98

Step 4. Obtain overall efficiency of the alternatives (S_i), using Eq. (8).

$$S_1 = ln\left(1 + \frac{1}{4}\ (|\ln(0.75)| + |\ln(0.93)| + |\ln(0.99)| + |\ln(1)|\ )\right) = 0.088$$

$$S_2 = ln\left(1 + \frac{1}{4}\ (|\ln(0.87)| + |\ln(0.86)| + |\ln(0.96)| + |\ln(0.89)|\ )\right) = 0.106$$

$$S_3 = ln\left(1 + \frac{1}{4}\ (|ln(1)| + |ln(0.94)| + |ln(0.96)| + |ln(0.94)|\ )\right) = 0.040$$

$$S_4 = ln\left(1 + \frac{1}{4}\ (|ln(0.75)| + |ln(1)| + |ln(1)| + |ln(0.98)|\ )\right) = 0.074$$

Step 5. Now, calculate the performance of the alternatives by removing each criterion. The result in Table 5 using Eq. (9). But first let's present an example $\grave{S_{11}}$.

$$\grave{S_{11}} = ln\left(1 + \frac{1}{4}\ (\ |\ln(0.93)| + |\ln(0.99)| + |\ln(1)|\ )\right) = 0.021$$

Table 5. Values of $\grave{S_{11}}$

Alternatives	$C1$	$C2$	$C3$	$C4$
Alt1	0.021	0.072	0.086	0.088
Alt2	0.074	0.072	0.061	0.08
Alt3	0.040	0.025	0.030	0.025
Alt4	0.004	0.074	0.074	0.069

Step 6. Calculating the absolute value of the deviations using formula of Eq. (10).

$$E_1 = |0.021 - 0.088| + |0.072 - 0.106| + |0.086 - 0.040| + |0.088 - 0.074| = 0.161$$

$$E_2 = |0.074 - 0.088| + |0.072 - 0.106| + |0.061 - 0.040| + |0.08 - 0.074| = 0.075$$

$$E_3 = |0.040 - 0.088| + |0.025 - 0.106| + |0.030 - 0.040| + |0.025 - 0.074| = 0.188$$

$$E_4 = |0.040 - 0.088| + |0.074 - 0.106| + |0.074 - 0.040| + |0.069 - 0.074| = 0.155$$

Step 7. Finally, compute weight for each criterion using Eq. (11), as presented in Figure 4.

$$w_1 = 0.278$$

$$w_2 = 0.129$$

$$w_3 = 0.325$$

$$w_4 = 0.268$$

Figure 4. Weights of criteria.

Step 8. After calculating weights for every criterion we now using VIKOR method to rank alternatives but first we get Table 4.

Table 4. Normalized decision matrix.

Alternatives	$C1$	$C2$	$C3$	$C4$
Alt1	0.75	0. 93	0.99	1
Alt2	0.87	0.86	0.96	0.89
Alt3	1	0.94	0.96	0.94
Alt4	0.75	1	1	0.98

Step 9. Determine the PIS (best f_j^*) and NIS (worst f_j^-) by using Eq. (13) as presented in Table 5.

Table 5. PIS and NIS.

W_j	**0.278**	**0.129**	**0.325**	**0.268**
f_j^*	1	1	1	1
f_j^-	0.75	0.86	0.96	0.89

Step 10. Compute (S_i) and (R_i) of each alternative using Eq. (15) and Eq. (16) and the result will be founded in Table 6.

Step11. Calculate the value of VIKOR index, using Eq. (17) the result in Table 6. Notice that, v = 0.5**.**

Table 6. Final ranking of the alternatives.

Alternatives	$C1$	$C2$	$C3$	$C4$	S_i	R_i	Q_i	Rank
Alt1	0.278	0.06	0.081	0	0.419	0.278	0.103	3
Alt2	0.145	0.129	0.325	0.268	0.867	0.325	1	1
Alt3	0	0.055	0.325	0.146	0.526	0.325	0.684	2
Alt4	0.278	0	0	0.049	0.327	0.278	0	4
V= 0.5				S^*, R^*	0.327	0.278		
				S^-, R^-	0.867	0.325		

Step 13. After evaluating and ranking we found that the order for best alternatives of selecting the best smart city is A2, A3, and A4 as presented in Figure 5.

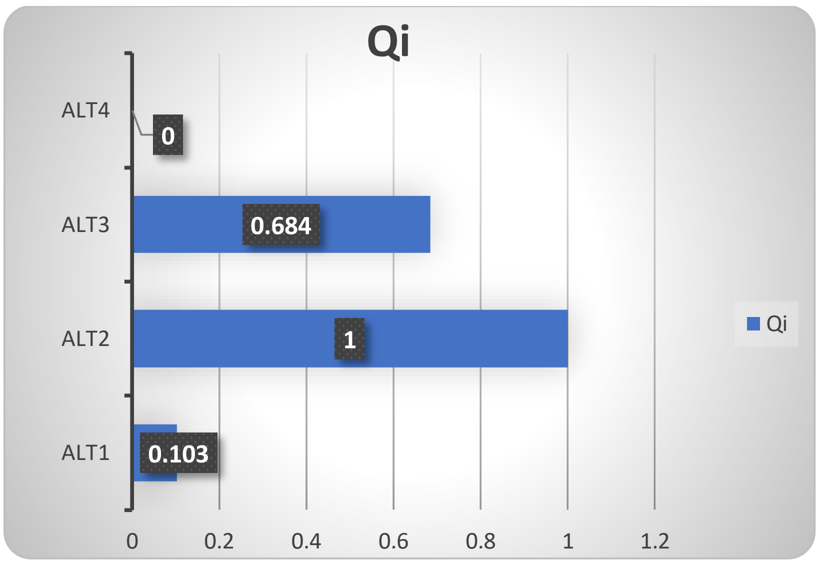

Figure 5. Ranking the alternatives.

4.4 Determining ranking of alternatives using MCDM methods

To deduce final best alternative, we use four methods (TOPSIS, CoCoSo, COPRAS)

4.4.1 TOPSIS Method

Ranking alternatives based on TOPSIS method shown in Table 7.

Table 7. Final ranking using TOPSIS method.

Alternatives	d^+	d^-	S_i	Rank
Alt1	0.587	0.0929	0.136	4
Alt2	0.02	0.02	0.5	2
Alt3	0.016	0.012	0.43	3
Alt4	0.026	0.038	0.59	1

4.4.2 CoCoSo Method

Ranking alternatives based on CoCoSo method shown in Table 8.

Table 8. Final ranking using CoCoSo method.

Alternatives	K_{ia}	K_{ib}	K_{ic}	K_i	Rank
Alt1	0.232	2.95	0.631	2.83	3
Alt2	0.368	5.195	1	4.059	1
Alt3	0.250	3.27	0.679	3.013	2
Alt4	0.149	2	0.404	2.218	4

4.4.3 COPRAS Method

Ranking alternatives based COPRAS method shown in Table 9.

Table 9. Final ranking using COPRAS method.

Alternatives	S^+	S^-	Q_i	Rank
Alt1	0.108	0.152	0.2515	2
Alt2	0.101	0.141	0.2557	1
Alt3	0.088	0.146	0.2374	4
Alt4	0.104	0.152	0.2465	3

4.5 Comparative Analysis

A comparative analysis can ensure experts to validate the outcomes by some changes in the essential model and clarify the robustness of the proposed methodology. Therefore, comparative analysis use comparing ranking results obtained by a MCDM methods used in this paper using Spearman's rank correlation coefficient.

The comparative analysis is compare of the ranking from MCDM techniques including COPRAS, TOPSIS, CoCoSo, and VIKOR. The final ranking of VIKOR, TOPSIS, CoCoSo and COPRAS methods is shown in Table 10 and Figure 6 represent the graphical chart of the ranking order for each method.

Table 10. Comparison of other MCDM methods.

Alternatives	VIKOR	TIPOSIS	CoCoSo	COPRAS
Alt1	3	4	3	2
Alt2	1	2	1	1
Alt3	2	3	2	4
Alt4	4	1	4	3

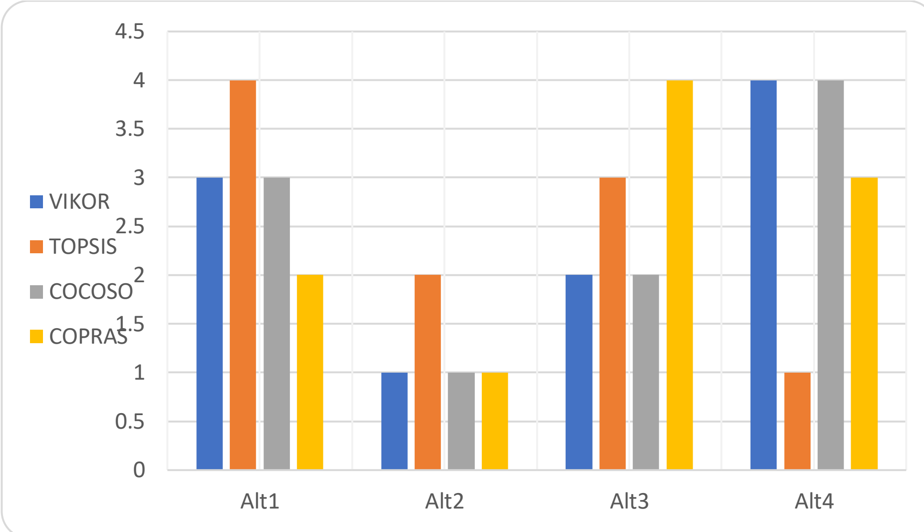

Figure 6. Final ranking of other MCDM methods.

Spearman's rank correlation coefficient, often denoted as r_s, is a measure of the strength and direction of a monotonic relationship between two variables. In other words, it assesses how well the variables are related, with direction and strength taken into account. Spearman's rank correlation coefficient ranges from -1 to 1:

- -1 indicates a perfect negative relationship (as one increases, the other decreases).
- 1 indicates a perfect positive relationship (as one increases, the other also increases).
- 0 indicates no relationship.

The Spearman's rank correlation coefficient can be calculated using, $r_s = 1 - \frac{6 \sum {d_i}^2}{m.(m^2-1)}$, where d_i difference in ranking of the alternative by the two methods and m is the number of alternatives.

5. Conclusions

Smart buildings, or "smart structures," are becoming increasingly popular due to their potential to enhance energy efficiency, improve indoor air quality, and optimize building operation costs. While these benefits are widely recognized, it is crucial to address challenges associated with the integration of technology into building systems. The first challenge is ensuring reliable connectivity. To maximize the potential of smart buildings, it is necessary to establish a robust network infrastructure that can handle data transfer at a high rate. This requires a careful selection of connectivity hardware, software, and security measures. Additionally, connectivity speed and reliability should be taken into account, as delays in data transmission can significantly impact the effectiveness of smart building systems. Another challenge is ensuring compatibility and integration of different smart building systems and components. The ability to easily connect, integrate, and synchronize different technologies is crucial for creating a fully functioning smart building ecosystem. This can be achieved by implementing a consistent set of standards and protocols across all components, ensuring smooth communication and seamless data sharing. Another challenge is dealing with data privacy and security. Smart buildings contain sensitive data, such as occupant information, energy usage patterns, and environmental conditions. It is crucial to protect this data from unauthorized access and ensure its confidentiality and integrity. This can be achieved by implementing strong data encryption, secure access controls, and regular security audits. Moreover, there is the challenge of balancing energy efficiency, occupant comfort, and the integration of cutting-edge technology. Smart buildings must not only minimize energy consumption but also be able to accommodate and utilize new technologies without compromising their energy efficiency or occupant comfort. Despite these challenges, smart buildings hold immense potential for creating more sustainable, energy-efficient, and technologically advanced cities. By addressing the issues associated with smart building integration and focusing on innovative solutions, countries like Egypt can successfully navigate the complex path to building a smart future. After applying analysis on MCDM methods we found that VIKOR and CoCoSo methods have the same result in this study. In conclusion, after comparing the performance of the CoCoSo and VIKOR methods in the MCDM process, the two methods demonstrated comparable performance. The use of the CoCoSo method ensures consistency in decision-making, while the VIKOR method offers a more comprehensive understanding of the alternatives. Overall, these two methods can provide reliable guidance in selecting the best smart building technologies for the New Capital of EGYPT.

References

[1] Lim, Y., Edelenbos, J., & Gianoli, A. (2023). What is the impact of smart city development? Empirical evidence from a Smart City Impact Index. Urban Governance. https://doi.org/10.1016/j.ugj.2023.11.003.

[2] Zhang, F., Chan, A. P., & Li, D. (2023). Developing smart buildings to reduce indoor risks for safety and health of the elderly: A systematic and bibliometric analysis. Safety science, 168, 106310. https://doi.org/10.1016/j.ssci.2023.106310.

[3] Singh, M., & Pant, M. (2021). A review of selected weighing methods in MCDM with a case study. International Journal of System Assurance Engineering and Management, 12, 126-144. https://doi.org/10.1007/s13198-020-01033-3

[4] Ayan, B., Abacıoğlu, S., & Basilio, M. P. (2023). A Comprehensive Review of the Novel Weighting Methods for Multi-Criteria Decision-Making. Information, 14(5), 285. https://doi.org/10.3390/info14050285

[5] Keshavarz-Ghorabaee, M., Amiri, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2021). Determination of objective weights using a new method based on the removal effects of criteria (MEREC). Symmetry, 13(4), 525. https://doi.org/10.3390/sym13040525.

[6] Han, Z., Li, X., Sun, J., Wang, M., & Liu, G. (2023). An interactive multi-criteria decision-making method for building performance design. Energy and Buildings, 282, 112793. https://doi.org/10.1016/j.enbuild.2023.112793.

[7] Taherdoost, H., & Madanchian, M. (2023). Multi-criteria decision making (MCDM) methods and concepts. Encyclopedia, 3(1), 77-87. https://doi.org/10.3390/encyclopedia3010006.

[8] Smarandache, F. (1998). Neutrosophy: neutrosophic probability, set, and logic: analytic synthesis & synthetic analysis.

[9] Smarandache, F. (2001). A unifying field in logics: Neutrosophic logic, neutrosophic set, neutrosophic probability and statistics. arXiv preprint math/0101228

[10] Abdel-Basset, M., Saleh, M., Gamal, A., & Smarandache, F. (2019). An approach of TOPSIS technique for developing supplier selection with group decision making under type-2 neutrosophic number. Applied Soft Computing, 77, 438-452. https://doi.org/10.1016/j.asoc.2019.01.035

[11] Abdel-Monem, A., S. Mohamed , S., & S. Aziz , A. (2023). A Multi-Criteria Decision Making Methodology for Assessment Performance of Electrocoagulation System. Multicriteria Algorithms With Applications, 1, 19–30.

[12] Abouhawwash, M., Jameel, M., & S. Askar, S. (2023). Multi-Criteria Decision Making Model for Analysis Hydrogen Production for Economic Feasibility and Sustainable Energy. Multicriteria Algorithms With Applications, 1, 31–41.

[13] Trung, D. D., & Thinh, H. X. (2021). A multi-criteria decision-making in turning process using the MAIRCA, EAMR, MARCOS and TOPSIS methods: A comparative study. Advances in Production Engineering & Management, 16(4), 443-456. https://doi.org/10.14743/apem2021.4.412.

[14] Saidin, M. S., Lee, L. S., Marjugi, S. M., Ahmad, M. Z., & Seow, H. V. (2023). Fuzzy Method Based on the Removal Effects of Criteria (MEREC) for Determining Objective Weights in Multi-Criteria Decision-Making Problems. Mathematics, 11(6), 1544. https://doi.org/10.3390/math11061544

[15] Shanmugasundar, G., Sapkota, G., Čep, R., & Kalita, K. (2022). Application of MEREC in multi-criteria selection of optimal spray-painting robot. Processes, 10(6), 1172. https://doi.org/10.3390/pr10061172

[16] Mesran, M., Siregar, D., Nasution, S. D., Sahir, S. H., Diansyah, T. M., Agustina, I., ... & Rahim, R. (2019, March). The VIKOR Method to Support the Effectiveness of Decisions in Determining Work Incentive Recipients. In Journal of Physics: Conference Series (Vol. 1175, No. 1, p. 012043). IOP Publishing. https://doi.org/10.1088/1742-6596/1175/1/012043

[17] Sayadi, M. K., Heydari, M., & Shahanaghi, K. (2009). Extension of VIKOR method for decision making problem with interval numbers. Applied Mathematical Modelling, 33(5), 2257-2262. https://doi.org/10.1016/j.apm.2008.06.002

[18] Shumaiza, Akram, M., Al-Kenani, A. N., & Alcantud, J. C. R. (2019). Group decision-making based on the VIKOR method with trapezoidal bipolar fuzzy information. Symmetry, 11(10), 1313. https://doi.org/10.3390/sym11101313

[19] Yazdani, M., Zarate, P., Kazimieras Zavadskas, E., & Turskis, Z. (2019). A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. Management Decision, 57(9), 2501-2519. https://doi.org/10.1108/MD-05-2017-0458

[20] Çelikbilek, Y., & Tüysüz, F. (2020). An in-depth review of theory of the TOPSIS method: An experimental analysis. Journal of Management Analytics, 7(2), 281-300. https://doi.org/10.1080/23270012.2020.1748528

[21] Tzeng, G. H., & Huang, J. J. (2011). Multiple attribute decision making: methods and applications. CRC press.

[22] Yoon, K. P., & Hwang, C. L. (1995). Multiple attribute decision making: an introduction. Sage publications.

[23] Smarandache, F. (2023). Foundation of Revolutionary Topologies: An Overview, Examples, Trend Analysis, Research Issues, Challenges, and Future Directions. Neutrosophic Systems With Applications, 13, 45–66. https://doi.org/10.61356/j.nswa.2024.125

[24] M. Sabry, W. (2023). An Integrated Neutrosophic Approach for the Urban Energy Internet Assessment under Sustainability Dimensions. Neutrosophic Systems With Applications, 12, 22–35. https://doi.org/10.61356/j.nswa.2023.109

Received: Jun 26, 2023. Accepted: Jan 13, 2024.