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MCDM MODEL FOR CRITICAL SELECTION OF BUILDING AND INSULATION MATERIALS FOR OPTIMISING ENERGY USAGE AND ENVIRONMENTAL EFFECT IN PRODUCTION FOCUS

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Abstract. In the context of sustainable buildings, an ecological study of building and insulating materials is critical since it may assist affirm or shift the path of new technology development. Utilising sustainable material is a part of the sustainable improvement. For this reason, material fabrication is the primary process for the energy usage and release of intense environmental gaseous. The fabrication of the insulation and building materials, as in every fabrication process, comprises an energy consumption of crude materials in addition to the pollutants' release. In buildings, insulation is a relevant technological resolution for cutting energy usage. This study aims to assess the primary energy consumption and the environmental effects of the fabrication of building and thermal isolation materials by using a new hybrid MCDM model. The proposed new hybrid MCDM model includes Fuzzy FUCOM, CCSD and CRADIS methods. While the subjective weights of the criteria were determined with the fuzzy FUCOM method, the objective weights of the criteria were determined with the CCSD method. Construction materials were listed with the CRADIS method. According to the fuzzy FUCOM method, the most important criterion was determined as the CR3 criterion, while the most important criterion according to the CCSD method was determined as the CR1 criterion. According to the combined weights, the most important criterion was determined as the CR3 criterion. According to the CRADIS method, the material with the best performance was determined as Cement Plaster. The methodology used in this study is a novel approach therefore it has not been used in any study before. In addition, since the CRADIS method is a newly developed MCDM method, the number of articles related to this method is low. Therefore, this research gap will be filled with this study.

Keywords: building and insulation materials, environmental effect, energy usage, material production, Fuzzy FUCOM, CCSD, CRADIS, sustainability.

Introduction

The hazardous activities raised by humans is emerging in several critical harms such as flooding, wildfires, tsunami, and aridness owing to global warming, land use for waste, aquatic toxicity, photochemical smog, terrestrial toxicity, resource depletion, eutrophication, ozone depletion, acidification, ozone layer's depletion, sea level's rising, and terrain loss. In particular, global energy consumption contributes to dirtiness, worldwide greenhouse gaseous emissions and ecological deterioration (Batouli et al., 2014). Four main industries that conduce the most to power usage are the transportation, industrial, agriculture, and construction (commercial/residential) industries, a significant fraction of it being explained through the buildings' operation and construction. Construction sectors have a more significant role in causing these ecological problems. In the EU, the construction industry is liable for over 0.40 of all power usage, contributing to CO_2 gaseous emissions (Rajagopalan, 2005; Swamy, 2006; Chatwal & Sharma, 2004).

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The utilisation of building and insulation materials in large quantities has resulted in extensive resource depletion. Building and insulation materials produce millions of tons each year waste in the world. These materials have high tangible energy, emerging in significant CO_2 emissions. For instance, the palpable energy of steel is approximately four times that of cement (Scientific and Industrial Research Organization, 2019). Cement is one of the highest CO_2 emitting materials. For this reason, a significant CO_2 amount is generated in the processing of cement-based building materials. If global building and insulation materials usage remains constant, worldwide cement generation could reach 3500 million mt through 2050. Therewithal, the cement'sannual generation could exceed 5000 million mt with about 4000 million mt of CO_2 gaseous emissions if the consumption and production of building and insulation materials increase. Because of the widespread use of building and insulation materials, the effect of these products outweighed the effect of other resources. Due to the frequent variation in human demands and lifestyle, the mean life of construction is diminishing, and renovation or demolition of constructions concludes in more recycling or landfills each year.

Sustainability is now a focal point of the construction sector, and ecological relevance of buildings are increasing amongst the generic potential and public construction buyers (Anjaneyulu, 2002). Given the importance of balancing ecological, economic, and social needs in project implementation, the maintainability principle must be integrated into the academic community and design administration applications. The modern construction aims to manage and create a healthy artificial ecological source on design performance and ecological sources. To improve design value and quality, contemporary structure accentuates the importance of incorporating stability into design planning, administration, decision-making, and evaluation. The goals of sustainable construction are directly affected by project planning and successful implementation. As a result, sustainable design planning projects use design management methodologies that promote financial, environmental, and social maintainability. Methodical strategies, the perspectives of overall partners, expertise and knowledge in applying a maintainable improvement design, and their capability to perform them correctly are essential success components for maintainable building.

In sustainable construction, there are several primary foundations of the lifecycle of a construction: source reuse, quality of lifecycle, lesser utilised sources, elimination or reduction of adverse environmental effects, use of recyclable sources, decrease in building life cycle expenses, elimination of toxic materials. Maintainable planning is a planning that seeks to maximise the artificial environment through minimising or eradicating negatory ecological effects. Green buildings entail increasing building performance in order to utilise energy, materials, and water more effectively while minimising adverse effects on human health (Erdogan et al., 2019).

With an emphasis on environmental implications, lifecycle evaluation has recently gained international admission in the construction industry (Bribián et al., 2009) and is utilised to select ecologically better materials as well as to evaluate and optimise structure operations (Asdrubali et al., 2013). A greater understanding of the energy embodied and ecological effects of construction materials may support the development and production of more maintainable materials and their precedence in the building industry and design (Cabeza et al., 2013).

As a result, less resource use will result in less emissions, decreasing the ecological effects of building structures and defining development possibilities toward more maintainable resolutions. Furthermore, lifecycle evaluation is broadly utilised in building design to crosscheck various options. Many researchers have concentrated on construction resolutions, such as diverse kinds of building envelopes (Gonzalez-García et al., 2012; Islam et al., 2014; Monteiro & Freire, 2012), green roofs, and building construction (Pérez et al., 2012; Cerón-Palma et al., 2013). In these studies, the characteristics utilised to crosscheck diverse options are the formation of the construction mechanism, the materials utilised in every resolution, and the building's location (Ramesh et al., 2012; Marceau & VanGeem, 2006; Richman et al., 2009).

Lifecycle evaluation can also be used to help choosing which materials to contain in resolutions. Bribián et al. (2011) utilised the operation-sourced lifecycle evaluation system to assess the various construction materials' ecological effects of utilised in various structure resolutions, such as roofs, floors, insulation, and structure materials (Bribián et al., 2011).

Furthermore, several researchers have concentrated on assessing the CO_2 emissions and energy use in construction materials (Dixit et al., 2012; Moncaster & Symons, 2013).

The significance of insulating materials for heat have recently sparked considerable attention in the ecological realm among building materials (Papadopoulos, 2005; Anastaselos et al., 2009; Baetens et al., 2011; Balo, 2011, 2015). These materials play a significant role because they also affect the ecological effects of structure and the building's utilise phase. Insulation in the structure envelope, for instance, can decrease power need in buildings through upwards of 64% in the summer and up to 37% in the winter, as well as CO_2 emissions (Cabeza et al., 2010).

As a result, the first step toward more efficient functioning energy use is to decrease the power needed to sustain a comfortable internal temperature. With respect to the nearly zero-emission construction, using passive envelope resolutions will conclude in raised insulating thicknesses in structures. As a result, these materials' support to the ecological effects of buildings over their life cycle are critical (Pargana et al., 2014), and the ecological evaluation of various insulating resolutions is a significant topic in construction sustainability. In general, present lifecycle evaluations of insulating materials compared the ecological effects of material an imparted amount with the exact thermal insulating needs (Schmidt et al., 2004; Ardente et al., 2008; Kymäläinen & Sjöberg, 2008).

This study aims to evaluate the primary energy consumption and the environmental effects of the fabrication of building and thermal isolation materials by using a new and strength hybrid MCDM model which consists of fuzzy FUCOM, CCSD and CRADIS. Therefore, both expert judgements and objective data will be taken into account while evaluating construction materials in this study. Thus, a strong MCDM model will be created. It is anticipated to obtain rigor results as objective and subjective data are considered in this study. Fuzzy FUCOM method is used to achieve subjective weights of criteria and CCSD method is utilised to obtain objective weights of criteria. Furthermore, CRADIS method is used to rank construction materials. To the best our knowledge, there is no study that combined the MCDM methods employed in this study. Besides, there are not many publications related to the CRADIS method since it is a relatively new MCDM technique. Therefore, this research will fill this research gap. As a result, this study is original and contributes to the literature.

1. Literature review

Material choice is one of the most significant yet challenging work that structure engineers face because it is immediately concerned with all planning efficiency (Reddy, 2004). Environmental building and insulation material choices should be made systematically, with each criterion being investigated for its impact on environment.

The product designer has the exclusive right to choose the materials. Numerous scholarly technics are being developed in most industries for choosing materials with a low ecologic impact. However, in the building sector, these technics lag. Choosing building and insulation materials is so important for construction. Nowadays, the primary causes for choosing materials in an unscholarly operation are a lack of norms and incompatible industry contributions. There are many contradictory statements in the material industry, which is one of the reasons for material selection. For instance, the concrete sector demands that they use the most maintainable material because they are made from waste material and has low energy use. The timber industry claims that timber is the most maintainable material because it is entirely natural and renewable. According to the steel sector, steel is the most maintainable material because it is greatly recyclable. Different agencies in different countries have developed various assessment models and tools to assess the ecological effects of buildings. Even though this equipment has been meaningfully utilised and applied in their origin's relevant zones, implementation issues arise, particularly in the course of local rapport in other nations owing to characteristics related to the climatic conditions, particular geographic location, materials, and construction methodologies.

While criteria-based assessment tools award credits for assessing a set of criteria for waste evaluation, research can also be considered a critical step in building applications. As seen below in Table 1, some efforts have been made in the field of environmental emissions evaluation and estimation.

Besides, Balo (2017) used AHP technique which takes into account environmental impacts of the insulating materials' production. Seo et al. (2016) investigated the CO_2 gaseous emissions generated during the material generation, structure, and transportation phases. They stated that the production stage accounts for 93.4% of CO_2 emissions. Huang et al. (2017) developed a method for calculating CO_2 emissions of the urban constructions in the Chinese province of Xiamen. They concluded that the power utility and material generation stages account for 45% and 40% of the emissions, respectively. They stated that implementing lesser CO_2 policies could conclude in a 2.98% reduction in energy consumption of urban buildings by 2020 (Huang et al., 2017). Motuzienė et al. (2016) assessed the three kinds of ecological effects of building external walls with AHP; timber frame, log, and masonry. A few factors were considered, including principal power usage, lifecycle expense, depletion of the ozone layer, and global warming.

Reza et al. (2011) evaluated environmental impacts of flooring mechanisms with AHP-based life cycle analysis. As a coarse-grained aggregate, Rashid et al. (2017) demonstrated a preliminary and analytical investigation into advancing a maintainable mould off concrete through blending ceramic-sourced waste. Environmental impact of the feed stock use and CO_2 footprint through concrete were carefully considered. TOPSIS and AHP were used by Zhou et al. (2009) to classify and identify maintainable products based on financial, mechanical, and ecological attributes. Mathiyazhagan et al. (2019) eliminated mechanic variants and replaced them with social attributes. This sorting is compatible with current research suppositions which suggest assessing structure materials using three attributes; ecological, social, and financial (Diabat et al., 2014). Using financial and environmental criteria, Kim et al. (2009) used AHP to assess material recycling potency. Berardi (2012) compared the environmental performance of assessed and certified buildings. Although no methodological specifics, such as parameters or problems, were discussed in the research, the outcomes showed which fields of the structures performed the worst and best. Wallhagen and Glaumann (2011) presented that different approaches result in different results and recommended using different approaches to increase the ecological efficiency of the building. In order to understand the reasons for the differences in the results, it is also important to understand the topics addressed and the assessment procedures used.

The construction sector minimizes the ecological footprint by creating waste and exploiting resources, despite the fact that environmental issues are essential to its sustainability. It gradually modifies its conventional methods to take environmental considerations into account while

Table 1. Research in the field of environmental emissions evaluation and estimation

Methodology	Research issue	Refs.
TOPSIS	The decision-support mechanism for optimum roof material choice	Rahman et al. (2012)
AHP	Material choice in produce planning	Desai et al. (2012)
GRA	As commercial present materials choice in maintainable planning	Zhao et al. (2016)
VIKOR	Material choice implementation	Prasenjit et al. (2009)
ANP and TOPSIS	Choice of the proper material usage equipment	Onut et al. (2009)
AHP and TOPSIS	The sluice material choice in small-scale hydropower facilities	Kumar and Singal (2015)
	Material choice for sugar sector	Anojkumar et al. (2015)
	Material choice for a dedicated engineering planning	Rao and Davim (2008)
TOPSIS and DOE	Robot choice problem	İç (2012)
DANP and VIKOR	Material choice with target-sourced attributes	Liu et al. (2014)
	The most efficient vendor choice for conductive the material recycled	Hsu et al. (2012)
VIKOR and TOPSIS	The produced mass non-heat treated cylindrical cap produce choice	Huang et al. (2009)
Fuzzy TOPSIS	Ecological material choice	Mayyas et al. (2016)
	Grinding wheel corrosive material choice	Maity and Chakraborty (2013)
Finite element analysis and ELECTRE	Gas turbine elements' materials choice	Shanian et al. (2012)
Fuzzy ANP and PROMETHEE	Material usage tool choice problem	Tuzkaya et al. (2010)
Interval 2-tuple linguistic VIKOR	Material choice for planning at engineering	Liu et al. (2013)
Fuzzy AHP and VIKOR	Pipe-material choice in sugar sector	Anojkumar et al. (2014)
Fuzzy AHP, VIKOR and TOPSIS	Material choice in sugar sector	Anojkumar et al. (2015)
Fuzzy extended AHP	Maintainable materials choice for construction designs	Akadiri et al. (2013)
Fuzzy VIKOR	A car element's material choice	Girubha and Vinodh (2012)
PCI and Grey CoCoSo	Pavement Condition Assessment	Elmansouri et al. (2022)
Fuzzy AHP and TOPSIS	The choice of phase-change material	Rathod and Kanzaria (2011)
	Material choice operation and the most efficiency planning method	Aly et al. (2013)

making decisions. Building and insulation materials are detrimental to the ecology; their effects are growing as the use of these materials grow. With raised knowledge and awareness of these effects, endeavours are being made to prevent these adverse consequences and to mitigate their effect. Environmental considerations are routinely disregarded while planning building projects. As a result, materials are chosen without taking the environment into account. Sustainable construction material choice is one of them. Building and insulation material choice is a significant consideration in building construction and design decisions, and ecological concerns must be factored into the assessment operation.

This study will evaluate construction materials with fuzzy FUCOM, CCSD, and CRADIS methods. The subjective weightings of the evaluation attributes will be obtained with the fuzzy FUCOM methodology. The objective weights of the evaluation attributes will be obtained by the CCSD method. Construction materials will be listed with the CRADIS method in terms of ecological effects.

Many decision-making problems have been solved with the fuzzy FUCOM method, such as assessment of fuel vehicles (Pamucar et al., 2021), evaluation of road sections (Mitrović Simić et al., 2020), assessing strategies to enhance the resilience of the healthcare sector (Khan et al., 2022) and prioritizing occupational safety risks (Golcuk et al., 2022). The CCSD is a method used to determine the objective weights of the criteria. This method has been used many times in the literature, such as stacker selection (Ulutaş et al., 2020), technological forecasting method selection (Dahooie et al., 2019a), wind turbine selection (Zavadskas et al., 2022) and corporate financial performance evaluation (Dahooie et al., 2019b). Since the CRADIS method is a newly developed method, the number of articles related to this method is few. Studies using this method are as follows: market assessment (Puška et al., 2022a), green supplier selection (Puška et al., 2022b), selection of IoT service provider (Krishankumar & Ecer, 2023), sustainable supplier selection (Puška et al., 2023) and occupational risk evaluation (Wang et al., 2023).

2. Methodology

The proposed methodology has been shown in Figure 1 and explained steps of developed algorithm.

After preliminary discussions, experts were brought together to form an expert team which represents the first step of the proposed methodology research flow. This expert team was asked to evaluate criteria gathered from the literature and to determine which of these criteria would be used in the study. Expert team has determined 6 criteria. These criteria are as follows.

- EmbEn [MJ]: All the energy used to produce the materials that make up the building (transporting and manufacturing the materials, in addition to the services in the financial that support this activity).
- Kg SO_{2eq}: If this compound increases, the acidification potential rises.
- Kg CO_{2eq}: If this compound increases, global warming potential rises.
- Kg C_2H_{4eq}: If this compound increases, photochemical oxidant creation potential rises.
- Kg PO_{4eq}: If this compound increases, eutrophication potential rises.
- About Recycling Potential: Reuse and recycling of waste material decreases the need of virgin and fresh materials in structure of novel buildings. It aids in conserving embodied energy correlate with building materials and decreasing their carbon footprints.

After determining the criteria, the expert team was asked to determine the material alternatives. Finally, since data on some materials determined by experts could not be found, these materials were removed. In that way has been formed MCDM model that consist of 15 alternatives and 6 criteria. In the next stage, we have applied subjective-objective (Fuzzy FUCOM and CCSD) model for determining criteria weights. CRADIS method has been used for evaluation 15 materials, and finally sensitivity and comparative analysis were performed.

2.1. Fuzzy FUCOM method

The stages of the fuzzy FUCOM methodology are briefly explained below (Pamucar & Ecer, 2020).

Stage 1: Evaluation attributes are identified by experts. These criteria are denoted as a set $C = \{C_1, C_2, ..., C_n\}$.

Stage 2: The evaluation criteria are ranked by each expert. The assessment attributes are sorted by each specialist from the most significant one to the least important one.

Stage 3: The evaluation criteria are compared by each expert. Experts use fuzzy linguistic expressions presented in Table 2 to compare criteria; then, fuzzy comparative significance is computed using Eqn (1):

$$\varphi_{k/k+1} = \frac{\omega_{C_{j(k+1)}}}{\omega_{C_{j(k)}}} = \frac{\left(\omega^l_{C_{j(k+1)}}, \omega^m_{C_{j(k+1)}}, \omega^u_{C_{j(k+1)}}\right)}{\left(\omega^l_{C_{j(k)}}, \omega^m_{C_{j(k)}}, \omega^u_{C_{j(k)}}\right)}. \quad (1)$$

The evaluation criteria' fuzzy vector of comparative significance is determined by Eqn (2):

$$\theta = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/k+1}\right), \quad (2)$$

where $\varphi_{k/k+1}$ denotes the importance that the criterion of $C_{j(k)}$ rank has in relation to the criterion of $C_{j(k+1)}$ rank.

Stage 4: The fuzzy weights of attributes are calculated. Two conditions should be satisfied in this process.

Condition 1: Comparative significance of criteria ($C_{j(k)}$ and $C_{j(k+1)}$) $\varphi_{k/k+1}$ should be equal to their weight coefficients' ratio. This condition is presented in Eqn (3):

$$\frac{w_k}{w_{k+1}} = \varphi_{k/k+1}. \quad (3)$$

Condition 2: The weight coefficients' final values should fulfil transitivity, i.e., that $\varphi_{k/(k+1)} \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$, i.e., that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$.

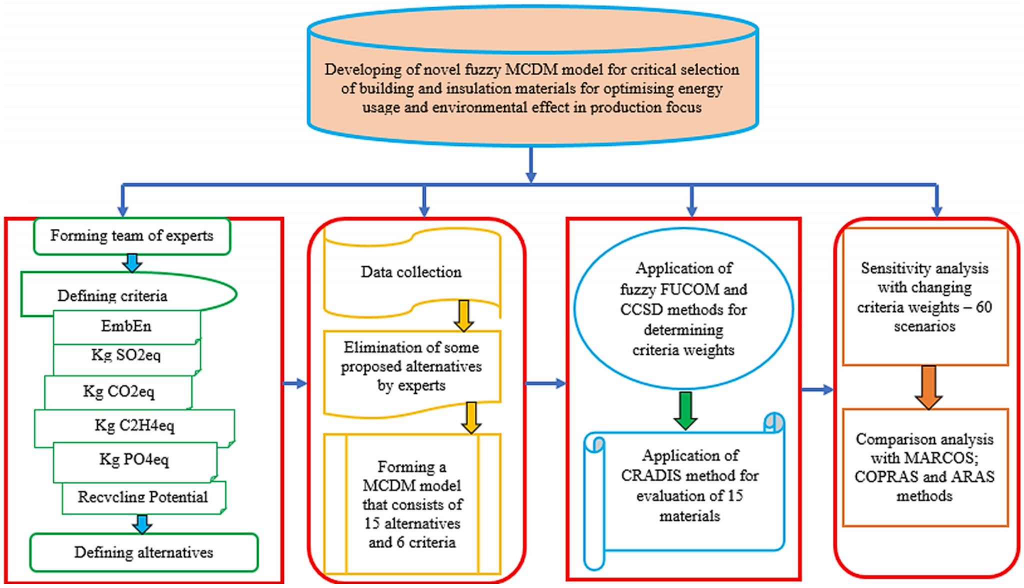

Figure 1. Proposed methodology

This condition is shown in Eqn (4):

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{\frac{k+1}{k+2}}. \tag{4}$$

Depending on the settings described, linear modelling for obtaining fuzzy weights of criteria. Equation (5) indicates this linear model.

$$\min \vartheta$$
$$s.t. \begin{cases} \left| w_k - w_{k+1} \otimes \varphi_{k/(k+1)} \right| \le \vartheta \\ \left| w_k - w_{k+2} \otimes \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \le \vartheta \\ \sum_{j=1}^{n} w_{js} = 1 \\ w_{js}^{l} \le w_{js}^{m} \le w_{js}^{u} \\ w_{js}^{l} \ge 0 \end{cases}, \tag{5}$$

where $\tilde{w}_{js} = \left(w_{js}^{l}, w_{js}^{m}, w_{js}^{u}\right)$ and $\varphi_{k/(k+1)} = \left(\varphi_{k/k+1}^{l}, \varphi_{k/k+1}^{m}, \varphi_{k/k+1}^{u}\right)$.

Table 2 presents the linguistic terms and their fuzzy number equivalents used to compare the criteria.

Table 2. Fuzzy linguistic scales (Guo & Zhao, 2017)

Linguistic Terms	Fuzzy Numbers
Equally Significant (ES)	(1, 1, 1)
Weakly Significant (WS)	(2/3, 1, 3/2)
Moderately Significant (MOS)	(3/2, 2, 5/2)
Very Significant (VS)	(5/2, 3, 7/2)
Absolutely Significant (AS)	(7/2, 4, 9/2)

The fuzzy weights $\left(\tilde{w}_{js}\right)$ found through the fuzzy FUCOM method are transformed to crisp weightages (w_{js}) with the following formula:

$$w_{js} = \frac{w_{js}^{l} + 4 \times w_{js}^{m} + w_{js}^{u}}{6}. \tag{6}$$

2.2. CCSD method

CCSD is a technique to identify the objective weightages of the evaluation attributes. This method's steps are indicated as follows (Wang & Luo, 2010; Dahooie et al., 2019a).

Stage 1: A decision matrix (T) involving m options, B_1, ..., B_m based on the n criteria, C_1, ..., C_n is organised:

$$T = \left[t_{ij}\right]_{m \times n}. \tag{7}$$

In Eqn (7), t_{ij} indicates ith alternative's performance on the jth criterion.

Stage 2: Eqn (8) (for *BN* (beneficial attributes)) and 9 (for *NBF* (non-beneficial attributes)) are utilised to normalise the matrix:

$$z_{ij} = \frac{t_{ij} - \min\left(t_{ij}\right)}{\max\left(t_{ij}\right) - \min\left(t_{ij}\right)}; \tag{8}$$

$$z_{ij} = \frac{\max\left(t_{ij}\right) - t_{ij}}{\max\left(t_{ij}\right) - \min\left(t_{ij}\right)}. \tag{9}$$

Stage 3: The criterion D_j is removed for taking into account its impact on decision-making. Equation (10) is used to compute the performance value (Hwang & Yoon, 1981):

$$f_{ij} = \sum_{k=1,\, k \ne j}^{n} z_{ik} w_k. \tag{10}$$

Stage 4: Eqn (11) is used to obtain the correlation coefficient (CC_j) between F_{ij} and the value of D_j criterion:

$$CC_j = \frac{\sum_{i=1}^{m}\left(z_{ij} - \bar{z}_j\right)\left(f_{ij} - \bar{f}_j\right)}{\sqrt{\sum_{i=1}^{m}\left(z_{ij} - \bar{z}_j\right)^2 \sum_{i=1}^{m}\left(f_{ij} - \bar{f}_j\right)^2}}, \tag{11}$$

where

$$\bar{z}_j = \frac{\sum_{i=1}^{m} z_{ij}}{m}; \tag{12}$$

$$\bar{f}_j = \frac{\sum_{i=1}^{m} f_{ij}}{m}. \tag{13}$$

Stage 5: In order to determine weightages (w_j) of attributes, the below non-linear optimisation modelling is solved:

$$\text{Minimise } J = \sum_{j=1}^{n}\left(w_{jCC} - \frac{\sigma_j \sqrt{1 - CC_j}}{\sum_{k=1}^{n} \sigma_k \sqrt{1 - CC_k}}\right)^2; \tag{14}$$
$$s.t. \sum_{j=1}^{n} w_{jCC} = 1.$$

In Eqn (14), σ_j indicates D_j criterion's standard deviation. This value is computed by Eqn (15):

$$\sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(z_{ij} - \bar{z}_j\right)^2}. \tag{15}$$

With Eqn (16), the criteria weights obtained through the Fuzzy FUCOM methodology and the criteria weightages found through the CCSD method are combined, and thus the weightages integrated of the attributes are computed (Zavadskas & Podvezko, 2016):

$$w_{jIN} = \frac{w_{js} w_{jCC}}{\sum_{j=1}^{n} w_{js} w_{jCC}}. \tag{16}$$

2.3. CRADIS methodology

The CRADIS methodology will be utilised to sort the materials. The stages of the CRADIS methodology are explained below (Puška et al., 2022c).

Stage 1: The decision matrix is created. The decision matrix is displayed in Eqn (7).

Stage 2: The values in the decision matrix are normalised by Eqn (17) (for *BN*) and Eqn (18) (for *NBF*):

$$u_{ij} = \frac{t_{ij}}{\max\left(t_{ij}\right)}; \tag{17}$$

$$u_{ij} = \frac{\min\left(t_{ij}\right)}{t_{ij}}. \quad (18)$$

Stage 3: The decision matrix aggravated is achieved through Eqn (19):

$$s_{ij} = u_{ij} . w_{jIN}. \quad (19)$$

Stage 4: The anti-ideal and ideal resolutions are determined with Eqns (20) and (21):

$$v_i = \max s_{ij}; \quad (20)$$

$$v_{ai} = \min s_{ij}. \quad (21)$$

Stage 5: Deviations from ideal and anti-ideal resolutions are calculated through Eqns (22) and (23):

$$d^+ = \max v_i - s_{ij}; \quad (22)$$

$$d^- = s_{ij} - \min v_{ai}. \quad (23)$$

Stage 6: The degrees of the deviations for each of the options from anti-ideal and ideal resolutions are computed as:

$$o_i^+ = \sum_{j=1}^{n} d^+; \quad (24)$$

$$o_i^- = \sum_{j=1}^{n} d^-. \quad (25)$$

Stage 7: The utility function for each of the alternatives pertaining to the deviations from the optimal options is computed as:

$$K_i^+ = \frac{o_{opt}^+}{o_i^+}; \quad (26)$$

$$K_i^- = \frac{o_i^-}{o_{opt}^-}. \quad (27)$$

In Eqn (26), o_{opt}^+ denotes the optimum option having the minimum distance from the ideal resolution. In Eqn (27), o_{opt}^- denotes the optimum option having the biggest distance from the anti-ideal resolution.

Stage 8: The average deviation value (Q_i) for each of the alternatives is calculated as:

$$Q_i = \frac{K_i^+ + K_i^-}{2}. \quad (28)$$

The option with the maximum Q_i is identified as the best alternative.

3. Application and results

First of all, experts who have worked in the construction industry for years were contacted to determine the insulation material with the best performance for optimising energy usage and environmental effect in production focus. 12 experts with at least 10 years of experience in the construction industry were reached. Two of these experts could not attend face-to-face meetings due to their workload. Therefore, face-to-face preliminary interviews were conducted with 10 experts. The education and experiences of the experts are shown in Table 3.

Table 3. Education and experiences of the experts

Experts	Education	Experience
Expert 1	BD: Civil Engineering MD: Civil Engineering	15 Years
Expert 2	BD: Civil Engineering	12 Years
Expert 3	BD: Material Engineering and Civil Engineering	11 Years
Expert 4	BD: Civil Engineering	17 Years
Expert 5	BD: Civil Engineering MD: Civil Engineering PhD: Civil Engineering	22 Years
Expert 6	BD: Chemical Engineering and Civil Engineering	14 Years
Expert 7	BD: Civil Engineering	16 Years
Expert 8	BD: Civil Engineering	14 Years
Expert 9	BD: Civil Engineering	12 Years
Expert 10	BD: Civil Engineering MD: Civil Engineering	12 Years

The decision matrix showing the values in other material alternatives and criteria is shown in Table 4.

First of all, 10 managers were asked to prioritise the criteria. Expert 1 listed the criteria as follows:

$$CR_2 > CR_3 > CR_5 > CR_1 > CR_4 > CR_6.$$

Table 5 shows the linguistic evaluations of Expert 1.

According to Expert 1, attribute weightages are found through resolving the modelling in Eqn (5). Table 6 shows the criteria weights according to Expert 1.

As can be seen, the ϑ value is close to zero, so the results of Expert 1 are said to be consistent. The fuzzy FUCOM methodology is performed by taking the opinions of other experts. The attribute weightages according to all experts are shown in Table 7.

As can be seen from Table 7, the x value of all experts is close to 0, so the results of all experts are consistent. The fuzzy weights of the attributes are transformed to crisp weights by Eqn (6). These crisp weights are then combined with the arithmetic mean. Table 8 shows the crisp weights and arithmetic means of the criteria.

By applying Eqns (7)–(15) to the decision matrix in Table 3, criteria weights are calculated according to the CCSD (w_{jCC}) method. Then, using Eqn (16), the criteria weights obtained by the Fuzzy FUCOM (w_{js}) methodology and the criteria weights found through the CCSD method are combined. Table 9 shows the attributes weights abovementioned and the integrated weights (w_{jIN}).

As can be seen from Table 9, the CR_3 criterion was determined as the most important criterion according to the Fuzzy FUCOM method, and the CR_1 criterion was determined as the most important criterion according to the CCSD method. According to the combined weights, the CR_3 criterion was determined as the most important criterion. Using Eqns (17) and (18), the decision matrix is normalised. The normalised decision matrix is displayed in Table 10.

Table 4. The energy usage and environmental effect of some common building and insulation materials throughout the lifecycle (Giama & Papadopoulos, 2015; Gardezi et al., 2015; Sun et al., 2022; Wang et al., 2018; Bolden et al., 2013)

Criteria Building Materials	EmbEn [MJ] (CR1)	Kg SO_{2eq} (CR2)	Kg CO_{2eq} (CR3)	Kg C_2H_{4eq} (CR4)	Kg PO_{4eq} (CR5)	About Recycling Potential (CR6)
Stonewool	24.90	0.01303	2.17293	0.00059	0.00132	28%
Glasswool	60.10	0.01904	3.30205	0.00105	0.00158	25%
Expanded Polystyrene	76.16	0.01268	3.24197	0.00054	0.00096	27%
Acrylic Plaster	4.96	0.00087	0.20961	0.00009	0.00007	2%
Plasterboard	6.03	0.00167	0.39033	0.00007	0.00019	7%
Brick	2.76	0.00070	0.23595	0.00005	0.00007	32%
Cement Plaster	1.42	0.00050	0.22134	0.00002	0.00005	2%
Steel	9.76	0.00395	0.63761	0.00016	0.00018	90%
Polyurethane Foam	92.30	0.01934	4.42797	0.00212	0.00279	20%
Ceramic Tiles	15.72	0.00418	0.95001	0.00021	0.00031	20%
Cement Portland	3.33	0.00131	0.85807	0.00005	0.00018	0.2%
Extruded Polystyrene	92.38	0.01646	4.04462	0.00088	0.00125	27%
Reinforced Concrete	0.48	0.90673	0.34	0.03596	0.08972	25.9%
Common Plaster	1.45	0.00036	0.26146	0.00003	0.00005	2%
Stone	16.73	0.00671	1.01494	0.00024	0.00057	95%

Table 5. Expert 1's linguistic assessments

Criteria	CR_2	CR_3	CR_5	CR_1	CR_4	CR_6
Linguistic Variables	ES	WS	MOS	VS	VS	VS

Table 6. The criteria weights w.r.t. Expert 1

Criteria	Fuzzy Weights
CR_1	(0.038, 0.109, 0.111)
CR_2	(0.142, 0.292, 0.292)
CR_3	(0.161, 0.278, 0.278)
CR_4	(0.058, 0.123, 0.123)
CR_5	(0.061, 0.138, 0.138)
CR_6	(0.082, 0.152, 0.152)
ϑ	0.050

Table 7. The results of Fuzzy FUCOM

Experts Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
CR_1	(0.038, 0.109, 0.111)	(0.100, 0.173, 0.173)	(0.037, 0.105, 0.112)	(0.061, 0.132, 0.143)	(0.065, 0.101, 0.101)
CR_2	(0.142, 0.292, 0.292)	(0.052, 0.10 0, 0.100)	(0.056, 0.141, 0.141)	(0.135, 0.164, 0.164)	(0.075, 0.127, 0.127)
CR_3	(0.161, 0.278, 0.278)	(0.130, 0.165, 0.165)	(0.167, 0.261, 0.266)	(0.212, 0.362, 0.372)	(0.145, 0.176, 0.176)
CR_4	(0.058, 0.123, 0.123)	(0.202, 0.372, 0.372)	(0.150, 0.261, 0.261)	(0.078, 0.133, 0.133)	(0.065, 0.141, 0.153)
CR_5	(0.061, 0.138, 0.138)	(0.054, 0.140, 0.140)	(0.205, 0.205, 0.205)	(0.070, 0.119, 0.119)	(0.227, 0.388, 0.399)
CR_6	(0.082, 0.152, 0.152)	(0.080, 0.126, 0.126)	(0.047, 0.092, 0.092)	(0.090, 0.157, 0.157)	(0.082, 0.130, 0.130)
ϑ	0.050	0.046	0.055	0.033	0.036
Experts Criteria	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10
CR_1	(0.046, 0.141, 0.154)	(0.103, 0.121, 0.121)	(0.151, 0.178, 0.178)	(0.115, 0.172, 0.172)	(0.304, 0.420, 0.469)
CR_2	(0.050, 0.126, 0.126)	(0.077, 0.148, 0.148)	(0.231, 0.393, 0.414)	(0.092, 0.180, 0.180)	(0.127, 0.132, 0.132)
CR_3	(0.183, 0.183, 0.183)	(0.086, 0.137, 0.137)	(0.072, 0.113, 0.113)	(0.210, 0.335, 0.335)	(0.078, 0.111, 0.112)
CR_4	(0.142, 0.232, 0.237)	(0.273, 0.392, 0.392)	(0.051, 0.108, 0.114)	(0.046, 0.091, 0.091)	(0.082, 0.118, 0.118)
CR_5	(0.134, 0.232, 0.232)	(0.085, 0.149, 0.149)	(0.077, 0.129, 0.129)	(0.079, 0.185, 0.185)	(0.067, 0.118, 0.131)
CR_6	(0.062, 0.159, 0.159)	(0.070, 0.114, 0.114)	(0.091, 0.139, 0.139)	(0.060, 0.117, 0.117)	(0.094, 0.137, 0.137)
ϑ	0.049	0.029	0.037	0.048	0.025

Table 8. Criteria crisp weights

Experts Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	A.M.
CR_1	0.098	0.161	0.095	0.122	0.095	0.156
CR_2	0.267	0.092	0.127	0.159	0.118	0.168
CR_3	0.259	0.159	0.246	0.339	0.171	0.201
CR_4	0.112	0.344	0.243	0.124	0.130	0.184
CR_5	0.125	0.126	0.205	0.111	0.363	0.168
CR_6	0.140	0.118	0.085	0.146	0.122	0.123
Experts Criteria	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	A.M.
CR_1	0.127	0.118	0.174	0.163	0.409	0.156
CR_2	0.113	0.136	0.370	0.165	0.131	0.168
CR_3	0.183	0.129	0.106	0.314	0.106	0.201
CR_4	0.218	0.372	0.100	0.084	0.112	0.184
CR_5	0.216	0.138	0.120	0.167	0.112	0.168
CR_6	0.143	0.107	0.131	0.108	0.130	0.123

Table 9. Integrated weights of attributes

Criteria Weights	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
w_{jCC}	0.204	0.133	0.186	0.13	0.203	0.144
w_{js}	0.156	0.168	0.201	0.184	0.168	0.123
w_{jIN}	0.190	0.134	0.223	0.143	0.204	0.106

Table 10. The normalised matrix

Criteria Building Materials	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Stonewool	0.0193	0.0276	0.0965	0.0339	0.0379	0.2947
Glasswool	0.008	0.0189	0.0635	0.019	0.0316	0.2632
Expanded Polystyrene	0.0063	0.0284	0.0647	0.037	0.0521	0.2842
Acrylic Plaster	0.0968	0.4138	1.0000	0.2222	0.7143	0.0211
Plasterboard	0.0796	0.2156	0.537	0.2857	0.2632	0.0737
Brick	0.1739	0.5143	0.8884	0.4	0.7143	0.3368
Cement Plaster	0.338	0.72	0.947	1.0000	1.0000	0.0211
Steel	0.0492	0.0911	0.3287	0.125	0.2778	0.9474
Polyurethane Foam	0.0052	0.0186	0.0473	0.0094	0.0179	0.2105
Ceramic Tiles	0.0305	0.0861	0.2206	0.0952	0.1613	0.2105
Cement Portland	0.1441	0.2748	0.2443	0.4	0.2778	0.0021
Extruded Polystyrene	0.0052	0.0219	0.0518	0.0227	0.04	0.2842
Reinforced Concrete	1.0000	0.0004	0.6165	0.0006	0.0006	0.2726
Common Plaster	0.3310	1.000	0.8017	0.6667	1.000	0.0211
Stone	0.0287	0.0537	0.2065	0.0833	0.0877	1.000

As a calculation example, the value of Stonewool material in CR_1 is normalized as follows:

$$u_{11} = \frac{\min\left(t_{ij}\right)}{t_{11}} = \frac{0.48}{24.9} = 0.0193.$$

Utilising Eqn (19), the aggravated value for each material is obtained. Aggravated value of Stonewool material in CR_1 is calculated as follows:

$$s_{11} = u_{11} \times v_{1IN} = 0.19 \times 0.0193 = 0.0037.$$

Table 11 indicates the aggravated decision matrix, including these values.

Ideal and anti-ideal resolutions were determined with Eqns (20) and (21), and then deviations from ideal and anti-ideal resolutions were computed by Eqns (22) and (23).

As an example, deviations from ideal and anti-ideal resolutions are calculated for Stonewool material in CR_1:

$$d^{+} = \max v_i - s_{11} = 0.223 - 0.0037 = 0.2193;$$

$$d^{-} = s_{11} - \min v_{ai} = 0.0037 - 0.0001 = 0.0036.$$

Table 11. The aggravated decision matrix

Criteria Building Materials	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Stonewool	0.0037	0.0037	0.0215	0.0048	0.0077	0.0312
Glasswool	0.0015	0.0025	0.0142	0.0027	0.0064	0.0279
Expanded Polystyrene	0.0012	0.0038	0.0144	0.0053	0.0106	0.0301
Acrylic Plaster	0.0184	0.0554	0.2230	0.0318	0.1457	0.0022
Plasterboard	0.0151	0.0289	0.1198	0.0409	0.0537	0.0078
Brick	0.0330	0.0689	0.1981	0.0572	0.1457	0.0357
Cement Plaster	0.0642	0.0965	0.2112	0.1430	0.2040	0.0022
Steel	0.0093	0.0122	0.0733	0.0179	0.0567	0.1004
Polyurethane Foam	0.0010	0.0025	0.0105	0.0013	0.0037	0.0223
Ceramic Tiles	0.0058	0.0115	0.0492	0.0136	0.0329	0.0223
Cement Portland	0.0274	0.0368	0.0545	0.0572	0.0567	0.0002
Extruded Polystyrene	0.0010	0.0029	0.0116	0.0032	0.0082	0.0301
Reinforced Concrete	0.1900	0.0001	0.1375	0.0001	0.0001	0.0289
Common Plaster	0.0629	0.134	0.1788	0.0953	0.2040	0.0022
Stone	0.0055	0.0072	0.0460	0.0119	0.0179	0.1060

Table 12. The deviations from ideal solutions

Criteria Building Materials	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Stonewool	0.2193	0.2193	0.2015	0.2182	0.2153	0.1918
Glasswool	0.2215	0.2205	0.2088	0.2203	0.2166	0.1951
Expanded Polystyrene	0.2218	0.2192	0.2086	0.2177	0.2124	0.1929
Acrylic Plaster	0.2046	0.1676	0	0.1912	0.0773	0.2208
Plasterboard	0.2079	0.1941	0.1032	0.1821	0.1693	0.2152
Brick	0.1900	0.1541	0.0249	0.1658	0.0773	0.1873
Cement Plaster	0.1588	0.1265	0.0118	0.08	0.019	0.2208
Steel	0.2137	0.2108	0.1497	0.2051	0.1663	0.1226
Polyurethane Foam	0.2220	0.2205	0.2125	0.2217	0.2193	0.2007
Ceramic Tiles	0.2172	0.2115	0.1738	0.2094	0.1901	0.2007
Cement Portland	0.1956	0.1862	0.1685	0.1658	0.1663	0.2228
Extruded Polystyrene	0.2220	0.2201	0.2114	0.2198	0.2148	0.1929
Reinforced Concrete	0.0330	0.2229	0.0855	0.2229	0.2229	0.1941
Common Plaster	0.1601	0.089	0.0442	0.1277	0.019	0.2208
Stone	0.2175	0.2158	0.177	0.2111	0.2051	0.117

Table 12 and Table 13 present the deviations from anti-ideal and ideal resolutions, respectively.

The grades of the deviations for each of the alternatives were calculated with Eqns (24) and (25). Using Eqns (26) and (27), K_i^+ and K_i^- were computed. As an example, K_i^+ and K_i^- values of Stonewool material are calculated:

$$K_1^+ = \frac{o_{opt}^+}{o_1^+} = \frac{0.338}{1.2654} = 0.2671;$$

$$K_1^- = \frac{o_i^-}{o_{opt}^-} = \frac{0.0724}{0.9997} = 0.0724.$$

Finally, the average deviation value for each alternative was computed by Eqn (28). As an example, the average deviation value of Stonewool material is calculated:

$$Q_1 = \frac{K_1^+ + K_1^-}{2} = \frac{0.2671 + 0.0724}{2} = 0.1698.$$

All results are given in Table 14.

According to Table 14, the order of construction materials is as follows: Cement Plaster, Common Plaster, Brick, Acrylic Plaster, Reinforced Concrete, Steel, Plaster Board, Cement Portland, Stone, Ceramic Tiles, Stonewool, Expanded Polystyrene, Extruded Polystyrene, Glasswool and Polyurethane Foam. With reference to the results, the best construction material is identified as Cement Plaster.

Table 13. The deviations from anti-ideal solutions

Building Materials \ Criteria	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6
Stonewool	0.0036	0.0036	0.0214	0.0047	0.0076	0.0311
Glasswool	0.0014	0.0024	0.0141	0.0026	0.0063	0.0278
Expanded Polystyrene	0.0011	0.0037	0.0143	0.0052	0.0105	0.0300
Acrylic Plaster	0.0183	0.0553	0.2229	0.0317	0.1456	0.0021
Plasterboard	0.015	0.0288	0.1197	0.0408	0.0536	0.0077
Brick	0.0329	0.0688	0.198	0.0571	0.1456	0.0356
Cement Plaster	0.0641	0.0964	0.2111	0.1429	0.2039	0.0021
Steel	0.0092	0.0121	0.0732	0.0178	0.0566	0.1003
Polyurethane Foam	0.0009	0.0024	0.0104	0.0012	0.0036	0.0222
Ceramic Tiles	0.0057	0.0114	0.0491	0.0135	0.0328	0.0222
Cement Portland	0.0273	0.0367	0.0544	0.0571	0.0566	0.0001
Extruded Polystyrene	0.0009	0.0028	0.0115	0.0031	0.0081	0.03
Reinforced Concrete	0.1899	0	0.1374	0	0	0.0288
Common Plaster	0.0628	0.1339	0.1787	0.0952	0.2039	0.0021
Stone	0.0054	0.0071	0.0459	0.0118	0.0178	0.1059

Table 14. The proposed modelling's results

Building Materials \ Results	o_i^+	o_i^-	K_i^+	K_i^-	Q_i	Rankings
Stonewool	1.2654	0.0720	0.2671	0.0724	0.1698	11
Glasswool	1.2828	0.0546	0.2635	0.0550	0.1592	14
Expanded Polystyrene	1.2726	0.0648	0.2656	0.0652	0.1654	12
Acrylic Plaster	0.8615	0.4759	0.3924	0.4764	0.4344	4
Plasterboard	1.0718	0.2656	0.3153	0.2659	0.2906	7
Brick	0.7994	0.5380	0.4229	0.5385	0.4807	3
Cement Plaster	0.6169	0.7205	0.5479	0.7210	0.6345	1
Steel	1.0682	0.2692	0.3164	0.2696	0.2930	6
Polyurethane Foam	1.2967	0.0407	0.2607	0.0411	0.1509	15
Ceramic Tiles	1.2027	0.1347	0.2811	0.1351	0.2081	10
Cement Portland	1.1052	0.2322	0.3058	0.2325	0.2692	8
Extruded Polystyrene	1.2810	0.0564	0.2639	0.0567	0.1603	13
Reinforced Concrete	0.9813	0.3561	0.3444	0.3564	0.3504	5
Common Plaster	0.6608	0.6766	0.5115	0.6771	0.5943	2
Stone	1.1435	0.1939	0.2956	0.1942	0.2449	9

4. Sensitivity analysis

The next part of the paper has analysed the effect of the changing criteria weights through 60 scenarios. Each value of criteria CR_1–CR_6 has been modified using the Eqn (29) (Tripathi et al., 2022; Biswas et al., 2022):

$$W_{n\beta} = \left(1 - W_{n\alpha}\right)\frac{W_\beta}{\left(1 - W_n\right)}. \tag{29}$$

In Eqn (29), $W_{n\beta}$ represents the corrected values of overall attributes values, $W_{n\alpha}$ indicates the lowered values of the attribute CR_1 in scenarios S1–S10, CR_2 in scenarios S11–S20, etc., concluding with scenarios S51–S60. W_β is the original value of each of the attributes considered, and W_n is the initial value of the attribute CR_1 in scenarios S1–S10, CR_2 in scenarios S11–S20, etc., concluding with scenarios S51–S60.

Criteria weights can be changed with different percentages (Puška & Stojanović, 2022; Badi et al., 2022), and in this paper have been modified in interval 5–95%. Simulated criteria values are shown in Figure 2.

After reproducing CRADIS method in 60 scenarios, results have been obtained and shown in Figure 3. These results confirm the best solution in the formed MCDM model but also show differences among alternatives with the separate influence of simulated criteria weights.

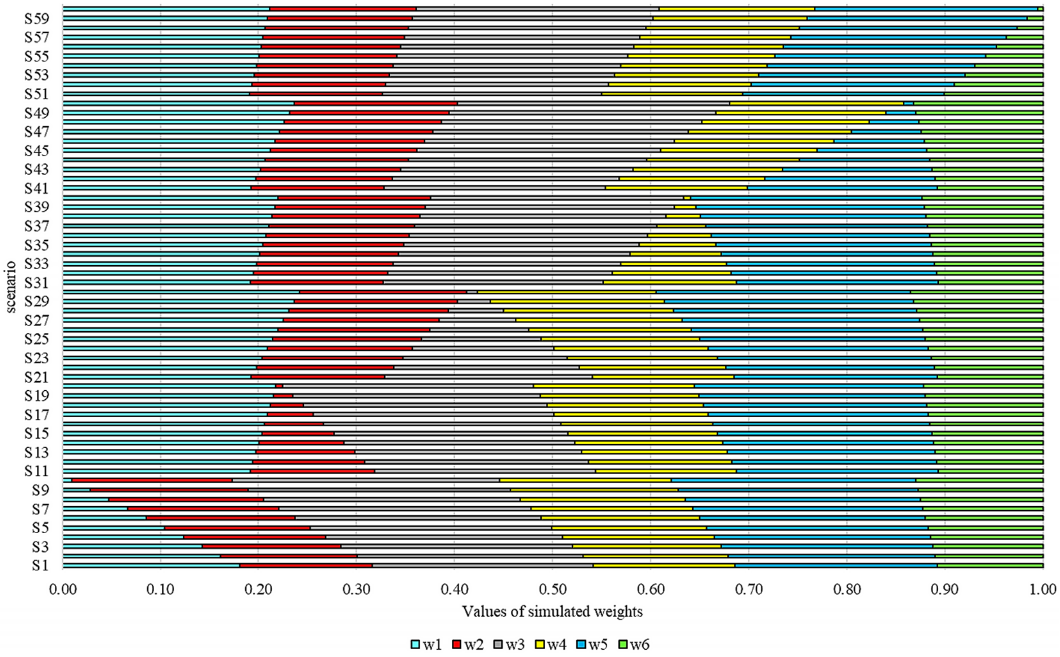

Figure 2. Values of simulated criteria weights in 60 scenarios

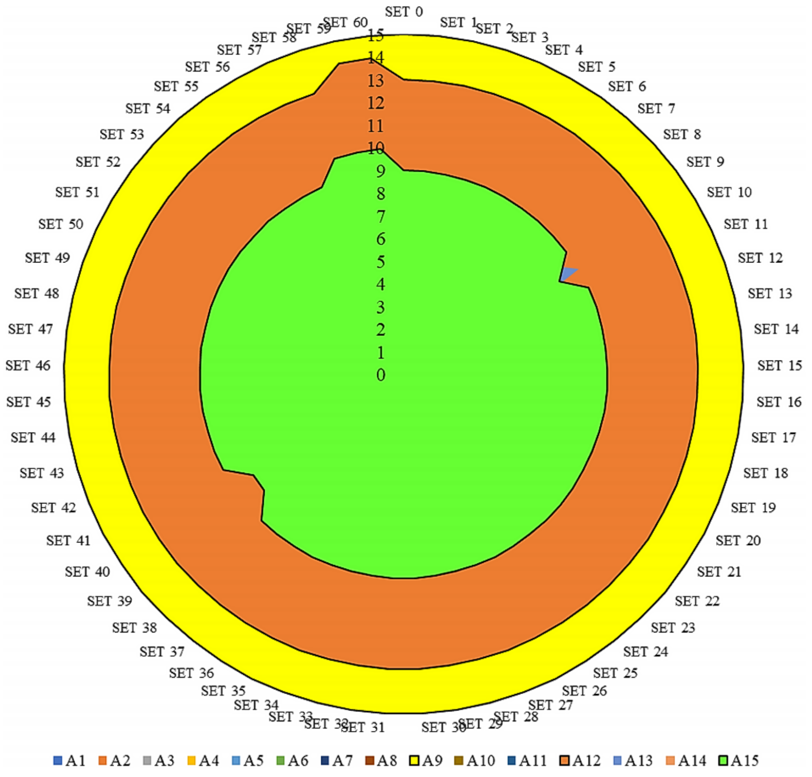

Figure 3. Results of sensitivity analysis

Obtained results display that Cement Plaster is the best material in 59 scenarios, while in one scenario (S40), Common Plaster showed the best performance. A consequence of such results is reducing the value of the fourth criterion for 95% (from 0.143 to 0.07). In a total of 34 scenarios no changes among all 15 alternatives, while 26 have changes that are not high. For example, when reducing weights of CR_1 in interval 45–95%, changes are as follows: A5 = 7»6, A8 = 6»5, A11 = 8»7, A13 = 5»6 (S5), A13 = 5»7 (S6 and S7), A13 = 5»8 (S8 and S9), A13 = 5»9 (S10), and A15 = 9»8 (S10). Reducing the second criterion weight does not influence ranking alternatives. When reducing weights of CR_3 in interval 45–95% changes are as follows: A5 = 7»8, A11 = 8»7. When reducing weights of CR_4 in interval 85–95% changes are as follows: A7 = 2»1 (S40), A11 = 8»9, A14 = 2»1 (S40), and A15 = 9»8 (S10). When

Table 15. The results of MCDM methods

Building Materials / Results of MCDM methods	MARCOS	ARAS	COPRAS	Proposed Model
Stonewool	11	11	10	11
Glasswool	14	14	12	14
Expanded Polystyrene	12	12	11	12
Acrylic Plaster	4	4	4	4
Plasterboard	7	7	5	7
Brick	3	3	3	3
Cement Plaster	1	1	1	1
Steel	6	6	6	6
Polyurethane Foam	15	15	14	15
Ceramic Tiles	10	10	9	10
Cement Portland	8	8	7	8
Extruded Polystyrene	13	13	13	13
Reinforced Concrete	5	5	15	5
Common Plaster	2	2	2	2
Stone	9	9	8	9

the reducing weights of CR_5 in interval 85–95% changes are as follows: A4 = 4»5, A13 = 5»4. When reducing weights of CR_6 changes are as follows: A5 = 7»6 (S51–S60), A8 = 6»7 (S51–S53), A8 = 6»8 (S54–S60), A11 = 8»7 (S54–S60), A15 = 9»10 (S58–S60), A2 = 14»13 (S59–S60), A12 = 13»14 (S59–S60).

Comparisons were made with the results of other MCDM methods (MARCOS (Stević et al., 2020), COPRAS (Zavadskas et al., 2007) and ARAS (Zavadskas et al., 2010)) to confirm whether the proposed methodology achieves accurate results. The results of other MCDM methodologies and the results of the proposed modelling are indicated in Table 15.

As can be seen from Table 15, while the results of MARCOS, ARAS and the proposed methodology are the same, the results of the COPRAS methodology are different from the results of these three methods. However, the correlation coefficient between the results of COPRAS and the results of the proposed methodology was identified as 0.796. Therefore, it is concluded that the proposed method obtains accurate results.

Conclusions

A high ratio of resource use is comprised worldwide as a consequence of the enormous consumption of embodied energy and building-insulation materials.

Unfavourable environmental effects can be reduced to a degree through reducing construction material consumption or reducing the effects due to each construction material. This can be accomplished in two ways to reduce environmental risks. First, construction material usage may be decreased. Natural resources are gradually depleting due to rising population and demand. Reusing and recycling building and insulation materials avoids the requirement for new sources, decreasing construction material usage or conserving natural sources. Second, material selection can be done considering environmental impacts. The designer plays a significant part in material selection. To evaluate the judgment, the designer should have access to a technique for material selection in order to achieve the goal of minimising environmental impacts.

In this research, building and insulation materials were evaluated with fuzzy FUCOM, CCSD, and CRADIS methods. The subjective weights of the evaluation criteria were obtained with the fuzzy FUCOM method. The objective weights of the evaluation criteria were found by the CCSD method. These materials were listed with the CRADIS method. As a result of analysis, cement plaster was obtained as the best construction material in terms of ecological effects. By comparing the proposed method with the MARCOS, COPRAS and ARAS methods, it has been tried to determine whether the proposed method reaches the correct results. According to the comparison results, it is concluded that the proposed method achieves correct results. In addition, sensitivity analysis was performed in this study. The weights of the criteria were changed for the sensitivity analysis. 60 scenarios were created for the change of weights. As a result of the sensitivity analysis, it has been determined that the proposed method is sensitive to the change in criteria weights.

According to the results of the proposed model, construction companies will harm the environment less by using cement plaster material in their construction. Due to the rapid increase in global warming and environmental pollution today, construction companies are also required to use environmentally friendly construction materials in construction. Therefore, it would be appropriate for construction companies to prefer cement plaster construction material, which are more environmentally friendly and offer good performance in terms of optimization of energy use.

This study has some limitations. Only 15 materials were examined in this study. In addition, only 10 experts were consulted. Fifteen materials examined were evaluated on the basis of only five criteria. Since only 5 criteria were taken into consideration in this study, as a result of this study, cement plaster material was determined as a material that is less harmful to the environment than other materials. However, it will be possible to change the results by increasing the number of criteria, especially considering other environmental criteria. In this study, most of the criteria, which were considered, affects the ozone layer. As it is known, there are more factors that affect global warming. This is also one of the limitations of this study. Therefore, future studies may focus on criteria related to other global warming and environmental pollution. They can also add financial criteria to the assessment alongside more environmental criteria. Thus, they could choose materials with a wider perspective. Besides, future studies can get different ideas by meeting with more experts or meeting with experts in different fields (environmental engineering and ecological engineering etc.) and transfer them to their studies. Additionally, future studies can obtain different studies by using fuzzy extensions of MCDM methods.

While decisions done along the construction life-cycle have an effect on the environment, material selection done in the pre-utilize stage dedicate to the greatest environmental impacts that consists during the utilize stage. To mitigate these environmental impacts, using new materials with less environmental impacts be beneficial.

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