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A new hybrid MCDM method for optimizing natural stone selection for building envelopes

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Abstract: Most kinds of natural stones are perfect coating materials. Through utilizing stones with less thermal conductivity coefficients, isolation of constructions improves with energy effective resolution. Modern building technologies prefer either decreasing stone to the weakest plausible extents or utilizing natural stones because natural stones have lower thermal conductivity with lighter weights. For this reason, first, the thermal and physical characteristics of natural stones used as coating material on the exterior walls of the buildings were investigated in this study. Then, in the light of these characteristics, natural stones with the best performance in terms of energy efficiency were determined using multi-criteria decision-making methods including FFSWARA and COBRA. The findings show that compressive strength is the most significant criteria and Isparta andesite stone is the most superior natural stone in terms of performance. This study contributes to the literature in three ways. First, the COBRA method used in this study has recently been introduced to the literature. Therefore, it has not been covered much in the literature. Second, this method has not been used in the selection of natural stone selection in the literature to our best knowledge. Third, this method has not been used together with the FFSWARA method before.

Keywords: Cladding, energy efficiency, green building, MCDM, natural stone, optimization.

1. Introduction

Energy use in general, and energy waste in particular, are currently being closely examined (Hasan, 1999). In the building sector, energy performance is a topic that requires to be taken into consideration. It is common knowledge that 40% of the energy usage in the world is associated to buildings (Alqaed, 2022). Turkey, like other nations throughout the world, purposes to consume less energy, notably in the construction industry. To meet the increasing need, one of the main drivers of global-warming and climate change is this enormous and expanding amount of energy usage and dependency on fossil fuels. There is a constant need for more effective use of sturdy building materials with a lower negatory ecological effect due to the increasing need of building developments to preserve environment. The prevailing exposure circumstances (micro-climate) and the building envelope's capacity to control heat transmittance define a building's climatic response (building physics).

The materials forming the shape of the envelope determine its capacity for thermal quality. Depending on the resources for construction that are available or accessible, many building envelope configurations are possible (Balaji et al., 2013). A building's façade cladding mechanism is a crucial component of its sustainability. Understanding how the building external wall's thermal behaviour affects the internal ambient is crucial to decrease energy usage in constructions (Jin et al., 2012).

The curtainwall's performance determines the costs and energy use of a building. Thus, while choosing a material for a façade, energy efficiency is the main factor. Some non-green products have great energy efficiency during use but high energy and resource consumption during production. As a result, choosing an energy-efficient façade material is crucial to green buildings (Shameri et al., 2011). A careful selection of the building's outer materials is one of the passive planning solutions that may be used to lessen the demand for heating and cooling (LEED, 2023). Natural stones have always been effective to guarantee efficiency in buildings for centuries because it has been a feature of architecture that has always been significant in both formal and technical building aspects, which it has established a biunique relationship. The countless heritage stone structures and monuments serve as living proof that stone is among the oldest building materials that have stood against time. Its use has evolved throughout the years from thick stone masses used for building envelope to thin building materials used as part of the covering mechanism on building façades (Ioannidou et al., 2014).

Natural stone now appears as thin covering plates or panels within façade mechanisms or light curtainwall due to the improvement in curtainwall mechanisms, which are composed of horizontal and vertical constructional components anchored together and connected to the building's supporting structure, offering overall the typical elements of a building envelope without reducing the building construction's load carrying capacity (Nacheman, 2005). Façades made of natural stone significantly improve a building's overall technical and aesthetic performances. People's perceptions of aesthetics are strongly influenced by façades, but this feature must also be considered as a complicated mechanism that is subject to a range of mechanical and physical forces, including actions involving air, moisture, and heat as well as dynamic and static loadings (Camposinhos et al., 2013).

Thermal conduction or transfer can be characterized as the energy transmission due to adjacent structures' temperature differences. The amount of transferred heat relies on a few elements like shape, porosity, temperature interval, uniaxial pressure, and moisture (Clauser, & Huenges, 1995; Singh et al., 2007). Thermal isolation is an important tool in energy conservation. The thermal insulation mechanisms can be characterized through thermal conductivity coefficient. The thermal conductivity coefficient is mainly regulated through the texture and mineral composition of the natural stone. A natural stone's thermal conductivity coefficient is defined through metrics of thermal resource and temperature gradient in the natural stone (Popov et al., 1999). Using stones with a low thermal conductivity to aid building insulation is one component of energy efficiency. This causes lower heating needs in cold locations and lower energy use for air conditioning in equatorial regions. When determining if a natural stone is suitable for insulation that saves energy, its thermal and physical characteristics are crucial to examine.

The outer walls of a structure, also referred to as the whole frontage, are among the biggest parts of buildings and play a significant role in the heat transfer between outdoor and indoor settings. It accounts from 20% up to 30% of the total energy usage and has a high thermal transmittance (Nadoushani et al., 2017). Since many decades, namely from the first energy laws for sixties and seventies, the developments in building standards have been concentrated on lowering the energy requirements for cooling and heating buildings by enhancing the external walls' thermal isolation, particularly in relation to the materials used for the façade (Balo, 2011; Khalid et al., 2021; Wu et al., 2022). Other requirements for whole frontage coating materials, however, should also be considered when making a decision. A modern façade design that creates a distinctive image for the building is also important therefore the effect of material used in façades on the design need to be considered (Menka, 2017; Sagbansua & Balo, 2017).

Because it influences the building's ultimate shape, project cost, construction time, and sustainability, choosing a façade coating material is a multi-criteria decision making (MCDM) problem. Due to their inherent capability to evaluate various alternatives with respect to various criteria in order to potentially select the best alternative, MCDM methodologies, a subfield of operational research, are becoming more and more important as potential tools for resolving and analysing complicated decision problems (Chakraborty et al., 2015). Making decisions about façade coating materials getting more challenging for designers and master developers because of various criteria. The choice of building materials based on a single criterion is insufficient; a tool with many criteria will allow for the inclusion of all variables that can have an impact and should be taken into account when choosing a façade.

The process of choosing natural stone for the façade system is typically based on a variety of aspects and criteria, including the material's qualities, the area's location, and the climate (Tovarović et al., 2017). Therefore, it is essential to use an integrated method. Making judgments about how to accomplish various goals in the course of the planning operation is an important stage, particulary when many diverse criteria must be taken into account. The tools to make the procedure simpler and more effective are provided by MCDM (Han et al., 2015; Van Stijn et al., 2022).

A study with MCDM techniques investigating the performance of natural stones, which can be used as coating materials in buildings, on energy efficiency has not been found in the literature, according to the authors' best knowledge. However, other studies using MCDM techniques are given in Table 1.

Table 1. The review of studies using MCDM techniques.

Multi-attribute decision analysis	Stakeholders	Weighting	Other methodologies	Ref.
WSM	-	The methodology represented through Mroz	Diverse weighting scenarios, LCA	(Basińska et al., 2020)
AHP	-	Own prediction (diverse weight schemas)	Diverse weight schemas	(Marques et al., 2020)
Interval TOPSIS	-	Own prediction (diverse weight schemas)	Sensitivity analysis (diverse weight schemas)	(Streimikiene et al., 2020)
Fuzzy AHP	Specialists in the construction industry	Specialist (pairwise crosscheck)	-	(Bostancioglu et al., 2021)
ELECTRE TRI-rC	Specialists (not defined)	Specialist (Simon Roy Figueira procedure)	Sensitivity analysis, comfort and energy optimisation, LCC analysis, LCA	(Rocchi et al., 2018)
PROMETHEE V	Specialists in the energy industry and construction	Swing methodology	Sensitivity analysis	(Seddiki et al., 2016)
COPRAS-G, COPRAS	Specialists (not defined)	Specialist questionnaire (assessment from the most significant to the minimum significant)	Concordance coefficient through Kendal	(Zavadskas et al., 2008)
AHP	-	Specialist (pairwise crosscheck)	The Choquet integral	(Moghtadernejad et al., 2020)
AHP	Specialists in the construction industry	Specialist (pairwise crosscheck)	-	(Bostancioglu et al., 2019)
AHP	Specialists in the construction industry (engineers, researchers, and architects)	Specialist (pairwise crosscheck)	-	(Rosasco & Perini, 2019)
AHP, TOPSIS	Specialists in the construction industry	Specialist (questionnaire)	Sensitivity analysis (diverse weight schemas)	(Guzman-Sanchez et al., 2018)
MULTI-MOORASVNS	Specialists in building planning (designers, engineers, and architects)	Specialist (pairwise crosscheck)	Decision of attribute weightages through SWARA methodology, neutrosophic sets, sensitivity analysis.	(Zavadskas et al., 2017)
VIKOR, ELECTRE III, TOPSIS, MULTIMOORA, ELECTRE IV	Specialists in air conditioning, ventilation, heating and in civil engineers.	Specialist questionnaire (assessment from the most significant to the minimum significant)	Decision of attributes weightages through SWARA methodology	(Zavadskas et al., 2013)

COPRAS, VIKOR, TOPSIS, SAW	Specialists in structure (from the construction products' certification centre, researchers, reconstruction, and construction enterprises)	Own prediction and specialist questionnaire (assessment from the most significant to the minimum significant)	Concordance coefficient through Kendal	(Ginevičius et al., 2008)

In Table 2, the studies about façade cladding mechanism are summarized.

Table 2. The studies about façade cladding mechanism.

Methodologies of selection/investigation	Investigated attributes	Research findings and conclusions	Ref.
Experimental-data analysis	Combustibility/fire resistance	2 sheet gypsum-boards of 1.25 cm in thickness supported with glass-fiber were approved satisfying to supply one hour fire capacitance with load-bearing floor and wall	(Prafitasiwi et al., 2022)
E-QUEST software/ case research analysis	Materials/ design	Choosing the proper kind of color or glass in addition to efficient shading mechanisms which react to the zone's sun irradiation	(Yu & Song, 2018)
Experimental methodology	Design/ sustainability	The simulation research displayed that conic Al2O3/In2O3/ TiO2 have higher adsorption, higher performance, and lesser reflection	(Kundu & Tyagi, 2017)
Experimental methodology	Design/ sustainability	After 3 years investigation, the superficies temperature raises up to 16.50C in paints and up to 300C in claddings	(Radmard et al., 2020)
Rhino software/ grasshopper	Design	Full potency hexagonal adaptable mechanism was represented to accomplish the maximal visible comfortable level depend on the consumers' precedence	(Suryanita et al., 2022)
Case research data analysis	Materials/ sustainability/ lifecycle evaluation	Proposals for optimising the lifecycle operation of ceramic front line panels for more ecological efficiency and some suggestions for façade materials' better choice	(Han et al., 2015)
Experimental methodology	Energy-saving/ materials/ sustainability	A raise of 8 percent in the whole cooling-load computed at 30 percent moisture and 280C was gauged notional to the basis case assessed at zero percent moisture and 240C	(Zomorodian & Tahsildoost, 2018)
Experimental methodology	Maintenance/ durability	Choosing a proper heating-time, it could check the substrate's melting depth, decrease the dilution ratio, and keep the corrosion resistance and hardness of the coating	(Pastore & Andersen, 2022)
Experimental-information analysis	Maintenance/ durability	Weld coating can prepare more conglutination between the clads and substrate to improve tribological and mechanical properties	(Ranjan & Das, 2022)
Experimental processes	Energy saving/cost/ lifecycle evaluation	Depend on detailed evaluation, the Ni-sourced alloy cladding displays the most efficiency	(Sayed & Fikry, 2019)
Multi-attribure analysis	Maintenance/lifecycle evaluation	The upkeep policy can be altered if the weightage of the performance and durability attributes are, at minimum, 1 percent, and the creative resolution can be modified if the weightage is, at minimum, 17 percent	(Theodosiou et al., 2019)
Envi-met software	Design/sustainability	The findings indicate that there is a relationship between the temperature trend and the construction façade reflectance, but this has a so restricted effect on outside micro-climate	(Mawardi et al., 2022)
ReCiPe technique	Energy saving/cost/ lifecycle evaluation	The analysis outcomes displayed that the perovskite façade was the many maintainable alternatives for construction	(Zhang et al., 2021)
Design builder simulation	Energy saving/designs	The more isolated walls and windows could have reverse impacts on cooling loads and interior thermal comfort	(Alchapar & Correa, 2020)
Thermal analysis package COMSOL	Design/sustainability	The all impact at DSF can exceed 25 percent of whole shell heatflow	(Rahmanian & Rahmani, 2018)
Case research analysis	Sustainability/materials/cost	Design optimisation should contain 4 attributes; comfort, economic, environment, and energy	(Do & Chan, 2021)
Mathematical modelling	Energy saving/materials/sustainability	The external wall integrated could supply 15 percent – 72 percent degradation in yearly heat-gain and 7 percent –38 percent degradation in yearly heat-loss	(Lee et al., 2008)

Design builder software	Energy saving/materials/design/sustainability	Utilizing a double-skin and simple DSF one with phase change material decreases the heating energy required through 18 percent and 40 percent	(LEED, 2023)
CFD analysis/ANSYS fluent	Energy-saving/design/sustainability	OVF warranties an energy conserving varying from 20 percent to 55 percent	(Liu et al., 2019)

For stone walls to operate as intended, it is crucial to specify the right stone type as an exterior wall component, i.e., effective selection of the cladding natural stones at the design stage. A high-quality external wall envelope and other components will perform poorly from the viewpoint of energy performance if the requirements of this selection stage are not met (insulation material and building material).

Finally, the purpose of this research is to create standards for maintainable planning and suggestions for choosing an effective natural stone façade coating material for cold regions while taking façade thermal performance into account. In this study, the FFSWARA method is used to weight the criteria and the COBRA method is used to rank the natural stones. The FFSWARA method is preferred due to its easy computation steps and easy data collection for FFSWARA. The COBRA method integrates different kinds of distances from different reference locations to rank choices.

This characteristic allows it to produce more dependable findings when compared to other reference-based MCDM techniques (TOPSIS, CODAS, and EDAS, among others). This research makes three distinct contributions to the existing body of knowledge. The COBRA method, which is the focus of this research, has just been introduced to the academic literature thus there has been less attention given to this method in the existing literature. Also, to the best of our knowledge, this method has not been used in the literature for the purpose of selecting natural stone. Furthermore, the use of this method in conjunction with the FFSWARA method has not been previously documented.

2. Materials and methods

In this study, the weights of the criteria to assess natural stones will be found with the FFSWARA method, while the natural stone with the best performance will be selected with the COBRA method.

2.1. FFSWARA

With the FFSWARA method, the criteria used in the selection of natural stone will be weighted. The steps of the FFSWARA method are shown below.

Step 1: each decision maker rank nature stone selection criteria then these rankings are aggregated by geometric mean. Therefore, final ranking of criteria is obtained.

Step 2: each decision maker assigns linguistic terms, which are indicated in Table 3, as comparative significance values. In other words, decision makers determine $j-1$th criterion is how important from the jth criterion. These linguistic terms are converted to fermatean fuzzy numbers by using Table 3.

Table 3. Linguistic terms and Fermatean Fuzzy numbers (Ayyildiz, 2022).

Linguistic terms	Fermatean Fuzzy Numbers
Extremely insignificant	(0.10, 0.975)
Not significant	(0.20, 0.85)
Slightly significant	(0.35, 0.70)
Moderately significant	(0.55, 0.50)
significant	(0.70, 0.35)
Very significant	(0.85, 0.20)
Extremely significant	(0.975, 0.10)

Step 3: assigned comparative significance values by decision makers are aggregated by the Fermatean Fuzzy weighted averaging operator shown in equation 1 (Ayyildiz, 2022).

$$v_j = V(\mu_j, \pi_j) = \left(\sqrt[3]{1 - \prod_{k=1}^{K} 1 - (\mu_{jk})^3}, \prod_{k=1}^{K} \pi_{jk}\right) \quad (1)$$

Step 4: the positive score value $A^+(j)$ for each attribute is computed as (Ayyildiz, 2022).

$$A^+(j) = 1 + \mu_j^3 + \pi_j^3 \quad (2)$$

Step 5: comparative coefficient for each criterion (cco_j) is obtained by using equation 3 (Ayyildiz, 2022).

$$cco_j = \begin{cases} 1, & j = 1 \\ A^+(j) + 1, & j > 1 \end{cases} \quad (3)$$

Step 6: recomputed weight (rew_j) for each criterion is computed as (Ayyildiz, 2022).

$$rew_j = \begin{cases} 1, & j = 1 \\ \frac{rew_{(j-1)}}{cco_j}, & j > 1 \end{cases} \quad (4)$$

Step 7: final weights of criteria are obtained as (Ayyildiz, 2022).

$$w_j = \frac{rew_j}{\sum_{j=1}^{n} rew_j} \quad (5)$$

In this study, the weights of the criteria to assess natural stones will be found with the FFSWARA method, while the natural stone with the best performance will be selected with the COBRA method.

2.2. COBRA

The natural stone with the best performance will be chosen with the COBRA method. The stages of the COBRA methodology are presented below (Krstić et al., 2022).

Step 1: first, the decision matrix (E) is arranged.

$$E = [e_{ij}]_{m \times n} \quad (6)$$

Step 2: the values in the decision matrix are normalized by Equation 7.

$$f_{ij} = \frac{e_{ij}}{max\ e_{ij}} \quad (7)$$

Step 3: the weighted normalized matrix is obtained by Equation 8.

$$G = [g_{ij}]_{m \times n} = [f_{ij} \times w_j]_{m \times n} \quad (8)$$

Step 4: negative ideal, positive ideal and average solutions for each criterion are computed. Equations 9 and 11 are used for beneficial criteria and equations 10 and 12 are used for non-beneficial criteria. Equation 13 is used for both non-beneficial and beneficial criteria.

$$NIS_j = min\ (f_{ij} \times w_j) \quad (9)$$

$$NIS_j = max\ (f_{ij} \times w_j) \quad (10)$$

$$PIS_j = max\ (f_{ij} \times w_j) \quad (11)$$

$$PIS_j = min\ (f_{ij} \times w_j) \quad (12)$$

$$AS_j = \frac{\sum_{i=1}^{m} (f_{ij} \times w_j)}{m} \quad (13)$$

Step 5: the distances from the negative ideal ($d(NIS_j)$), the positive ideal ($d(PIS_j)$) solutions, additionally, the negative ($d(AS_j^-)$) and positive ($d(AS_j^+)$) distances from the mean solution are determined as following.

$$d(S_j) = dE(S_j) + \rho \times dE(S_j) \times dT(S_j) \quad (14)$$

In equation 14, S_j indicates any solution (PIS_j, AS_j or NIS_j) and ρ shows the correction coefficient achieved as following.

$$\rho = max\ dE(S_j) - min dE(S_j) \quad (15)$$

In equation 14, $dT(S_j)$ and $dE(S_j)$ indicate the taxicab and euclidean distances, respectively, for the positive ideal resolution achieved as follows.

$$dT(PIS_j)_i = \sum_{j=1}^{n} |PIS_j - f_{ij} \times w_j| \quad (16)$$

$$dE(PIS_j)_i = \sqrt{\sum_{j=1}^{n}(PIS_j - f_{ij} \times w_j)^2} \quad (17)$$

Additionally, these distances for negative ideal solution are computed as follows.

$$dT(NIS_j)_i = \sum_{j=1}^{n}|PIS_j - f_{ij} \times w_j| \quad (18)$$

$$dE(NIS_j)_i = \sqrt{\sum_{j=1}^{n}(PIS_j - f_{ij} \times w_j)^2} \quad (19)$$

Besides, positive and negative distances from the mean resolution are computed as follows.

$$dT(AS_j)_i^+ = \sum_{j=1}^{n}\varepsilon^+|AS_j - f_{ij} \times w_j| \quad (20)$$

$$dE(AS_j)_i^+ = \sqrt{\sum_{j=1}^{n}\varepsilon^+(AS_j - f_{ij} \times w_j)^2} \quad (21)$$

$$\varepsilon^+ = \begin{cases} 1 & if\ AS_j < f_{ij} \times w_j \\ 0 & if\ AS_j > f_{ij} \times w_j \end{cases} \quad (22)$$

$$dT(AS_j)_i^- = \sum_{j=1}^{n}\varepsilon^-|AS_j - f_{ij} \times w_j| \quad (23)$$

$$dE(AS_j)_i^- = \sqrt{\sum_{j=1}^{n}\varepsilon^-(AS_j - f_{ij} \times w_j)^2} \quad (24)$$

$$\varepsilon^- = \begin{cases} 1 & if\ AS_j > f_{ij} \times w_j \\ 0 & if\ AS_j < f_{ij} \times w_j \end{cases} \quad (25)$$

Step 6: comprehensive distances values (dC_i) are computed by equation 26.

$$dC_i = \frac{d(PIS_j)_i - d(NIS_j)_i - d(AS_j)_i^+ + d(AS_j)_i^-}{4} \quad (26)$$

The option with the smallest comprehensive distances value is identified as the best option.

3. Results and discussion

It is crucial to completely analyse the consequences of the significant features of natural stones early in the design process, in order to accomplish the energy efficiency with stone coating. Natural stone is bonded to a support structure that has already been built in the traditional coating method that has been used for decades in constructions. These elements work together to form a building's outer shell. Natural stone is becoming more preferred as a material used to make energy efficient façades.

In this study, 10 natural stones used in constructions were evaluated. While determining these natural stones, the opinions of 10 experts were consulted. Experts have defined 15 criteria to identify these 10 stones and evaluate them. The values of these natural stones in the evaluation criteria are taken from the literature. These evaluation criteria are shown in Table 4.

Table 4. The evaluation criteria.

Criteria
Thermal insulation coefficient, k (λ)
Strength decrease after freezing %
Resistance to friction wear according to DIN 52108 (Bohme method)
Strength decrease after freezing %
Frost resistance (Weight reduction)
P-wave velocity reduction after frost
Tensile strength in bending
Compressive strength
Actual porosity (total porosity)
Water absorption at atmospheric pressure; by volume (apparent porosity)
Water absorption at atmospheric pressure; by weight
Specific gravity of solid part
Schmidt hammer hardness
Unit bulk weight (dry) (density)
Hardness

The weights of evaluation criteria were obtained with the FFSWARA method. 10 experts were first asked to rank the criteria from most significant to minimum important, and then these rankings were combined with the geometric mean (G.M.). The rankings of the criteria and the combined rankings with the geometric mean are presented in Table 5.

Table 5. The rankings of criteria.

Criteria \ Experts	Exp1	Exp2	Exp3	Exp4	Exp5	Exp6	Exp7	Exp8	Exp9	Exp10	G.M.
Hardness	13	14	13	13	14	14	14	13	14	13	13
Schmidt hammer hardness	14	13	15	15	13	13	15	15	15	14	15
Unit bulk weight (dry) (density)	4	5	4	5	3	3	5	4	3	5	4
Specific gravity of solid part	7	7	6	6	5	7	6	6	7	6	6
Water absorption at atmospheric pressure; by weight	5	4	5	4	6	5	4	5	5	4	5
Water absorption at atmospheric pressure; by volume (apparent porosity)	6	6	7	7	7	6	7	7	6	7	7
Actual porosity (total porosity)	12	11	12	11	12	11	11	11	11	12	11
Compressive strength	1	1	2	2	1	1	1	2	1	1	1
Tensile strength in bending	2	2	1	1	2	2	2	1	2	2	2
Seismic velocity (P-wave sound velocity)	15	15	14	14	15	15	13	14	12	15	14
P-wave velocity reduction after frost	10	9	10	9	10	10	10	10	9	10	10
Weight reduction in freezing	8	10	9	10	8	9	8	9	10	8	9
Strength decrease after Freezing %	9	8	8	8	9	8	9	8	8	9	8
Resistance to friction wear according to DIN 52108 (Bohme method)	11	12	11	12	11	12	12	12	13	11	12
Thermal insulation coefficient, k (λ)	3	3	3	3	4	4	3	3	4	3	3

Each experts assigns linguistic terms, which are indicated in Table 3, as comparative significance values. These linguistic terms are converted to Fermatean fuzzy numbers by using Table 3. Then, these Fermatean fuzzy numbers are aggregated by equation 1. The weights of the assessment criteria are found by using equations 2-5. Table 6 indicates the results of the FFSWARA methodology.

Table 6. The results of the FFSWARA.

Criteria \ Results	$V(\mu_j, \pi_j)$	$A^+(j)$	cco_j	rew_j	w_j
Compressive strength			1	1	0.46111
Tensile strength in bending	(0.2151, 0.7763)	0.5421	1.5421	0.64847	0.29901
Thermal insulation coefficient, k (λ)	(0.6772, 0.2042)	1.3020	2.3020	0.2817	0.12989
Unit bulk weight (dry) (density)	(0.5581, 0.3981)	1.1107	2.1107	0.13346	0.06154
Water absorption at atmospheric pressure; by weight	(0.6807, 0.1780)	1.3098	2.3098	0.05778	0.02664
Specific gravity of solid part	(0.6570, 0.1120)	1.2822	2.2822	0.02532	0.01168
Water absorption at atmospheric pressure; by volume (apparent porosity)	(0.4701, 0.3041)	1.0758	2.0758	0.0122	0.00563
Strength decrease after freezing %	(0.7179, 0.0414)	1.3699	2.3699	0.00515	0.00237
Weight reduction in freezing	(0.4501, 0.4002)	1.0271	2.0271	0.00254	0.00117
P-wave velocity reduction after frost	(0.7961, 0.0257)	1.5045	2.5045	0.00101	0.00047
Actual porosity (total porosity)	(0.3873, 0.4859)	0.9434	1.9434	0.00052	0.00024
Resistance to friction wear according to DIN 52108 (Bohme method)	(0.3873, 0.4859)	0.9434	1.9434	0.00027	0.00012
Hardness	(0.3719, 0.5574)	0.8783	1.8783	0.00014	0.00006
Seismic velocity (P-wave sound velocity)	(0.2566, 0.6768)	0.7069	1.7069	0.00008	0.00004
Schmidt hammer hardness	(0.2151, 0.7763)	0.5421	1.5421	0.00005	0.00002

According to Table 6, the criteria are listed in order of importance as follows: compressive strength, tensile strength in bending, thermal insulation coefficient, k (λ), unit bulk weight (dry), (density), water absorption at atmospheric pressure; by weight, solid part' specific gravity, water absorption at atmospheric pressure; by volume (apparent porosity), strength decrease after freezing %, weight reduction in freezing, p-wave velocity reduction after frost, actual porosity, (total porosity), resistance to friction wear according to din 52108 (bohme methodology), hardness, seismic velocity, (p-wave sound velocity) and Schmidt hammer hardness. Accordingly, the most significant criteria were determined as compressive strength, while the least important criterion was determined as Schmidt hammer hardness criterion. After the weights of the evaluation criteria are found, the stages of the COBRA methodology are commenced. The data to be used in the decision matrix are taken from (Sert, 2010). Data used in this study is shown in Table 7.

Table 7. Data used in this study.

Criteria \ Results	Infrared	Ancient coffee	Hanging gray	Nevşehir white	Erciyes black	Desert yellow	Dried rose	Isparta köfke	Nevşehir göreme	Isparta andesite
Thermal insulation coefficient, k (λ)	0.47	0.5	0.51	0.39	0.3	0.25	0.35	0.2-0.4	0.37	2.2
Strength decrease after freezing % resistance to friction wear according to DIN 52108 (Bohme method)	27.0	18.0	36.3	49.8	89.3	92.0	32.3	15.5	38	18.1
Strength decrease after freezing %	4.1	4	4.05	5.0	3.95	5.2	5.40	4 - 23	0.5	0.9
Frost resistance (weight reduction)	0.21	0.24	0.19	0.77	0. 55	0.64	0.53	1.5	4.09	23.7
P-wave velocity reduction after frost	3.5	3.6	4.2	6.0	4.1	6.1	3.9	5	4.2	0.04
Seismic velocity (P-wave sound velocity)	2700	3000	1800-2100	1900-2300	2000-2500	1500-2100	2000-2400	2300	2400	4860
Tensile strength in bending	110	110	70	40	50	75	60	55	72	163
Compressive strength	380-470	370-520	340-400	50-60	65-110	25-30	90-95	60-120	102	500-700
Actual porosity (total porosity)	33.2	32.7	32.8	46.5	51.1	56.5	43.3	40	45	4.86
Water absorption at atmospheric pressure; By volume (apparent porosity)	28.55	22.74	24.40	27.42	37.56	42.77	23.10	28	24.14	2.3
Water absorptionat atmospheric pressure; By weight	16.50	13.26	14.27	20.00	31.30	39.34	15.21	20	17.00	0.98
Specific gravity of solid part	2.590	2.549	2.545	2.560	2.453	2.500	2.674	2.38	2.58	2.62
Schmidt hammer hardness	24	23	31	5	19	13	12	18	12	33
Unit bulk weight (dry) (density)	1.730	1.715	1.711	1.371	1.200	1.087	1.5164	1.4	1.42	2.35
Hardness	3	3	3	2-3	2-3	2	2	2	3	3

Some of the values shown in Table 7 are interval values. This situation was asked to the experts. Experts found it appropriate to make real numbers by taking the arithmetic mean of the interval values. Thus, the decision matrix is created. Table 8 shows the decision matrix.

Table 8. The decision matrix.

Natural stones \ Criteria	Thermal insulation coefficient, k (λ)	Resistance to friction wear according to DIN 52108 (Bohme method)	Strength decrease after freezing %	Weight reduction in freezing	P-wave velocity reduction after frost	Seismic velocity, (P-wave sound velocity)	Tensile strength in bending	Compressive strength
Infrared	0.47	27	4.1	0.21	3.5	2700	110	425
Ancient coffee	0.5	18	4	0.24	3.6	3000	110	445
Hanging gray	0.51	36.3	4.05	0.19	4.2	1950	70	370
Nevşehir white	0.39	49.8	5	0.77	6	2100	40	55
Erciyes black	0.3	89.3	3.95	0.55	4.1	2250	50	87.5
Desert yellow	0.25	92	5.2	0.64	6.1	1800	75	27.5
Dried rose	0.35	32.3	5.4	0.53	3.9	2200	60	92.5
Isparta köfke	0.3	15.5	13.50	1.5	5	2300	55	90
Nevşehir göreme	0.37	38	0.5	4.09	4.2	2400	72	102
Isparta andesite	2.2	18.1	0.9	23.7	0.04	4860	163	600

Natural Stones \ Criteria	Actual porosity (total porosity)	Water absorption at atmospheric pressure; By volume (apparent porosity)	Water absorption at atmospheric pressure; by weight	Specific gravity of solid part	Schmidt hammer hardness	Unit bulk weight (dry) (density)	Hardness
Infrared	33.2	28.55	16.5	2.59	24	1.73	3
Ancient coffee	32.7	22.74	13.26	2.549	23	1.715	3
Hanging gray	32.8	24.4	14.27	2.545	31	1.711	3
Nevşehir white	46.5	27.42	20	2.56	5	1.371	2.50
Erciyes black	51.1	37.56	31.3	2.453	19	1.2	2.50
Desert yellow	56.5	42.77	39.34	2.5	13	1.087	2
Dried rose	43.3	23.1	15.21	2.674	12	1.5164	2
Isparta köfke	40	28	20	2.38	18	1.4	2
Nevşehir göreme	45	24.14	17	2.58	12	1.42	3
Isparta andesite	4.86	2.3	0.98	2.62	33	2.35	3

With the aid of equation 7, the decision-matrix displayed in table 8 is normalized. Table 9 presents the normalized decision-matrix.

Table 9. The normalized decision matrix.

Natural stones \ Criteria	Thermal insulation coefficient, k (λ)	Resistance to friction wear according to DIN 52108 (Bohme method)	Strength decrease after freezing %	Weight reduction in freezing	P-wave velocity reduction after frost	Seismic velocity (P-wave sound velocity)	Tensile strength in bending	Compressive strength
Infrared	0.214	0.293	0.304	0.009	0.574	0.556	0.675	0.708
Ancient coffee	0.227	0.196	0.296	0.01	0.59	0.617	0.675	0.742
Hanging gray	0.232	0.395	0.3	0.008	0.689	0.401	0.429	0.617
Nevşehir white	0.177	0.541	0.37	0.032	0.984	0.432	0.245	0.092
Erciyes black	0.136	0.971	0.293	0.023	0.672	0.463	0.307	0.146
Desert yellow	0.114	1	0.385	0.027	1	0.37	0.46	0.046
Dried rose	0.159	0.351	0.4	0.022	0.639	0.453	0.368	0.154
Isparta köfke	0.136	0.168	1	0.063	0.82	0.473	0.337	0.15
Nevşehir göreme	0.168	0.413	0.037	0.173	0.689	0.494	0.442	0.17
Isparta andesite	1	0.197	0.067	1	0.007	1	1	1

Natural stones \ Criteria	Actual porosity (total porosity)	Water absorption at atmospheric pressure; By volume (apparent porosity)	Water absorption at atmospheric pressure; By weight	Specific gravity of solid part	Schmidt hammer hardness	Unit bulk weight (dry) (density)	Hardness
Infrared	0.588	0.668	0.419	0.969	0.727	0.736	1
Ancient coffee	0.579	0.532	0.337	0.953	0.697	0.73	1
Hanging gray	0.581	0.57	0.363	0.952	0.939	0.728	1
Nevşehir white	0.823	0.641	0.508	0.957	0.152	0.583	0.833
Erciyes black	0.904	0.878	0.796	0.917	0.576	0.511	0.833
Desert yellow	1	1	1	0.935	0.394	0.463	0.667
Dried rose	0.766	0.54	0.387	1	0.364	0.645	0.667
Isparta köfke	0.708	0.655	0.508	0.89	0.545	0.596	0.667
Nevşehir göreme	0.796	0.564	0.432	0.965	0.364	0.604	1
Isparta andesite	0.086	0.054	0.025	0.98	1	1	1

Using equations 9-26, the order of natural stones is reached. Table 10 indicates the results of the COBRA method and the ranking of natural stones.

Table 10. The results of MCDM method.

Natural stones \ Results	$d(PIS)$	$d(NIS)$	$d(AS)^+$	$d(AS)^-$	dC	Rankings
Infrared	0.186	0.424	0.171	0.006	-0.10075	3
Ancient coffee	0.171	0.444	0.187	0.006	-0.1135	2
Hanging gray	0.282	0.34	0.112	0.02	-0.0375	4
Nevşehir white	0.593	0.121	0.001	0.159	0.1575	10
Erciyes black	0.549	0.138	0.011	0.128	0.132	8
Desert yellow	0.579	0.147	0.017	0.162	0.14425	9
Dried rose	0.53	0.141	0.001	0.116	0.126	6
Isparta köfke	0.539	0.141	0.002	0.121	0.12925	7
Nevşehir göreme	0.506	0.154	0	0.102	0.1135	5
Isparta andesite	0.126	0.633	0.4	0.019	-0.222	1

According to the results of the COBRA method, they are ranked from the best natural stone to the worst natural stone as follows: isparta andesite, ancient coffee, infrared, hanging gray, nevşehir göreme, dried rose, isparta köfke, erciyes black, desert yellow, and nevşehir white. The natural stone named isparta andesite was determined as the best natural stone, while the natural stone named nevşehir white was determined as the worst natural stone.

The COBRA method was compared with other MCDM methods (TOPSIS, VIKOR, CODAS and MARCOS) that use distance measurement techniques to confirm whether the COBRA method yields accurate results. Table 11 indicates the results of the other MCDM methodologies and the COBRA methodology.

Table 11. The results of MCDM method.

Natural stones \ Results	TOPSIS	VIKOR	CODAS	MARCOS	COBRA
Infrared	3	3	3	3	3
Ancient coffee	2	2	2	2	2
Hanging Ggay	4	4	4	4	4
Nevşehir white	10	10	10	10	10
Erciyes black	8	8	8	8	8
Desert yellow	9	9	5	5	9
Dried rose	6	6	9	9	6
Isparta köfke	7	7	7	7	7
Nevşehir göreme	5	5	6	6	5
Isparta andesite	1	1	1	1	1

The VIKOR, TOPSIS, and COBRA methods gave identical ranking results in terms of determining the optimum natural stone for use as cladding in the building envelope, taking into account energy efficiency parameters. In other words, the results of the three methods exactly match each other. In all three methods, isparta andesite stone was found to be the most energy-efficient wall cladding material among all natural stones. Nevşehir white was found to be the least energy-efficient wall cladding material.

The ranking results obtained by the VIKOR, TOPSIS, and COBRA methods overlap with each other; likewise, the CODAS and MARCOS methods overlap with each other. But there are differences in the ranking of the three natural stones when the CODAS and MARCOS methods are compared with the VIKOR, TOPSIS, and COBRA methods. In the VIKOR, TOPSIS, and COBRA methods, the energy efficiency rankings of desert yellow, dried rose, and nevsehir goreme were 9, 6, and 5, respectively, whereas these rankings were 5, 9, and 6, respectively, for the same stones in the CODAS and MARCOS methods. However, when all methods were evaluated together, it was determined that the place of all other natural stones in the ranking, including maximum and minimum energy-efficient materials, did not change.

4. Conclusions

Architects must consider a variety of criteria when selecting the right sort of stone, including appearance, project size, intended usage, and most importantly the composition that will offer sufficient durability and strength. Building insulation is improved by using natural stones with low heat conductivity since they provide an energy-efficient alternative.

The most common usage of natural stones in building coverings is ornamental insulating materials. It is crucial to choose natural stones with various thermal and physical qualities to get optimum thermal performance from the walls. These stones thermal efficiency should be defined exactly to prevent energy wasting in construction insulations.

The goal of this study is to improve the living conditions of the community's residents, and it focuses in particular on how the thermal properties of natural stone used in construction affect thermal comfort. At the same time, this study emphasizes the value of natural stone as a cladding material for construction walls. As seen in Table 10, the results of the VIKOR, TOPSIS and COBRA methods are the same. The Pearson Correlation coefficient between the outputs of the COBRA methodology and the outputs of the CODAS methodology are 0.842. Likewise, the Pearson correlation coefficient between the outputs of the COBRA methodology and the outputs of the MARCOS methodology is 0.842. According to these results, it can be said that the COBRA methodology has achieved accurate results.

Based on the research results, which examined the ranking of natural stones using the COBRA technique and other criteria, this study highlights the importance of factors such as compressive strength in assessing the quality of natural stones. In contrast, the criteria of Schmidt hammer hardness were shown to be of little significance. The aforementioned observation has significant importance for professionals in the field of architecture and stakeholders within the construction sector. It underscores the need of giving priority to certain attributes, namely the compressive strength, when making choices about the use of natural stones in construction projects.

The study's prospective trajectory is on enhancing the living circumstances of communities, with a specific emphasis on investigating the impact of the thermal properties of natural stones on thermal comfort. The research emphasizes the need of strategically using stones with varied thermal and physical properties to improve the thermal performance of buildings. This approach aims to minimize energy loss in construction insulations.

In conclusion, the study not only presents an up-to-date hierarchy of natural stones but also gives significant insights for prospective architectural deliberations. A comprehensive approach is required when selecting stones, with an emphasis on sustainability, energy economy, and thermal performance as crucial factors. The COBRA technique has shown consistent and trustworthy outcomes, highlighting its potential as a viable instrument for conducting comparable evaluations in further studies.

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