Journal of Engg. Research **Vol. 5 No. (3) September 2017 pp.** *125-149*

تصنيف قدرة المنشار من حجارة الزينة والبناء باستخدام طرق MCDM المختلفة

مهدي عبد الله كمران*، مازيار خوشسيرات*، رضا ميكائيل وفاطمة نيكخو*****
* قسم الهندسة الصناعية، جامعة أورمية للتكنولوجيا، أورميا، إيران.
** قسم هندسة التعدين، جامعة أورميا للتكنولوجيا، أورميا، إيران
*** قسم الهندسة الصناعية، كلية الهندسة، جامعة طهران، فومان، إيران
مراسلة المؤلف: *Kamran.m@uut.ac.ir*

الخلاصة

وقد قطع الحجر دورا هاما ومكانا في تطوير تكنولوجيا الحجر كأول وأهم عملية هندسية من إنتاج الحجر. اختيار الحجر المناسب مع ارتفاع الاستقرار مؤثرة جدا على الجودة والوقت واستهلاك الطاقة. ولذلك، فإن البت في اختيار الحجر مع عدة خصائص، في كثير من الأحيان معارضة لبعضها البعض، أمر صعب ومعقد. تدرس هذه الورقة تصنيف الحجارة المبنية والزخرفية القابلة للاشتعال فيما يتعلق بأربعة معايير فيزيائية وميكانيكية باستخدام ثمانية تقنيات متعددة المعايير لصنع القرار (MCDM). ولتحقيق هذه الدراسة تم فحص 12 نوعا مختلفا من الأحجار البنائية والزخرفية، سبعة منها كربونية وخمس منها أحجار الجرانيت. في المرحلة الأولى من المنهجية المقترحة، يتم استخدام ستة من تقنيات MCDM المعتمدة لترتيب الحجارة، حيث تشير النتائج إلى تصنيفات مختلفة ولكن مع ارتفاع معامل ارتباط سبيرمان. وفي المرحلة التالية، تم استخدام أسلوبان آخران من أساليب الإدارة المتكاملة (MCDM) من أجل توفير ترتيب نهائي متسق. وأظهرت النتائج أن هاتين الطريقتين تؤديان إلى ترتيب متماسك متماثل.

Ranking the saw ability of ornamental and building stones using different MCDM methods

Mehdi Abdollahi Kamran*, Maziar Khoshsirat*, Reza Mikaeil** and Fatemeh Nikkhoo***

**Department of Industrial Engineering, Urmia University of Technology, Urmia, Iran.*

***Department of Mining Engineering, Urmia University of Technology, Urmia, Iran*

****Department of Industrial Engineering, College of Engineering, University of Tehran, Fouman, Iran*

**Corresponding author: Kamran.m@uut.ac.ir*

ABSTRACT

Stone cutting has got an important role and place in the development of stone technology as the first and most important engineering process of stone production. The selection of proper stone with high sawability is very impressive on the quality and time and energy consumption. Therefore, deciding on the selection of stone with several characteristics, often opposing to each other, is difficult and complicated. This paper studies the ranking of building and decorative sawable stones with respect to four physical and mechanical criteria using eight multi-criteria decision-making (MCDM) techniques. For the study, 12 different kinds of building and decorative stones are examined, seven of which are carbonated and five of which are granite stones. In Phase I of the proposed methodology, six of the considered MCDM techniques are used to rank the stones, where the results indicate different rankings but with high Spearman ranking correlation coefficients. In the subsequent Phase II, two other MCDM methods are used to provide a coherent definitive ranking. The results showed that these two methods lead to identical coherent ranking.

INTRODUCTION

Regarding the development of its usage in the construction of structures and its decorative features, the stone industry has got an important role and place. One of the problems of this industry is the low productivity in the stone producing units. Stone cutting plays an important role as the first stage of stone production in the relevant factories. The optimum cutting process leads to a decrease in the waste of stone and energy, in addition to the increase in the added value of the stone and the quality of production. In this stage, different parameters such as stone specification, cutting machine specification, and the operator's skill are influential. Among all, stone specification is the most important parameter in the cutting process, and highly impacts on the quality, speed, and precision of the operations. Selection of proper, sawable stone applying to several scales is one of the most difficult decisions made by producers. Thus, multi-criteria decision-making (MCDM) methods are of great importance to solve these problems when deciding on the presence of opposing evaluation units is not so easy.

LITERATURE REVIEW

Previous researches on sawability of building and decorative stones show the effect of different factors on the sawing process of stones. Some researchers have studied the relation between operational parameters of sawing machine and sawability of stones. Buttner (1974) and Tonshoff & Warnecke (1982) surveyed, respectively, the speed of abrasion and the size of diamond devices, Ertingshausen (1985) studied the sawing depth, Jennings & Wright (1989) examined the rate of sawing per abrasion unit, and Konstanty (1991) studied the size and density of the diamond grain. Then, several studies were carried out during the period from 1997 to 2006 to investigate the impact of physical and mechanical parameters of stones on the performance of the sawing process. The results revealed that the impact strength, tensile strength, hardness, uniaxial compressive strength, and elasticity modulus are the most important effective parameters on stone sawability (Ceylanoglu & Gorgulu, 1997; Sun *et al.*, 2002; Eyuboglu *et al.*, 2003; Kahraman *et al.*, 2004; Delgado *et al.*, 2005). In addition, some researchers have represented different classification systems with the aim to evaluate the sawability of stones using the above-mentioned mechanical properties. The fuzzy classification system of Tutmez *et al.* (2007) and the classification system of Mikaeil *et al.* (2011b) are among these investigations, which, respectively, have classified stones into three and five different classes.

Some other studies also have been involved in the application of different MCDM methods within the realm of mine engineering. Ataei (2008) employed ELECTRE technique, in order to choose an appropriate location to construct the factory of alumina-cement in Eastern Azerbaijan province of Iran. In this study, five potential sites were investigated for the factory according to some criteria such as transportation, power and fuel supply, and ground. In addition, Ataei *et al.* (2008) and Zare Naghadehi *et al.* (2009) investigated six mining methods in Jajram mine of Iran in two separate studies employing fuzzy analytical hierarchy process (FAHP) and TOPSIS. The results of their study, regarding 13 criteria impacting on the selection of the suitable mining method, showed that Cut and Fill (conventional) was the best method. Aghajani Bazzazi *et al.* (2011) studied three transportation systems of shovel-truck, shovel-truck-in-pit crusher-belt conveyor, and loader truck with VIKOR technique to find the appropriate equipment in open mines. During recent years, Mikaeil *et al.* (2011a) employed MCDM techniques to rank the sawability of carbonate stones identified in their own classification system using TOPSIS technique. Mikaeil *et al.* (2013) also used a combination of fuzzy Delphi, FAHP, and TOPSIS techniques to rank the sawability of carbonate stones. Using the effective criteria in sawability of stones, they also could find out the rate of production of the observed stones. In another research in 2015, Mikaeil *et al.* (2015) used PROMETHEE technique to rank the sawability of stones.

Regarding the literature review and conducted investigations in the realm of sawability of stones, it can be seen that although good studies have been conducted focusing on MCDM techniques to rank the sawability of stones, so far, no comparative analysis has been carried out to solve the problem of ranking of stones between the results from different techniques of MCDM. Besides, a limited number of covered stones are within the stage of classification of stones. In this paper, eight well-known MCDM techniques will be employed, in order to solve the problem of ranking the sawability of building stones in two groups of carbonate and granite with the aim of comparing the result from different decision-making techniques, and finally, the results will be combined to represent a single consistent ranking.

METHODOLOGY

This paper is an extended from of the ranking model by Mikaeil *et al.* (2011a), which carries out the ranking of stones in two phases. Phase 1 is the initial ranking, while Phase 2 is the final ranking. Each of these phases will be explained in further detail below. Figure 1 illustrates the suggested model of ranking of sawability of building stones.

INITIAL RANKING

In this phase, an initial ranking of stones is obtained by using six popular MCDM methods and in the end, the results are compared with each other, in order to evaluate the efficiency of the methods. Required data, solving methods, and analysis of the comparison are explained in the following.

DECISION-MAKING ALTERNATIVES

In compliance with Mikaeil *et al.* (2010), Mikaeil *et al.* (2011a), and Mikaeil *et al.* (2012), this research studies the sawability of 12 different kinds of building and decorating stones, which are classified into two groups of carbonated and granite stones.

THE EVALUATION OF CRITERIA OF STONES

With respect to Mikaeil *et al.* (2011a) and Mikaeil *et al.* (2012), in this paper, four physical and mechanical characteristics of uniaxial compressive strength (UCS), Schmiazek F-abrasivity factor (SF-a), Young elasticity modulus (YM), and Mohs hardness (MH) will be considered as criteria of decision-making methods.

Uniaxial compressive strength is one of the most important properties of rocks. Factors that influence UCS are the constitutive minerals and their spatial positions, weathering or alteration rate, micro-cracks and internal fractures, density, and porosity. Therefore, this parameter can be considered as the representative of rock strength, density, weathering, and texture and matrix type.

"Abrasiveness is mainly affected by various factors such as mineral composition hardness of mineral constituents and grain characteristics such as size, shape, and angularity". Schimazek's F-abrasiveness is a proper criterion for evaluation of rock abrasivity.

According to the behavior of rock fracture process and chip formation in sawing process, the way that rocks reach the failure point has a significant impact on rocks' sawability. Young elasticity modulus can be regarded as the best measure of rock elasticity.

Mohs hardness has a high impact on the entire stone and eventually on its sawability. This parameter can be interpreted as the rock's resistance to penetration (Mikaeil *et al.*, 2011a; Mikaeil *et al.*, 2012).

WEIGHING OF CRITERIA

One of the steps of MCDM techniques is the determination of the importance level (weights) of the criteria related to the alternatives. The weights applied in this study has been followed by Mikaeil *et al.* (2010) and Mikaeil *et al.* (2011a), which is determined through FAHP.

DECISION-MAKING TECHNIQUES EMPLOYED IN PHASE 1

The six MCDM methods should be stated in a numbered or bulleted fashion. in order to perform the primary ranking process. These techniques are as follows:

1. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method.
2. ELECTRE II (ELimination and Et Choice Translating REality) method.
3. PROMETHEE II (Preference Ranking Organization METHod for Enrichment Evaluation).
4. VIKOR (VIse Kriterijumska Optimizacija kompromisno Resenje) method.
5. ORESTE (Organization, Rangement Et Synthese De Donnes Relationnelles) method.
6. Complex proportional assessment (COPRAS) method.

COMPARISON ANALYSIS

After ranking the stones through six different MCDM techniques, Spearman's ranking correlation coefficient was used to study the statistical relationship among the results. Spearman's ranking correlation coefficient, which is denoted by r_s, is constantly a number between +1 and -1 calculated according to Equation (1). The more the correlation degree is close to +1 or -1, the higher the strength of the relationship will be, and the more it is close to zero, the lower the intensity of the relationship will be. This coefficient shows the similarity between the two ranked sets of data, while +1 shows that the correlation between two rankings is complete and direct, and the number -1 represents the complete but reverse correlation between rankings.

$$r_s = 1 - \frac{6(\sum_{i=1}^{k} d_i^2)}{n(n^2-1)}, \tag{1}$$

where d_i is the difference between the ranking of each couple and n is the number of ranking (number of observation).

FINAL RANKING

One of the criticisms to decision-making techniques is the different responses to one given problem. Thus, the major goal of this paper is to achieve a final ranking of stones and conduct a single prioritization. To do so, after advising the initial ranking of stones, two other MCDM techniques of REGIME and QUALIFLEX were applied to compare the ranking obtained in Phase 1 and then represent a single consistent final ranking. Figure 1 shows an overview of the suggested approach used in this study.

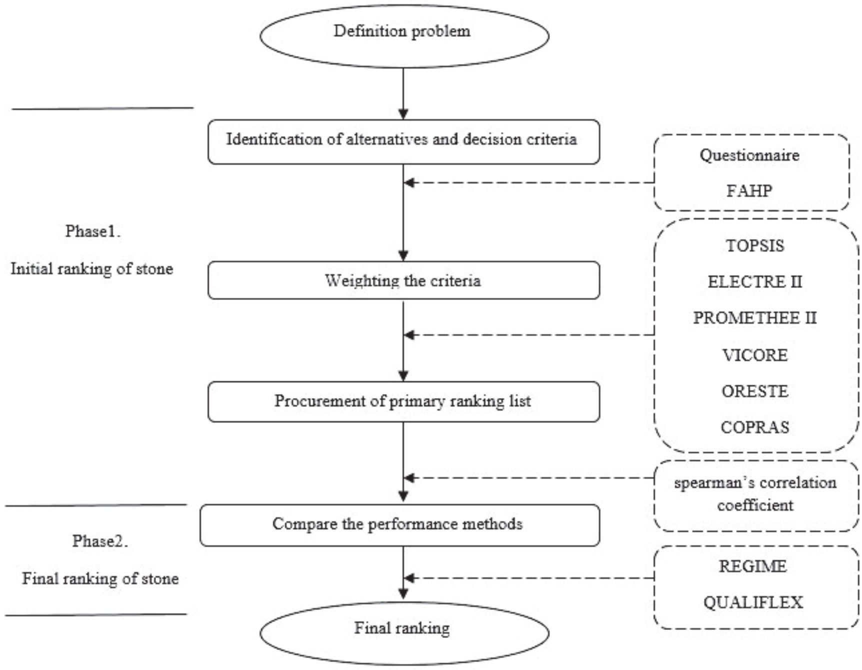

Figure 1. Suggested model of ranking.

MULTI-CRITERIA DECISION-MAKING (MCDM) METHODS

Multi-criteria decision-making techniques are powerful devices for solving the problems of decision-making in the presence of different and conflicting criteria. MCDM approaches are major parts of decision theory and analysis (Zavadskas & Turkis, 2011). The art of selection of and employing MCDM techniques is a decision-making problem by itself because of much diversity of techniques that leads to the confusion of decision makers. In this paper, eight decision-making techniques to rank the sawability of building stones will be discussed along with some explanation for each of them below.

TOPSIS METHOD

TOPSIS was introduced in 1981 by Hwang and Yun (Ching-Lai & Yoon, 1981). In this technique, alternatives are ranked based on their similarity to the ideal solution (i.e., the alternative with the shortest distance to the ideal positive solution and the longest distance to the ideal negative solution is considered as the best alternative). Simple mathematics and high flexibility in defining the selection set are two advantages of TOPSIS method (Alptekin, 2013). The steps to solve the problem through TOPSIS technique are as follows. All the values assigned to the alternatives with respect to each criterion form a decision matrix denoted by $X = [x_{ij}]_{m\times n}$. Let $W = (w_1,...,w_n)$ be the relative weight vector of the criteria, satisfying $\sum_{j=1}^{n} w_j = 1$.

Step 1: Calculate the normalized decision matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1,...,m; j = 1,...,n \tag{2}$$

Step 2: Calculate the weighted normalized decision matrix:

$$v_{ij} = w_j r_{ij} \quad i = 1,...m; j = 1,...,n \tag{3}$$

Step 3: Determine the ideal and negative ideal solution:

$$A^* = \{v_1^*,...,v_n^*\} = \{(\max_i v_{ij} \mid j \in J'), (\min_i v_{ij} \mid j \in J'')\}, \tag{4}$$

$$A^- = \{v_1^-,...,v_n^-\} = \{(\min_i v_{ij} \mid j \in J'), (\max_i v_{ij} \mid j \in J'')\}, \tag{5}$$

where J' is associated with the benefit criteria and J'' is associated with the cost criteria (Opricovic & Tzeng, 2004).

Step 4: Calculate the distances of the existing alternatives from the positive ideal and negative ideal solutions:

$$D_i^* = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^*)^2} \quad i = 1,...,m \tag{6}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \quad i = 1,...,m \tag{7}$$

Step 5: Calculate the relative closeness to the ideal alternatives:

$$C_i = \frac{D_i^-}{D_i^- + D_i^*} \quad i = 1,...,m \tag{8}$$

The value of C_i is a number between 0 and 1. The more it goes towards 1, the more it is close to the ideal solution and its alternative has a better ranking.

ELECTRE II METHOD

ELECTRE (ELimination and Choice Expressing Reality) was created by Benayoun and developed by Roy and his colleagues in the mid-1960s (Roy, 1968). In this method, the options are evaluated by outranking comparisons. The strong and weak rankings are recognized and ineffective options are removed. All these steps are performed by the concordance and discordance sets (Roy, 1991; Rogers *et al.*, 1999).

Despite the very useful outlook and several findings, which can be deduced from the results of ELECTRE, still, a detailed full ranking of alternatives does not exist. In order to achieve such a significant issue, Van delft & Nijkamp (1976) introduced a complementary technique to ELECTRE, which is well known as ELECTRE II. According to their method, net concordance and discordance values should be calculated (based on Equations (15) and (16)). Higher net concordance value and lower net discordance value lead to higher quality alternatives. If the full rankings based on net concordance value and net discordance value were not similar, an average ranking from the two rankings is applicable. The steps of ELECTRE II method are illustrated as follows.

Step 1: Calculate the normalized decision matrix, which represents the normalized criteria value:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad i = 1,...,m; j = 1,...,n \tag{9}$$

Step 2: Calculate the weighted normalized decision matrix:

$$v_{ij} = w_j r_{ij} \qquad i = 1,...m; j = 1,...,n \tag{10}$$

Step 3: Determine the concordance and discordance sets. For each pair of alternatives A_k and A_l ($k, l = 1,...,m$ and $k \neq l$), the set of criteria is divided into two distinct subsets. If alternative A_k is preferred over alternative A_l for all the criteria, then the concordance set is composed. This can be written as

$$S_{kl} = \{\forall j \mid r_{kj} \geq r_{lj}\} \tag{11}$$

The complement of S_{kl}, the discordance set, contains all the criteria for which A_k is worse than A_l. This can be written as

$$D_{kl} = \{\forall j \mid r_{kj} < r_{lj}\} = J - S_{kl}, \tag{12}$$

where J is the set of criteria.

Step 4: Calculate the concordance matrix.

The relative value of the concordance sets is measured by means of the concordance index. The concordance index is equal to the sum of the weights associated with those criteria and relations, which are contained in the concordance sets. Therefore, the concordance index I_{kl} between A_k and A_l is defined as

$$I_{kl} = \sum_{j \in S_{kl}} w_j \quad 0 \leq I_{kl} \leq 1 \tag{13}$$

Step 5: Calculate the discordance matrix. The discordance index NI_{kl} is defined as follows:

$$NI_{kl} = \frac{\max\limits_{j \in D_{kl}} |v_{kj} - v_{lj}|}{\max\limits_{j \in J} |v_{kj} - v_{lj}|} \quad 0 \leq NI_{kl} \leq 1 \tag{14}$$

Step 6: Calculate the net concordance and discordance values:

$$C_k = \sum_{l=1}^{m} I_{kl} - \sum_{l=1}^{m} I_{lk} \tag{15}$$

$$D_k = \sum_{l=1}^{m} NI_{kl} - \sum_{l=1}^{m} NI_{lk} \tag{16}$$

PROMETHEE II METHOD

PROMETHEE was introduced by Brans (1982) and then developed by Brans & Vincke (1985) and by Brans & Mareschal (1994). It has different versions such as PROMETHEE I (partial ranking), POMETHEE II (complete ranking), POMETHEE III (ranking based on distances), and POMETHEE IV (continuous form). Also during years 1992 and 1994, two interesting appendices were suggested by Brans and Mareschal with the titles of POMETHEE V (MCDA containing partial limitations) and POMETHEE VI (reflecting human mind) (Arab Halvaie, 2009). In this paper, PROMETHEE II is used to completely rank the stones. The steps of this technique are as follows.

Step 1: Normalize the decision matrix.

Step 2: Calculate the evaluative differences of i^{th} alternative with respect to other alternatives:

$$d_j(a,b) = g_j(a) - g_j(b) \qquad i = 1,...,m; j = 1,...,n, \tag{17}$$

$g_j(a)$ and $g_j(b)$ are the values of alternatives a and b in the decision-making matrix for each criterion.

Step 3: Calculate the preference function:

$$P_j(a,b) = \begin{cases} 1, & d_j(a,b) > 0 \\ 0, & d_j(a,b) \le 0 \end{cases} \quad i = 1,...,m \ ; j = 1,...,n \tag{18}$$

Step 4: Calculate the preference index:

$$\pi(a,b) = \sum_{j=1}^{n} w_j P_j(a,b) \tag{19}$$

The preference index is a number between 0 and 1. It shows the superiority degree of alternatives a and b towards each other in all criteria.

Step 5: Determine the leaving (φ^+) and the entering (φ^-) outranking flows as follows:

$$\varphi^+ = \frac{1}{m-1} \sum_{x \in A} \pi(a,x) \tag{20}$$

$$\varphi^- = \frac{1}{m-1} \sum_{x \in A} \pi(x,a) \tag{21}$$

The leaving outranking flow shows the strength of alternative a in defeating other alternatives, while the entering outranking flow states the weakness of alternative a in being defeated by other alternatives. The higher the φ^+ is, the better the alternative a is, and the lower the φ^- is, the better the alternative a is.

Step 6: Calculate the net outranking flow for each alternative:

$$\varphi(a) = \varphi^+ - \varphi^- \tag{22}$$

POMETHEE II represents the ranking of the alternative from the best to the worst through the above formula. Based on this technique, alternative a is better than b if

$$\varphi(a) > \varphi(b) \tag{23}$$

Also, for all $x \in A$ alternatives, we have

$$\sum_{x \in A} \varphi(x) = 0 \tag{24}$$

Therefore, the value of φ will be positive for some alternatives, and it will be negative for some, and the highest φ value gives the best value and vice versa (Kazem & Hadinejad, 2015).

VIKOR METHOD

VIKOR is an adaptive, MCDM technique introduced first by Opricovic (1998). VIKOR has been taken from the Serbian term of "VIse Kriterijumska Optimizacija kompromisno Resenje" that means multi-criteria optimization and compromise solution (Qazi Hussain & Tabarsa, 2012). This technique was developed by Opricovic & Tzeng (2002). In this technique, the focus is on the ranking and selection of a set of alternatives with opposing criteria. It was developed to optimize complicated systems through multiple criteria (Opricovic & Tzeng, 2004). The main aim of this technique is to rank and select from among a set of alternatives using criteria with different measurement units. The outcome of this technique is a list of adaptive rankings and one or a few adaptive solutions. The adaptive solution is the closest acceptable solution. The word ''adaptive'' conveys a relative agreement among criteria. The base of this technique is to minimize the evaluating vector of alternatives from the positive ideal point. It can be shown via the following equation (Asgari Ghashtrodkhani *et al.*, 2014):

$$L_{p,i} = \left\{ \sum_{j=1}^{n} \left[w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right]^p \right\}^{\frac{1}{p}} \quad 1 \le p \le +\infty, i = 1,\dots,m \tag{25}$$

In this equation, the $L_{p,i}$ index shows the distance of alternative A_i to the ideal solution. p is the order and norm of the distance, w_j is the weight of j^{th} criteria, and f_{ij} is the value of i^{th} alternative for the j^{th} criteria. Moreover, f_j^* and f_j^- are the best and the worst values of f_{ij}, respectively.

The algorithm of VIKOR technique consists of the following stages.

Step 1: Construct the decision matrix.

Step 2: Determine the best f_j^* and the worst f_j^- values of all criteria functions, $i = 1,\dots,m$ for positive criteria:

$$f_j^* = \max_i f_{ij}, \; f_j^- = \min_i f_{ij} \tag{26}$$

For negative criteria:

$$f_j^* = \min_i f_{ij}, \; f_j^- = \max_i f_{ij} \tag{27}$$

Step 3: Calculate S_i and R_i values:

$$L_{1,i} = S_i = \sum_{j=1}^{n} \left\{ w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right\} \tag{28}$$

$$L_{\infty,i} = R_i = \max \left\{ w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^-)} \right\} \tag{29}$$

Step 4: Calculate the VIKOR index value (Q_i):

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1-v) \left[\frac{R_i - R^*}{R^- - R^*} \right] \tag{30}$$

$$S^* = \min_i S_i, \;\; S^- = \max_i S_i, \;\; R^* = \min_i R_i, \;\; R^- = \max_i R_i,$$

where $v \in [0,1]$ is the weight for the maximum group ideality of the strategy. Regarding the following conditions, A_1 alternative as an adaptive solution with the lowest degree of Q is proposed as having the best ranking.

Condition 1: Characteristics of acceptance:

$$Q(A_2) - Q(A_1) \ge \frac{1}{I-1}, \tag{31}$$

where A_2 is the alternative with the second position in the ranking list by Q and I is the number of alternatives.

Condition 2: The stability of acceptance in decision-making:

Alternative A_1 should also have the highest rank in the ranking table of S or R, or both.

The ranking obtained from the above conditions as an adaptive solution will remain stable in the process of decision-making. In the case that one of the two conditions is not satisfied, a set of the following adaptive solutions is proposed:

1. Conditions A_1 and A_2 if only the second condition is not satisfied.

2. Conditions $A_1,...,A_m$ if the first condition is not satisfied, in which A_m is determined to be the highest degree of *m* with the help of Equation (32):

$$Q(A_m) - Q(A_1) < \frac{1}{I-1} \tag{32}$$

ORESTE METHOD

The MCDM technique of collective ranking (ORESTE) was first introduced by professor Marc Roubens, from the Polytechnic University, Belgium, in 1982 (Roubens, 1982). He tried to avoid the practical necessity existing in the MCDM technique based on removal (ELECTRE), in order to determine the weight of the criteria (Mohamedpur & Asgharizadeh, 2008). The aim of that technique is to rank *m* alternatives on the base of *n* criteria, so that a weak order is defined for each criterion on the set of alternatives, and also the weight of each criterion is defined in another weak order. ORESTE is valid for ranking of alternatives and is mainly suitable for problems with ordinal data, while, at the same time, it can be used for problems with numerical or mixed data (Chatterjee & Chakraborty, 2014). In ORESTE, if we consider **A** as a finite set of *m* alternatives, then these alternatives will be analyzed by the **C** set consisting of *k* criteria. The degree of importance of criteria is not determined based on their weight, but it is determined based on a distinctive structure on the **C** set called ‘’the weak order’’.

This structure is formed by relationships *P* and *I*. *“P”* shows priority, while *“I”*, the indifference of the index, shows asymmetry between them. The steps of ORESTE are as follows.

Step 1: Formation of the weak order on the set of all criteria:

$C_1\ P\ C_2\ I\ C_3\ P\ C_4\ ...\ C_k$

Step 2: Similar to the first step, the formation of the weak order on the set of alternatives for each criterion:

$$\begin{aligned}
&C_1\text{: } a_1\ P\ a_2\ P\ a_3 \ldots\ldots\ldots\ a_m\\
&C_2\text{: } a_1\ P\ a_2\ I\ a_3 \ldots\ldots\ldots\ a_m\\
&C_3\text{: } a_1\ P\ a_2\ I\ a_3 \ldots\ldots\ldots\ a_m\\
&\qquad\vdots\\
&C_k\text{: } a_1\ I\ a_2\ I\ a_3 \ldots\ldots\ldots\ a_m
\end{aligned}$$

Step 3: Change of priorities into ranks based on the mean Besson ranking method (determination of r_k and $r_k(m)$ values):

In ORESTE technique, based on the first and second weak orders, a ranking can be considered.

Step 4: Estimation of distance among alternatives:

The distance among alternatives is denoted by $d(o, m_k)$, as we have (Mohamedpur & Asgharizadeh, 2008)

$$\begin{aligned}
&\text{if } a\ p_k\ b \text{ then } d(o, a_k) < d(o, b_k)\\
&\text{if } r_1(a) = r_2(b) \text{ and } 1P2 \text{ then } d(o, a_1) < d(o, b_2),
\end{aligned} \tag{33}$$

and the estimation of the distances $d(o, m_k)$ is done as follows:

$$d(o, m_k) = \frac{1}{2}\left[r_k + r_k(m)\right] \tag{34}$$

Step 5: Global ranking of distance among alternatives:

In this step, the distances obtained in the previous step are ranked using mean Besson ranking method, and the problem returns to its ordinal form. The result of this ranking is in the form of $R(m_k)$, so that we have

$$R(a_1) \le R(a_2) \text{ if } d(o, a_1) \le d(o, a_2) \tag{35}$$

The ranks are located in the following scope:

$$1 \le R(m_k) \le mk$$

Step 6: Aggregation:

After the global ranking calculation, the global ranks of alternatives in each index are aggregated separately. Therefore, for an alternative *m*, we have

$$R(m) = \sum_{k=1}^{K} R(m_k) \tag{36}$$

In the aggregation stage, an ordinal, incremental structure based on *R*(*m*), considering the following relationships, will be defined:

$$\begin{aligned} &\text{if } R(a) < R(b) \text{ then } a\ P\ b \\ &\text{if } R(a) = R(b) \text{ then } a\ I\ b \end{aligned} \tag{37}$$

The alternative whose *R*(*m*) is smaller will be better, and a better ranking will be given to it. It means that an alternative is better when its total absolute ranks are smaller than other alternatives in all criteria (Roubens, 1982).

COPRAS METHOD

COPRAS is another decision-making technique used to prioritize and rank different alternatives. It employs the weights of criteria to do this task (Faraji Sabokbar *et al.*, 2015). This technique was first proposed by Zavadskas in 2008 (Zavadskas *et al.*, 2008). COPRAS is used to evaluate both the maximum and minimum criteria values. It considers the impact of minimum and maximum criteria on the results of evaluation separately (Valentinas, 2011). It is very operational and, at the same time, very simple without requiring complicated operations to rank alternatives. Operation stages of COPRAS are as follows.

Step 1: Normalize the decision matrix *D:* using the following formula:

$$D_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad i = 1, \ldots, m; j = 1, \ldots, n \tag{38}$$

Step 2: Determine the weighted normalized decision matrix *D:*

$$v_{ij} = w_j D_{ij} \quad i = 1, \ldots, m; j = 1, \ldots, n \tag{39}$$

Step 3: The sums S_{+i} and S_{-i} of weighted normalized values are computed for both beneficial and non-beneficial criteria, respectively:

$$S_{+i} = \sum_{j=1}^{n} v_{+ij}, \quad S_{-i} = \sum_{j=1}^{n} v_{-ij} \tag{40}$$

Step 4: Calculation of the relative weight of each alternative Q_i :

$$Q_i = S_{+i} + \frac{S_{-\min}\sum_{i=1}^{m} S_{-i}}{S_{-i}\sum_{i=1}^{m}(S_{-\min}/S_{-i})} = S_{+i} + \frac{\sum_{i=1}^{m} S_{-i}}{S_{-i}\sum_{i=1}^{m}(1/S_{-i})} \tag{41}$$

Step 5: Calculate the quantitative utility (U_i) for i^{th} alternative:

$$U_i = \frac{Q_i}{Q_{\max}} 100\%, \tag{42}$$

where $Q_{\max}$ shows the highest importance of each alternative, while the presence of a high value is indicative of more importance and ideality of alternatives. Therefore, the alternative with more U_i will have a better rank.

REGIME METHOD

REGIME was described in 1983, by Hinloopen *et al.*, and in 1986, by Hinloopen and Nijkamp (Chakraborty *et al.*, 2013). Its main advantage is its ability to use complex data (qualitative and quantitative) without requiring to change the qualitative data to quantitative data. In a world where a lot of data are not extant in a quantitative form, this fact is very important. REGIME produces a complete list of ranking for alternatives based on comparing the pairs with selected criteria. That is why it can be considered as an adaptive analysis. The ranking process though REGIME is as follows.

Step 1: Computing the concordance C_{il} using the following equation:

$$C_{il} = \sum_{j \in \hat{c}_{IL}} \pi_j , \tag{43}$$

where $\hat{c}_{IL}$ shows the set of adaption and includes criteria for priority of alternative a_i towards alternative a_L and π_j shows the weight of j^{th} criteria.

Step 2: Construction of the REGIME matrix:

This matrix consists of pair comparisons of alternatives regarding the alternatives in the problem. The entries of this matrix are -1 and +1 that become complete based on the decision-making matrix of the problem. Thus, if alternative *a* has a better rank than alternative *b* in the decision-making matrix for a criteria , then, according to REGIME matrix, +1 belongs to (a,b) pair in the same criterion; 0 else, -1 belongs to it.

$$C_{il,j} = \begin{cases} +1 & \text{if } r_{ij} < r_{lj} \\ 0 & \text{if } r_{ij} = r_{lj} \\ -1 & \text{if } r_{ij} > r_{lj} \end{cases} , \tag{44}$$

where $r_{ij}\,(r_{lj})$ are the ranks of alternatives $a_i\,(a_l)$ according to criterion g_j.

Step 3: The concordance index, for the alternative a_i is given by

$$C_{il} = \sum_{j} \pi_j C_{il,j} \tag{45}$$

Step 4: Construction of a pair-wise comparison matrix V_{il} defined as

$$V_{il} = \begin{cases} +1 & \text{if } c_{il} > 0 \\ -1 & \text{if } c_{il} < 0 \end{cases} \tag{46}$$

The main diagonal of this matrix is zero and its other elements are -1 and +1. The final ranking is obtained based on the data of this matrix. The alternative with the most numbers of element +1 will be the best choice.

QUALIFLEX METHOD

The early idea of QUALIFLEX technique was the generalized form of the permutation technique of Jacquet Lagreze (Alinezhad & Esfandiari, 2012). This method is based on an evaluation of all possible permutations of alternatives considering different criteria. This technique at the first level assumes a dominant and a subordinate, and then at a higher and more comprehensive level, the indexes are calculated for permutations. And finally, the best permutation is introduced. The steps of the algorithm is as follows.

Step 1: Construction of the decision matrix.

Step 2: Determine the weight of criteria.

Step 3: Ranking of alternatives towards criteria (formation of impact matrix).

Step 4: Formation of possible permutations for alternatives (we have *m* permutations and *m* shows the number of alternatives).

Step 5: Calculation of the concordance and discordance indexes at the level of pairs of alternatives. These indexes are determined as follows for every criterion and for every pair of alternatives existing in the permutation, and based on the comparison of the location of alternatives in the matrix of Step 3 and the permutation under study:

$$I_{jk}(a,b) = \begin{cases} +1 & \text{if they are concordance} \\ 0 & \text{if they are equal} \\ -1 & \text{if they are discordance} \end{cases}, \tag{47}$$

where *j* shows the criterion and *K* shows the number of the permutation.

Step 6: Calculation of concordance and discordance indexes of permutations in every criterion:

$$I_{jk} = \sum_{a,b \in A} I_{jk}(a,b) \tag{48}$$

Step 7: Calculation of the total concordance and discordance index for each permutation:

$$I_k = \sum_j \pi_j I_{jk}(a,b) \tag{49}$$

In this formula, π_j is the weight of the j^{th} criterion. The final ranking is done on the basis of the total index, and the permutation with the most total index will be considered as the best one, representing the final ranking.

APPLICATION OF DECISION-MAKING METHODS IN RANKING THE SAWABILITY OF STONES

According to Mikaeil *et al.* (2010) and Mikaeil *et al.* (2011a), twelve influencing parameters in sawability of building stones were introduced. They claimed that these parameters could be summarized into four distinctive impressive parameters (criteria) of uniaxial compressive strength

(UCS), Schmiazek F-abrasivity factor (SF-a), Young elasticity modulus (YM), and Mohs hardness (MH). They weigh the importance of these criteria through a fuzzy analytical hierarchy process. In this paper, the aforementioned criteria and weights are considered to survey the sawability of ornamental and building stones using eight different MCDM methods, and a final classification and ranking model will be represented. The decision-making matrix of ornamental and building (carbonate and granite) stones, criteria, and the weights are reported in Table 1.

Table 1. Decision matrix and criteria weights for stones (Mikaeil *et al.*, 2010; Mikaeil *et al.*, 2011a).

	Alternatives	**Criteria**			
		UCS	SF-a	YM	MH
		Mpa	N/mm	Gpa	n
Carbonate stones	Harsin (Marble)	71.5	0.135	32.5	3.5
	Anarak (Marble)	74.5	0.109	33.6	3.2
	Ghermez (Travertine)	53	0.122	20.7	2.9
	Hajiabad (Travertine)	61.5	0.124	21	2.9
	Darebokhari (Travertine)	63	0.127	23.5	2.95
	Salsali (Marble)	68	0.105	31.6	3.1
	Haftoman (Marble)	74.5	0.173	35.5	3.6
Granite stones	Chayan (Granite)	173	7.58	48.6	6.6
	Ghermez Yazd (Granite)	142	14.24	43.6	6.1
	Sefid Nehbandan (Granite)	145	24.25	35.5	5.75
	Khoramdare (Granite)	133	10.42	28.9	5.65
	Morvarid Mashhad (Granite)	125	8.52	31.2	5.6
	Weights	0.3716	0.3664	0.0855	0.1765

INITIAL RANKING PHASE

The results from the initial ranking of the sawability of stones through six MCDM methods (i.e., TOPSIS, ELECTRE II, PROMETHEE II, VIKOR, ORESTE, and COPRAS) are as follows.

TOPSIS METHOD

In this approach, after normalization of decision-making matrix, the weighted normalized matrix was determined using Equation (3). TOPSIS technique, in the next step, calculates the ideal and anti-ideal solutions through Equations (4) and (5). The relative closeness of each existing alternative to the ideal solution is calculated through Equations (6), (7), and (8). This process is shown in Table 2.

Table 2. Ranking of the sawability of different stones in TOPSIS method.

	Alternatives	D_i^-	D_i^*	C_i	Rank
Carbonate stones	Harsin (Marble)	0.0535	0.0413	0.5645	2
	Anarak (Marble)	0.0479	0.0690	0.5055	3
	Ghermez (Travertine)	0.0182	0.0741	0.1969	7
	Hajiabad (Travertine)	0.0270	0.0630	0.3003	6
	Darebokhari (Travertine)	0.0317	0.0580	0.3532	4
	Salsali (Marble)	0.0340	0.0748	0.3123	5
	Haftoman (Marble)	0.0884	0	1	1
Granite stones	Chayan (Granite)	0.0601	0.0994	0.3768	3
	Ghermez Yazd (Granite)	0.0802	0.1200	0.4004	2
	Sefid Nehbandan (Granite)	0.1919	0.0365	0.8400	1
	Khoramdare (Granite)	0.0337	0.1661	0.1687	4
	Morvarid Mashhad (Granite)	0.0110	0.1892	0.0548	5

ELECTRE II METHOD

In order to solve the problem through ELECTRE II technique, after normalization of the decision-making matrix and forming the normalized weighted matrix, the concordance and discordance matrices are determined for the alternatives. Ultimately, a detailed full ranking of alternatives is accessible through computing net concordance and discordance values based on Equations (15) and (16). The results from this process are shown in Table 3.

Table 3. Ranking of the sawability of different stones in ELECTRE II method.

	Alternatives	Net concordance	Initial Rank	Net discordance	Initial Rank	Average Rank	Final Rank
Carbonate stones	Harsin (Marble)	3.08	2	-3.5	2	2	2
	Anarak (Marble)	1.07	3	-1.3	3	3	3
	Ghermez (Travertine)	-4.34	7	5.13	7	7	7
	Hajiabad (Travertine)	-2.7	6	2.67	5	5.5	5
	Darebokhari (Travertine)	-0.52	4	-0.34	4	4	4
	Salsali (Marble)	-2.22	5	3.34	6	5.5	6
	Haftoman (Marble)	5.63	1	-6	1	1	1
Granite stones	Chayan (Granite)	1.04	3	0.04	3	3	3
	Ghermez Yazd (Granite)	1.26	2	-1.43	2	2	2
	Sefid Nehbandan (Granite)	2.22	1	-3.84	1	1	1
	Khoramdare (Granite)	-1.44	4	1.4	4	4	4
	Morvarid Mashhad (Granite)	-3.08	5	3.83	5	5	5

POMETHEE II METHOD

In PROMETHEE, first, the difference between choices in every criterion is calculated separately, from the normalized decision-making matrix. Then the preference index of choices is determined two by two with the help of preference function and Equation (19).

In the next step, after calculating the inflow and outflow, the absolute flow of ranking is calculated and based on it, stones are ranked descendingly. As a result of performing these techniques, it is observed that, in the group of carbonate stones, the Harsin stone and, in the group of granite stone, the white stone of Nehbandan are the best choices for decision-making. The results are reported in Table 4.

Table 4. Ranking of the sawability of different stones in POMETHEE II method.

	Alternatives	φ^+	φ^-	φ	Rank
Carbonate stones	Harsin (Marble)	0.819	0.181	0.638	1
	Anarak (Marble)	0.061	0.407	-0.346	5
	Ghermez (Travertine)	0.062	0.772	-0.710	7
	Hajiabad (Travertine)	0.199	0.635	-0.436	6
	Darebokhari (Travertine)	0.517	0.468	0.049	3
	Salsali (Marble)	0.379	0.650	-0.271	4
	Haftoman (Marble)	0.628	0.372	0.257	2
Granite stones	Chayan (Granite)	0.634	0.366	0.267	2
	Ghermez Yazd (Granite)	0.657	0.399	0.258	3
	Sefid Nehbandan (Granite)	0.776	0.224	0.552	1
	Khoramdare (Granite)	0.320	0.680	-0.360	4
	Morvarid Mashhad (Granite)	0.113	0887	-0.774	5

VIKOR METHOD

In order to provide a full ranking of stones through VIKOR method, first, the best and the worst values of all criteria are determined (Equations (26) and (27)). Then the utility and regret measures are determined for each alternative (Equations (28) and (29)), and finally using Equation (30), the VIKOR index value is determined. In these calculations, the value of v is considered to be equal to 0.5. Table 5 shows the final ranking results.

Table 5. Ranking of the sawability of different stones in VIKOR method.

	Alternatives	S_i		R_i		Q_i		Final Rank
		Score	Rank	Score	Rank	Score	Rank	
Carbonate stones	Harsin (Marble)	0.2991	2	0.2048	2	0.4402	2	2
	Anarak (Marble)	0.4567	3	0.3448	5	0.7154	4	4
	Ghermez (Travertine)	0.9084	7	0.3716	7	1	7	7
	Hajiabad (Travertine)	0.7490	6	0.2640	4	0.7675	5	5
	Darebokhari (Travertine)	0.6798	5	0.2479	3	0.7077	3	3
	Salsali (Marble)	0.6273	4	0.3664	6	0.8383	6	6
	Haftoman (Marble)	0	1	0	1	0	1	1
Granite stones	Chayan (Granite)	0.3664	1	0.3664	4	0.4832	3	3
	Ghermez Yazd (Granite)	0.5700	3	0.2400	2	0.2438	2	2
	Sefid Nehbandan (Granite)	0.4236	2	0.2168	1	0.0475	1	1
	Khoramdare (Granite)	0.8668	4	0.3097	3	0.7150	4	4
	Morvarid Mashhad (Granite)	0.9694	5	0.3716	5	1	5	5

ORESTE METHOD

In ORESTE method, the weak order of the criteria is obtained based on Table 1 in the form of UCS *P* SF-a *P* YM *P* MH. Similarly, the weak order for all alternatives is formed on the base of individual criteria using the data of decision-making matrix. Thus, there will be as many preference structures as the existing indexes. In the next step, regarding the formed structures, the initial ranking of criteria and alternatives is conducted using mean Besson ranking method. Thus, numbers 1 to 4 are given to all criteria. The same is repeated for alternatives also, and their initial ranking is obtained. After obtaining the initial ranks, the $d(o,m_k)$ intervals are determined with the help of Equation (34). Then, according to mean Besson ranking method, the determined intervals are changed to rankings after calculating $R(m)$ for all alternatives in all criteria (Equation (36)), and finally the alternatives are ranked. Thus, the alternatives with the least $R(m)$ gets a higher ranking. The results are shown in Table 6.

Table 6. Ranking of the sawability of different stones in ORESTE method.

Carbonate stones	Harsin	Anarak	Ghermez	Hajiabad	Darebokhari	Salsali	Haftoman
$R(m)$	35	47	90.5	81.5	65	69	18
Rank	2	3	7	6	4	5	1
Granite stones	Chayan	Ghermez Yazd	Sefid Nehbandan	Khoramdare	Morvarid Mashhad		
$R(m)$	30.5	31	33.5	53	62		
Rank	1	2	3	4	5		

COPRAS METHOD

In this technique, after forming the decision-making matrix, and normalizing it, the weighted normalized matrix is formed. Then, with the help of Equation (40), the value of every alternative is calculated separately according to negative and positive standards. Then, the degree of importance of each alternative (Q_i) is calculated using Equation (41), and finally, with the calculation of the index of performance of each alternative (U_i), according to Equation (42), the final ranking of stones is represented. The stone with a higher U_i is ranked as higher. The results are reported in Table 7.

Table 7. Ranking of the sawability of different stones in COPRAS method.

	Alternatives	S_{+i}	S_{-i}	Q_i	U_i	Rank
Carbonate stones	Harsin (Marble)	0.8924	0	0.8924	0.8924	2
	Anarak (Marble)	0.8403	0	0.8403	0.8403	3
	Ghermez (Travertine)	0.7148	0	0.7148	0.7148	7
	Hajiabad (Travertine)	0.7621	0	0.7621	0.7621	6
	Darebokhari (Travertine)	0.7844	0	0.7844	0.7844	5
	Salsali (Marble)	0.7897	0	0.7897	0.7897	4
	Haftoman (Marble)	1	0	1	1	1
Granite stones	Chayan (Granite)	0.7481	0	0.7481	0.8368	3
	Ghermez Yazd (Granite)	0.7600	0	0.7600	0.8500	2
	Sefid Nehbandan (Granite)	0.8941	0	0.8941	1	1
	Khoramdare (Granite)	0.6451	0	0.6451	0.7215	4
	Morvarid Mashhad (Granite)	0.6019	0	0.6019	0.6732	5

COMPARISON ANALYSIS

Spearman's ranking correlation coefficients among the results of six above MCDM methods at the end of Phase 1 are displayed in the form of SPSS software output (Tables 8 and 9).

Table 8. Spearman's ranking correlation coefficients for carbonate stones.

Methods	TOPSIS	ELECTRE II	PROMETHEE II	VIKOR	ORESTE	COPRAS
TOPSIS	1	0.964	0.857	0.929	1	0.964
ELECTRE II	0.964	1	0.786	0.964	0.964	0.893
PROMETHEE II	0.857	0.786	1	0.857	0.857	0.821
VIKOR	0.929	0.964	0.857	1	0.929	0.821
ORESTE	1	0.964	0.857	0.929	1	0.964
COPRAS	0.964	0.893	0.821	0.821	0.964	1

Table 9. Spearman's ranking correlation coefficients for granite stones.

Methods	TOPSIS	ELECTRE II	PROMETHEE II	VIKOR	ORESTE	COPRAS
TOPSIS	1	1	0.9	1	0.6	1
ELECTRE II	1	1	0.9	1	0.6	1
PROMETHEE II	0.9	0.9	1	0.9	0.7	0.9
VIKOR	1	1	0.9	1	0.6	1
ORESTE	0.6	0.6	0.7	0.6	1	0.6
COPRAS	1	1	0.9	1	0.6	1

Based on the results of the test, the r_s degree is between 0.786 and 1 for carbonated stones, while it is between 0.6 and 1 for granite stones. Therefore, a high correlation is observed in most of the methods for the first group of stones. According to this coefficient, two techniques of TOPSIS and ORESTE have similar highest correlations, in comparison with other techniques. Also, ELECTRE technique has the highest correlation with TOPSIS and ORESTE, and its result is reliable to some extent. On the other hand, in the group of granite stones, no difference was observed among the techniques of TOPSIS, ELECTRE II, VIKOR, and COPRAS. In this group, also the relationship among techniques is strong, while PROMETHEE has a high correlation with other techniques, and the lowest correlation coefficient belongs to ORESTE.

FINAL RANKING PHASE

The aim of this phase is to achieve a single consistent strategy to prioritize the sawability of stones. Regarding the different rankings of each of the Phase 1 techniques, in this section, we tried to combine the results from previous techniques employing REGIME and QUALIFLEX methods to conduct a final ranking. In order to attain such a ranking, differently employed decision-making techniques will be considered as criteria for selection, and the stones will be prioritized according to their rankings. It is worth mentioning that no stone has an advantage over the others, and all of them have the same weight.

REGIME METHOD

In this method, the impact matrix, which shows the ranking of stones in different previous techniques, is formed. Then, using Equation (44), the alternatives are compared to each other in a matrix called REGIME. Equal weights (1/6) are assigned to each criterion, in order to determine the concordance index between pairs of alternatives. Then, employing Equation (46), pair comparisons of V are conducted for carbonated and granite stones, and finally, regarding the number of positive elements in the lines of this matrix, the alternatives will be ranked. The results of ranking through REGIME method are reported in Table 10.

Table 10. Ranking of the sawability in REGIME method.

Carbonate stones	Harsin	Anarak	Ghermez	Hajiabad	Darebokhari	Salsali	Haftoman
Total no. of positive elements	5	4	0	1	3	2	6
Rank	2	3	7	6	4	5	1
Granite stones	Chayan	Ghermez Yazd	Sefid Nehbandan	Khoramdare	Morvarid Mashhad		
Total no. of positive elements	2	3	4	1	0		
Rank	3	2	1	4	5		

QUALIFLEX METHOD

The impacted matrix of QUALIFLEX is similar to the previous one. In this technique, all possible permutations for alternatives should be considered; therefore, a high volume of calculations is needed. According to the method, all 7! cases and all 5! cases should be considered for carbonate and granite stones, respectively. In order to reduce the number of check-ups in this study, we only examined the most likely possible scenarios, which are obtained in the first phase. For example, it was indicated that Ghermez stones had the seventh rank in all techniques, which was the last position in carbonate stones, while Harsin and Haftoman stones were in the first or second ranks. By using this logic, many permutations were deleted before happening. Thus, based on the rankings obtained, the number of contingent permutations decreased to 12 and 4 for carbonate and granite stones, respectively. Then, via Equations (47) and (48), concordance and discordance indices of permutations were calculated at the level of pairs of alternatives and criteria. In the last step, the whole permutations were determined using Equation (49). The final results showed that, in carbonate stones, the permutation of Haftoman > Harsin > Anarak > Darebokhari > Salsali > Hajiabad > Ghermez with a total index of 18.7 and, in granite stones, the permutation of Sefid Nehbandan > Ghermez Yazd > Chayan > Khoramdare > Morvarid Mashhad with a total index of 8.3 are the best among others. The results are presented in Table 11.

Table 11. Ranking of the sawability in QUALIFLEX method.

Carbonate stones	Harsin	Anarak	Ghermez	Hajiabad	Darebokhari	Salsali	Haftoman
Rank	2	3	7	6	4	5	1
Granite stones	Chayan	Ghermez Yazd	Sefid Nehbandan	Khoramdare	Morvarid Mashhad		
Rank	3	2	1	4	5		

FINAL RANKING

The consistent final ranking of ornamental and building stones is determined according to results of REGIME and QUALIFLEX methods. It can be seen that the two aforementioned methods produce similar rankings. Therefore, the obtained ranking from the two techniques is introduced as the final ranking of sawability of different stones (see Table 12).

Table 12. Final ranking of stones.

	Alternatives	**REGIME Rank**	**QUALIFLEX Rank**	**Final Rank**
Carbonate stones	Harsin (Marble)	2	2	2
	Anarak (Marble)	3	3	3
	Ghermez (Travertine)	7	7	7
	Hajiabad (Travertine)	6	6	6
	Darebokhari (Travertine)	4	4	4
	Salsali (Marble)	5	5	5
	Haftoman (Marble)	1	1	1
Granite stones	Chayan (Granite)	3	3	3
	Ghermez Yazd (Granite)	2	2	2
	Sefid Nehbandan (Granite)	1	1	1
	Khoramdare (Granite)	4	4	4
	Morvarid Mashhad (Granite)	5	5	5

CONCLUSION

In this paper, the ranking of sawability of 12 ornamental and building stones of the types carbonate and granite was studied employing eight prevalent MCDM methods. In the first phase, applying six different MCDM methods (i.e., TOPSIS, ELECTRE II, PROMETHEE II, VIKOR, ORESTE, and COPRAS) results in different rankings. This can be confusing to decide finally what the correct ranking is. Therefore, firstly, Spearman's rank correlation coefficient was investigated to query the correlations between the methods. Secondly, in the second phase, REGIME and QUALIFLEX methods were employed to combine the different rankings into an identical coherent ranking. According to the final ranking, in the group of carbonate stones, Ghermez and Haftoman had, respectively, the worst and the best ranks of sawability, while Sefid Nehbandan and Morvarid Mashhad had, respectively, the first and last rankings in granite stones. In carbonate stones, TOPSIS and ORESTE techniques had similar results, which were in agreement with the final ranking.

Also, PROMETHEE has the lowest correlation with other techniques, and it is not the best choice to rank stones. In the group of granite stones, the results from TOPSIS, ELECTRE II, VIKOR, and COPRAS are similar to the final ranking. Also, statistical studies showed that ranking through ORESTE had a slight correlation with the existing techniques in this group, and it is not a reliable choice in ranking granite stones. Regarding the results, it would be a difficult and complicated task to identify a highly reliable technique to rank stones, and no technique can be introduced as the completely perfect one. For example, ORESTE is an ideal technique for carbonate stones, but it produces weak results on granite stones. As a whole, regarding the results of the foregoing six techniques of ranking, TOPSIS can be introduced as a reasonable option. As a future work, it is suggested that more stones and some additional criteria are investigated, and other new techniques (e.g., EVAMIX, MOORA, MAPPAC, OCRA, NAIDAE, etc.) are employed (for more details, see Chatterjee *et al.*, 2011; Chakraborty, 2011; Matarazzo, 1991; Chatterjee & Chakraborty, 2012; Shmelev & Rodríguez-Labajos, 2009). Also, developing better-combining methods to achieve more reliable coherent rankings can be so promising.

REFERENCES

Aghajani Bazzazi, A., Osanloo, M. & Karimi, B. 2011. Deriving preference order of open pit mines equipment through MADM methods: Application of modified VIKOR method. Expert Systems with Applications **38**(3): 2550-2556.

Alinezhad, A. & Esfandiari, N. 2012. Sensitivity analysis in the QUALIFLEX and VIKOR methods. Journal of Optimization in Industrial Engineering **5**(10): 29-34.

Alptekin, N. 2013. Integration of SWOT analysis and TOPSIS method in strategic decision making process. The Macrotheme Review **2**(7): 1-8.

Arab Halvaie, A. 2009. Application of the police command prompt decisions. Human Bimonthly Police **6**(23): 21-43.

Asgari Ghashtrodkhani, O., Asgarian Abyane, H. & Vahidi, B. 2014. A new approach for planning transition development based on VIKOR method. International Electronics Conference – Tehran, Iran.

Ataei, M. 2008. Choosing the perfect place to establish alumina plant-cement using Electre. International Journal of Engineering at the University of Science and Technology of Iran, Special issue of Materials Engineering, Mining Engineering, Civil Engineering **19**(9): 55-63.

Ataei, M., Sereshki, F., Jamshidi, M. & Jalali, S.M.E. 2008. Suitable mining method for the Golbini No.8 deposit in Jajarm (Iran) by using TOPSIS method. Mining Technology: Transactions of the Institute of Mining & Metallurgy, Section A **117**(1): 1-5.

Brans, J.P. 1982. Lingenierie de la decision. Elaboration dinstruments daide a la decision. Methode PROMETHEE. In: Laide a la Decision: Nature. Instrument set Perspectives Davenir, Nadeau, R., Landry, M. (Eds.). Presses de Universite Laval, Quebec, Canada: 183-214.

Brans, J.P. & Vincke, P. 1985. Note—A preference ranking organization method: The PROMETHEE method. Management Science **31**(6): 647-656.

Brans, J.P. & Mareschal, B. 1994. The PROMCALC & GAIA decision support system for multicriteria decision aid. Decision Support Systems **12** (4-5): 297-310.

Buttner, A. 1974. Diamond tools and stone. Industrial Diamond Review: 89-93.

Ceylanoglu, A. & Gorgulu, K. 1997. The performance measurement results of stone cutting machines and their relations with some material properties. Proceedings of the Sixth International Symposium on Mine Planning and Equipment Selection. Rotterdam, Balkema: 393–398.

Chakraborty, S. 2011. Applications of the MOORA method for decision making in manufacturing environment. The International Journal of Advanced Manufacturing Technology **54**(9-12): 1155-1166.

Chakraborty, R., Ray, A. & Dan, P.K. 2013. Multi criteria decision making methods for location selection of distribution centers. International Journal of Industrial Engineering Computations **4**(4): 491-504.

Chatterjee, P., Athawale, V.M. & Chakraborty, S. 2011. Materials selection using complex proportional assessment and evaluation of mixed data methods. Materials & Design **32**(2): 851-860.

Chatterjee, P. & Chakraborty, S. 2012. Material selection using preferential ranking methods. Materials & Design **35**: 384-393.

Chatterjee, P. & Chakraborty, S. 2014. Flexible manufacturing system selection using preference ranking methods: A comparative study. International Journal of Industrial Engineering Computations **5**(15): 315-338.

Ching-Lai, H. & Yoon, K. 1981. Multiple attribute decision making: Methods and applications. Springer, Berlin Heidelberg: 128.

Delgado, N.S., Rodriguez, R., Rio, A., Sarria, I.D., Calleja, L. & Argandona, V.G.R. 2005. The influence of microhardness on the sawability of Pink Porrino granite (Spain). International Journal of Rock Mechanics & Mining Sciences **42**(1): 161–166.

Ertingshausen, W. 1985. Wear processes in sawing hard stone. Industrial Diamond Review **5**: 254–258.

Eyuboglu, A.S., Ozcelik, Y., Kulaksiz, S. & Engin, I.C. 2003. Statistical and microscopic investigation of disc segment wear related to sawing Ankara andesites. International Journal of Rock Mechanics & Mining Sciences **40**(3): 405-414.

Faraji Sabokbar, H., Rezvani, M.R., Behnam morshedi, H. & Rosta, H. 2015. Space-rating of Fars Province based upon services and tourist facilities. Human Geographical Research **46**(3): 561-586.

Jennings, M. & Wright, D.N. 1989. Guidelines for sawing stone. Industrial Diamond Review **49**(2): 70–75.

Kazem, S. & Hadinejad, F. 2015. PROMETHEE technique to select the best radial basis functions for solving the 2-dimensional heat equations based on Hermite interpolation. Engineering Analysis with Boundary Elements **50**: 29-38.

Kahraman, S., Fener, M. & Gunaydin, O. 2004. Predicting the sawability of carbonate rocks using multiple curvilinear regression analysis. International Journal of Rock Mechanics & Mining Sciences **41**(7): 1123–1131.

Konstanty, J. 1991. The materials science of stone sawing. Industrial Diamond Review **1**: 27-31.

Matarazzo, B. 1991. MAPPAC as a compromise between outranking methods and MAUT. European Journal of Operational Research **54**(1): 48-65.

Mikaeil, R., Ataei, M. & Yousefi, R. 2010. Prediction of sawability of building stones by using the fuzzy analytical hierarchy process. Publication of Geology of Engineering **4**(2): 1031-1058.

Mikaeil, R., Yousefi, R. & Ataei, M. 2011a. Sawability ranking of carbonate rock using fuzzy analytical hierarchy process and TOPSIS approaches. Scientia Iranica **18**(5):1106-1115.

Mikaeil, R., Yousefi, R., Ataei, M. & Abasian Farani, R. 2011b. Development of a new classification system for assessing of carbonate rock sawability. Archives of Mining Sciences **56**(1): 57-68.

Mikaeil, R., Ataei, M. & Yousefi, R. 2012. Representation of statistical relations predict disk sawability of building stones. Scientific-Research Publication of Mine Engineering. **7**(14): 31-40.

Mikaeil, R., Ozcelik, Y., Yousefi, R., Ataei, M. & Hosseini, S.M. 2013. Ranking the sawability of ornamental stone using fuzzy Delphi and multi-criteria decision-making. International Journal of Rock Mechanics and Mining Sciences **58**: 118-126.

Mikaeil, R., Kamran, M.A., Sadegheslam, G. & Ataei, M. 2015. Ranking sawability of dimension stone using PROMETHEE method. Journal of Mining & Environment **6**(2): 263-271.

Mohamedpur M. & Asgharizadeh, H. 2008. Rating in a research center of the institute of multi-criteria decision-making methods ORESTE. Research Management **1**(1): 217-233.

Opricovic, S. 1998. Multi-criteria optimization of civil engineering systems. Faculty of Civil Engineering **37**(12): 1379–1383.

Opricovic, S. & Tzeng, G.H. 2002. Multi-criteria planning of post-earthquake sustainable reconstruction. Computer-Aided Civil and Infrastructure Engineering **17**(3): 211–220.

Opricovic, S. & Tzeng, G. 2004. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research **156**(2): 445–455.

Qazi Hussain, M. & Tabarsa, N. 2012. The evaluation and ranking of mineral water industry FAHP using fuzzy and VIKOR. National Conference on Entrepreneurship and Business Management Knowledge. Mazandaran University.

Rogers M.G., Bruen M. & Maystre L.-Y. 1999. Electre and decision support: Methods and applications in engineering and infrastructure investment. Kluwer Academic Publishers. London.

Roy, B. 1968. Classement et choix en présence de points de vue multiples (la méthode ELECTRE). RAIRO-Operations Research-Recherche Opérationnelle **2**(1): 57–75.

Roy, B. 1991. The outranking approach and the foundation of ELECTRE methods. Theory and Decision **31**: 49-73.

Roubens, M. 1982. Preference relations on actions and criteria in multicriteria decision making. European Journal of Operational Research **10**(1): 51-55.

Shmelev, S.E. & Rodríguez-Labajos, B. 2009. Dynamic multidimensional assessment of sustainability at the macro level: The case of Austria. Ecological Economics **68**(10): 2560-2573.

Sun, L.A., Pan, J.B. & Lin, C. 2002. A new approach to improve the performance of diamond saw blades. Materials Letters **57**(4): 1010-1014.

Tonshoff, H.K. & Warnecke, G. 1982. Research on stone sawing. Advance in Ultra hard Materials Application Technology. P. Daniel (Ed). Harnbeam, England **1**: 36-49.

Tutmez, B., Kahraman, S. & Gunaydin, O. 2007. Multifactorial fuzzy approach to the sawability classification of building stones. Construction and Building Materials **21**(8): 1672-1679.

Van Delft, A. & Nijkamp, P. 1976. A multi-objective decision making model for regional development. Environmental Quality Control and Industrial Lead Use. Papers Regional Associations **36**(1): 35-57.

Valentinas, P. 2011. The comparative analysis of MCDA methods SAW and COPRAS. Inzinerine Ekonomika – Engineering Economics **22**(2): 134-146.

Zare Naghadehi, M., Mikaeil, R. & Ataei, M. 2009. The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran. Expert Systems with Applications **36**(4): 8218-8226.

Zavadskas, E.K., Kaklauskas, A., Turskis, Z. & Tamošaitiene, J. 2008. Selection of the effective dwelling house walls by applying attributes values determined at intervals. Journal of Civil Engineering and Management **14**(2): 85-93.

Zavadskas, E.K. & Turkis, Z. 2011. Multiple criteria decision making (MCDM) methods in economics: An overview. Technological and Economic Development of Economy **17**(2): 397-427.

Submitted: 17/07/2016
Revised : 25/12/2016
Accepted : 04/01/2017