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Decision-making method for choosing best alternatives for internal walls based on cost and sound insulation performance

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Abstract

The main objective for architects is to improve building quality for occupants. For user comfort and physical performance, primarily parameters of building elements such as sound insulation, thermal insulation, resistance to fire and moisture are evaluated. However, especially on walls, applications made to enhance these parameters such as designing a double wall, can be in contradiction with some other parameters such as cost, weight and thickness which are desired to be minimized. This reveals the problem of decision-making in the selection of building elements for architects.

This study aims to find the optimum internal wall that complies with the Acoustic Regulation of Turkey and maximizes the airborne sound insulation performance while minimizing other parameters (cost, weight, thickness). In this research, starting from the simplest single wall type, number 509 of non-load bearing masonry interior wall alternatives made of brick and autoclaved aerated concrete (AAC) blocks were generated. Values of the sound insulation, cost, weight and thickness parameters of the walls were calculated, and then optimal alternatives were selected by one of the most used MCDM (Multi-Criteria Decision Making) method namely as TOPSIS (The Technique for Order Preference by Similarity to Ideal Solution) method. Moreover, Copeland technique was used to aggregate the data obtained for different similar weighting values in the application of the TOPSIS Method. As a result, it was demonstrated that the combined method used in the study is a convenient method for decision making and yields satisfactory results.

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Keywords
Copeland method, Cost, Sound insulation, TOPSIS method.

1. Introduction

Growth in the construction industry has led to many environmental problems and has increased the need for sustainable building design in recent years (KPMG Türkiye, 2018). The main purpose of sustainable buildings is to concentrate on energy conservation and provide comfortable environments for occupants. User comfort, which can be defined as the state of wellbeing amongst building users, is achieved by controlling factors such as fire, sound, heat, light and water (Tekin et al, 2014). In Turkey, in order to meet these parameters, it is mandatory to comply with the relevant regulations and standards.

To ensure sound insulation, the "Regulation on Protection of Buildings Against Noise" was published on 31 May 2017 by the Turkish Ministry of Environment and Urbanization. In this regulation, sound insulation limit values are defined, in accordance with acoustical performance class ranging from A to F. Every building should comply with the minimum requirements. For new buildings, at least C acoustic performance class should be provided (Regulation, 2017).

However, modifications in building elements to achieve the desired class values of the regulation affect other design parameters as well. First, all practices affect "cost" which is an important criterion in evaluating the function of a building. Considering that resources are limited, minimizing cost is always the main objective in projects. Second, additional layers added to building elements to increase sound insulation increase weight as well. But, designing lightweight buildings is crucial in Turkey since 92% of the country is in earthquake zones (Declaration, 2018).

Lightweight wall materials decrease pressure on load-bearing systems and increase resistance to earthquakes. Third, designing thicker elements to increase sound insulation performance increases both unit cost and the weights. It also changes heat gains and losses in buildings and affects total energy consumption. For this reason, determination of the optimum thickness of elements is essential in design.

The aim of this study is to find the optimum internal wall complying with the Acoustic Regulation and maximizing the airborne sound insulation performance while minimizing other parameters (cost, weight, thickness). In this study, non-load-bearing masonry single walls, double walls and walls with linings were developed as types of interior wall alternatives. Then, values of all parameters of the walls were calculated and a decision matrix was created with the obtained values. Optimal wall selection according to the given criteria weights (importance levels) were selected through the TOPSIS method which is one of the well-known MCDM methods. While weighting criteria, a subjective evaluation in which sound insulation is the first, cost is second, weight and thickness are equally third, were considered (Sound Insulation > Cost > Weight = Thickness). Among the three different weightings that meet these evaluation conditions, sorting was calculated by using the Copeland method.

2. Methodology

In this study, numerous non load-bearing masonry interior wall alternatives maximizing sound insulation values were generated. Then, values of sound insulation, cost, thickness and weight parameters of walls were calculated. Walls that did not comply with

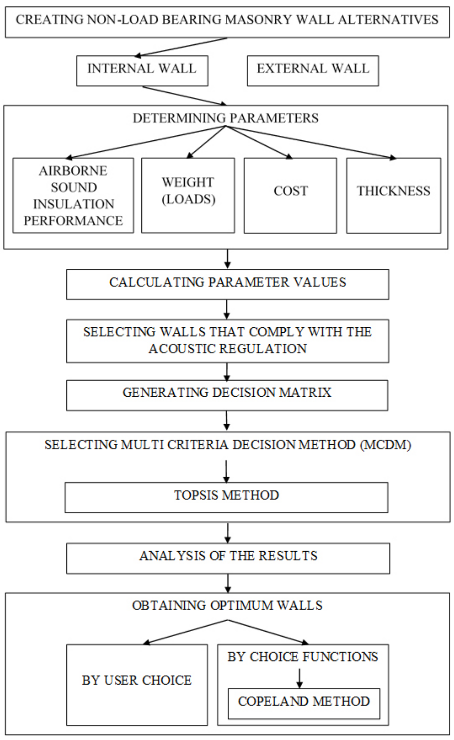


Figure 1. *General steps of methodology.*

the limits of the Acoustic regulation were eliminated. To find out the optimum wall type, all calculation results were brought together in a decision matrix and analyzed with a multi-criteria decision-making technique, TOPSIS. In this method, in order to reach a result, criteria were given importance levels (weights). The user can come to a result by either using a preferred criterion weighting through the TOPSIS method or by using the Copeland ranking method which brings together different weightings. General steps of methodology of the study are given in Figure 1.

2.1 Parameters, objectives and limit values

In Turkey, based on the latest statistical building census, 75% of buildings are used as housing. In addition, 51% of buildings are built in masonry, 48.4 %through frame system, and 0,6% through other construction systems (TUIK, 2001). In this research, residential buildings with masonry walls were studied.

Airborne sound insulation performance was calculated at the partition wall between the bedroom of a simple residential building (receiver room) and an adjacent room (source room). The volume of the receiver room was considered as 50 m^3 and wall dimensions have taken as length (l): 4 m, height (h) 2,7 m (approximately 10 m^2) as specified in the ISO 10140-5 standard (ISO, 2010).

Source and receiver rooms have been calculated to have equal internal temperatures. Thus, thermal insulation and condensation parameters were not analyzed. For protection against fire, in order to comply with "Regulation on Fire Protection in Buildings", all construction elements were selected as Class A1 non-combustible material (Regulation, 2007).

Wall types and building materials were selected to be the most widely used types and materials in Turkey. Sound insulation performance (D_{nTA}, dB), cost (Euro/m^2), weight (kN/m^2), and thickness (cm) parameters of the walls were calculated and analyzed.

2.1.1 Airborne sound insulation

Minimum airborne sound insulation values to be provided according to source and receiver room specifications ($D_{nT,A}$, dB) are determined in "Regulation on Protection of Buildings against Noise" given in Table 1 (Regulation,2017). As specified in Table 1, first, buildings are categorized based on their noise sensitivity and noisiness. Then, sound insulation values are defined in accordance with the combinations of different levels of noisiness and sensitivity. In this study, receiver room properties were selected as a residential bedroom that is highly sensitive to noise (Degree I) and adjacent source room was regarded as moderately noisy (MN). In this combination, the limit values are 52 dB for C-Class, 58 dB for B-Class and 62 dB for A-Class as highlighted in Table 1.

To provide A, B or C Class limits, it is necessary to primarily make improvements on the airborne sound insulation performance of the building elements. To improve sound insulation, general principles can be summarized as 1- increasing mass and density by means of increasing thickness 2- designing double walls 3-providing flexible connections 4- introducing an air gap between layers 5- increasing the air gap thickness 6- using porous elements in the

Table 1. *Minimum airborne sound insulation values to be provided according to source and receiver room specifications (DnT,A, dB) Limits for MN-I.*

Source Room Noisiness Level	Receiver Room Sensitivity Level	Acoustical Performance Class					
		A	B	C	D	E	F
High Level of Noisiness (HN) $L_{AF,max}$ > 75 dB	I - high	68	64	58	54	50	46
	II – moderate	65	61	55	51	47	43
	III - low	62	58	52	48	44	40
Moderate Noisiness (MN) 75 ≥ $L_{AF,max}$ > 55 dB	I - high	$\boxed{62}$	$\boxed{58}$	$\boxed{52}$	48	44	40
	II – moderate	59	55	49	45	41	37
	III - low	56	52	46	42	38	34
Low Level of Noisiness (LN) $L_{AF,max}$ ≤ 55 dB	I - high	56	52	46	42	38	34
	II – moderate	53	49	43	39	35	31
	III - low	50	46	40	36	32	28

cavity 7- avoiding factors that will form a sound bridge between walls, such as insulating the connection points of the elements like service pipes and ducts passing through the walls etc. (Mehta et al,1999).

*D*nT,A value was obtained from the following formulas (Hassan,2009).

$$D_{nT,A} = D_{nT,w} + C \;\; dB \qquad (1)$$

and

$$D_{nT,w} = R'_w + 10\log\left(\frac{0.16\,V}{T_0 S_s}\right) = R'_w + 10\log\left(\frac{0.32\,V}{S_s}\right) \qquad (2)$$

where

S_s: Area of partition wall, m^2

T_0 : Reference reverberation time (0.5s for houses)

V: Volume of receiver room, m^3

$R'_w = R_w - C_F$ and (3)

C_F: Correction value was calculated by the ratio of the unit weight of partition element (X) to average unit weight of all elements causing flanking transmissions (Y). For x=X/Y then C_F value was as following: for $x \leq 1$ $C_F = 0$, for $1<x\leq 2$ $C_F = 2$, for $2<x\leq 3$ $C_F = 4$ and for $3<x$ $C_F = 6$ (Hassan, 2009).

In order to determine Rw (C; C_{tr}) values, INSUL sound insulation prediction software was used. INSUL is based on models created by applying mass law theory that considers the critical frequency and approaches developed by B.H. Sharp, Cremer, Fahy, Ljunggren, Rindel and others. It was noted that the program reliably predicts sound insulation values with a 3-5 dB approximation (INSUL,2019).

In the calculation of C_F values, it was accepted that unit weights of the walls were equal. The lower and upper floors were considered as 15 cm reinforced concrete.

2.1.2. Cost

For construction cost estimation, "Construction Unit Price Methodology" by the Ministry of Environment and Urbanism is commonly used. Within the scope of construction unit price method; inputs of unit price are labor, machinery-equipment and material. A short description of the work for each of the inputs (laborer, mason etc.), machinery-equipment (excavator, bulldozer etc.) and material (brick, sand, cement etc.) were listed, unit and unit price of the work was determined with a code number given in the Construction and Installation Unit Prices Book (MoEU, 2017). An example of a unit price cost estimation is given in Table 2. Values were calculated in Turkish Lira (TRY) at first and then converted into Euro (EUR) (CBRT, 2019).

2.1.3. Weight (Loads)

Loads in a structure are generally classified as imposed (live) loads, permanent (dead) loads, horizontal loads and other loads such as load caused by temperature difference. Live loads, such as traffic loads may vary. Dead loads refer to the structure's self-weight and generally remain constant during the structure's life. Earthquake load and wind load are examples of horizontal loads (Toy-

Table 2. *Example of unit cost calculation.*

Item No	Analysis Name				Unit
15.220.1003	Building walls using 200-mm horizontally perforated bricks				m^2
Item No	Definition	Unit of Measure	Quantity	Unit Price	Amount (TRY)
	Material:				
10.130.2010	250 x 250 x200-mm horizontally perforated bricks (Including losses)	Qty	15,00	1,06	15,90
19.100.2416	Preparing lime mortar (with slaked lime bags)	m^3	0,018	141,40	2,55
10.130.9991	Water	m^3	0,01	6,84	0,07
	Labor:				
10.100.1013	Master bricklayer	h	0,68	15,70	10,68
10.100.1062	Unskilled worker (Construction worker)	h	1,36	11,50	15,64
	(Including loading, horizontal and vertical handling unloading at the construction site)				
	Material + Labor Cost:				44,84
	25% contractor's profit and overheads				11,21
	Price per m^2				56,05 (1)
(1) 56,05 TRY=8,89 Euro (18 Sep 2019- CBRT Exchange Rates)					

demir et al, 2000). In this study, only permanent-self loads of the non-load bearing walls were calculated. Total load of the wall was calculated as the sum of all elements' weights constituting the wall such as a block, mortar, plaster, steel studs, rockwool, gypsum board etc.

2.2. Creating non-load bearing masonry internal wall alternatives

Generating wall types started with the design of a single wall. Afterwards, alternatives were multiplied considering the general principles for improving sound insulation such as increasing mass and density by means of increasing thickness, adding layers, designing a double wall, introducing an air gap between layers, increasing the air gap thickness and using porous elements in the cavity.

Alternatives are presented in Table 3 below. Paint application on wall is not included in the study because it depends on subjective preferences in projects.

2.3. Building materials

In Turkey, the most commonly used infilling wall material is brick for masonry buildings (TUIK, 2001). In addition, Turkey is one of the biggest global AAC producers in Europe (TGUB, 2019). Therefore, brick and AAC blocks were chosen as wall materials for the study. Bricks used in this study are categorized in EN 771-1 as clay masonry units with LD (low gross dry density) and Category I (Level of confidence). Type of bricks are vertically perforated (VP), horizontally perforated (HP) Class-AB, horizontally perforated (HP) Class-W (CEN, 2016). AAC blocks were selected as non-reinforced blocks in EN 771-4 (BSI, 2015).

While determining the thickness and densities, the Ministry of Environment and Urbanization Unit Prices Book (which gives information about the most frequently produced materials) was taken into consideration (MoEU, 2017). Since the aim was to provide minimum wall thickness, blocks larger than 15 cm were not calculated for dou-

Table 3. *Internal wall alternatives.*

Alternatives							
	Type 1 (1)		Type 2(1)				
	Single Wall (SW)		Double Wall (DW)				
Cons_ truction Code	SW		DW		DW	DW	
			2 cm airgap		5 cm airgap	5 cm Rockwool	
Airgap Properties Code			a2		a5	r	
	Type 3 (2) (3)		Type 4 (2) (3) (4)				
	Single Wall+ Wall Lining		Double Wall+ Wall Lining				
Wall Lining Code	-5-G	-7,5-G	(a2)-5-G	(a2)-7,5-G	(a5)-5-G	(a5)-7,5-G	
Wall Lining Code	-5-2G	-7,5-2G	(a2)-5-2G	(a2)-7,5-2G	(a5)-5-2G	(a5)-7,5-2G	

(1) Cement plaster on two side
(2) Cement plaster on one side
(3) G: Gypsum board
5 - G: 5 cm rockwool in 5 cm airgap + single layer gypsum board
7,5 - G: 5 cm rockwool in 7.5 cm airgap + single layer gypsum board
5 - 2G: 5 cm rockwool in 5 cm airgap + double layer gypsum board
7,5 - 2G: 5 cm rockwool in 7.5 cm airgap + double layer gypsum board
with DU50 or 75 and DC50 or 75 metal cladding profiles
(4) a2: 2 cm airgap / a5: 5 cm airgap

ble walls. The density and thickness of the bricks and AAC blocks are given in Table 4.

Other properties are the following: Elasticity Modules (E, GPa): 2,5 for HP, 3 for VP-650kg/m^3, 4 for 750kg/m^3,1,75 for AAC 400 kg/m^3, 2,25 for AAC 500 kg/m^3 and 2,75 for AAC 600kg/m^3. Loss factors are 0,01 for both bricks and AAC blocks. Poisson's Ratio's (σ) are 0,25 for both bricks and AAC blocks. Properties of the other materials are: Gypsum board: 1,25 cm - 640 kg/m^3, Rockwool: 5 cm 50kg/m^3, Cement Plaster: 2 cm 2000 kg/m^3, Brick Mortar: Lime Cement Mortar-1800 kg/m^3. For AAC Block instead of mortar, a special adhesive was used.

2.4. Calculation of number of alternatives

Regarding the multiplication of the type, number of density and number of thickness, it was calculated that number of alternatives were 60 for Type 1, 19 for Type 2a, 19 for Type 2b, 19 for Type 2c, 240 for Type 3, 152 for Type 4 in Table 4. Hence, total amount of calculated walls was 509.

2.5. Multi-criteria decision making (MCDM) method

Decision-making is defined in literature as the process of selecting one or more of the various alternatives available in accordance with certain criteria and conditions, taking into account the expectations of decision-makers in order to solve a specific problem and to reach a desired goal (Beldek, 2009; Cristobal & Ramon, 2012). Each decision is made in a decision environment where information, alternatives, values and preferences come together at the time of decision making (Cristobal & Ramon, 2012). One of the main problems in decision making is the comparability of options (different systems, system states, different values of decision variables, etc.). The aim is to develop a measure that allows the establishment of a preference sequence over the options (Cristobal & Ramon, 2012; Kuru,2011).

Multi-criteria decision-making (MCDM) is referred to as the electoral process that a decision-maker makes by using at least two criteria in a set of finite or uncountable numbers without subjective judgments (Kuru, 2011; Öztel, 2016). This method is a tool that allows the best choice to be found in a variety of ways among the alternatives in the decision-making situations where there are often many conflicting criteria (Kuru, 2011; Triantaphyllou, 2000). The MCDM techniques used to solve the problems of different alternatives usually consist of the following stages: defining the problem, generating alternatives and creating criteria, selection of criteria, weighting, evaluation, selecting the appropriate MCDM and ultimately sequencing alternatives (Cristobal & Ramon, 2012; Öztürk, 2011). Belton and Stewart (2002) summarize these stages in three key stages: defining and constructing the problem, establishing and running the model and developing action plans (Belton & Stewart, 2002; 1000minds Ltd., 2017).

In literature, a wide range of MCDM methods have been formed depending on the type of problem. Some of these methods are; WSM (Weighted Sum Model) (Fishburn, 1967), SAW (Simple Additive Weighting) (MacCrimmon & Rand, 1968), MAUT (Multi-Attribute Utility Theory), MAVT (Multi-Attribute Value Theory) (Keeney & Raiffa, 1976), ELECTRE (ELimination Et Choix Traduisant la REalité) (Roy, 1968), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) (Hwang & Yoon, 1981), PROMETHEE (Preference Ranking Organization Method

Table 4. *Properties of the materials.*

Material	Code		Dry Density (kg/m^3)	Thickness (cm)	
					(Not calculated for double walls)
Brick	HP		600	10 - 12 - 13,5	19 - 20 - 24 – 25
	VP	W	650 - 750	11,5 - 14,5	17,5 - 19 - 24 - 25 - 30
		AB		-	19 - 24 - 29
AAC	AAC		400 - 500 - 600	10 - 12,5 - 13,5 - 15	17,5 - 19 - 20 - 22,5 - 25 - 30 - 35

For Enrichment Evaluations) (Brans et al., 1984), AHP (Analytic Hierarchy Process) (Saaty, 1988), SMART (Simple Multi-Attribute Rating Technique) (Edwards & Barron, 1994), ANP (Analytic Network Process) (Saaty, 1996), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) (Opricovic,1998), WPM (Weighted Product Method) (Triantaphyllou, 2000), COPRAS (Complex Proportional Assessment Method) (Zavadskas & Antucheviciene, 2007), ARAS (Additive Ratio Assessment) (Zavadskas & Turskis, 2010), MACBETH (Measuring Attractiveness by a Categorical Based Evaluation TecHnique) (Bana e Costa et al., 2012), MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) (Brauers & Zavadskas, 2006), MULTIMOORA (Brauers & Zavadskas, 2010) and MOOSRA (Multi-objective Optimization On The Basis Of Simple Ratio Analysis) (Brauers, 2004).

MDCM methods are grouped in different ways in literature regarding their approaches, and operations. Ishizaka and Nemery (2013) divided the MCDM methods into 3 groups depending on their approaches as “Full aggregation approach”, “Outranking approach” or “Goal, aspiration or reference level approach” (Ishizaka & Nemery, 2013; Tscheikner-Gratl et al., 2017). In “Full aggregation approach”, a score is evaluated for each criterion and then they are synthesized into a general score. Based on this score, all the options can be compared and ranked from the best to the worst case. AHP, ANP, MAUT, MAVT, MACBETH, WSM, SMART are the examples of this group. “Outranking approach” is based on pairwise comparisons like PROMETHEE and ELECTRE. “Goal, aspiration or reference level approach” sets a target for each criterion and defines the closest options to the ideal target or reference level. TOPSIS, COPRAS, ARAS, SAW, MOORA, MULTIMOORA, MOOSRA and VIKOR are examples of this approach (Ishizaka & Nemery, 2013).

There are cases where each method is superior to the others. For this reason, in selecting which MCDM method to be applied, the type of the problem, options, evaluation scale, uncertainty, dependence between qualifications, expectations of the decision-maker and quality of the data should be taken into consideration (Arıbaş & Özcan, 2016).

The most common method used by researchers to determine the criteria weight is the AHP method (İlter, 2016). However, depending on the number of criteria and alternatives, the method can be complex and time-consuming. So, it is not recommended for problems with a high number of alternatives (Velasquez & Hester, 2013). Another MCDM technique which is known for its ease of use is the TOPSIS method (Hwang & Yoon, 1981).

TOPSIS method

TOPSIS was first introduced by Hwang and Yoon (1981) as an alternative to the ELECTRE method. Afterwards, developed by Yoon (1987) and Hwang et al. (1993). TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). PIS is a solution that maximizes the utility/maximum criterion and minimizes the cost/minimum criterion (Ertuğrul & Özçil, 2014; Yıldırım & Önder, 2015).

The advantages of the TOPSIS method are summarized as follows: It is relatively simple, rational and comprehensible (Çatı et al., 2017; Ertuğrul & Özçil, 2014; Sanjay et al., 2019). It does not include complex algorithms and complex mathematical models (Yıldırım & Önder, 2015). It is suitable for large-scale data (Arıbaş & Özcan, 2016; Thor et al., 2013) and can be applied directly on data without a qualitative conversion if the necessary data are numerical values (Velasquez & Hester, 2013). It has good computational efficiency (Sanjay et al., 2019; Thor et al., 2013) allows evaluation criteria to be weighted (Çakır & Perçin, 2013; Ertuğrul & Özçil, 2014). It identifies the best alternative quickly (Arıbaş & Özcan, 2016; Sanjay et al., 2019) and interpretation of results is easy (Yıldırım & Önder, 2015). A disadvantage is that thresholds of criteria are not considered (Eray, 2015).

The TOPSIS method has been compared to some other MCDM methods in literature and has mostly been evaluated as more appropriate. For instance, İlter (2016) indicated that the TOPSIS method gives more stable results than the COPRAS method due to the difference between their normalization techniques. Ertuğrul and Özçil (2014) aimed to compare TOPSIS and VIKOR methods and found that the results of the TOPSIS method were healthier and more reliable. Benyoucef et. al. (2014) compared SAW, WPM, AHP and TOPSIS. The results demonstrate that TOPSIS gives results which are close to ideal. According to Kuru (2011) and Ertuğrul & Karakaşoğlu (2008) SAW, TOPSIS and VIKOR compared, TOPSIS and VIKOR have the ability to better distinguish the results of evaluation.

TOPSIS has been used extensively in business and marketing management (Mohammadi Dehcheshmeh, 2018; Saldanlı & Sırma, 2014), finances (Yıldırım & Önder, 2015), engineering systems such as sustainability assessment, renewable energy options and water resources management (Ömürbek et al., 2015, Štreimikienė & Baležentis, 2013; Yazdani-Chamzini et al., 2013), human resources management (Karakış, 2016), problems regarding selection of the most appropriate option among alternatives such as laptop, air conditioner or composite laminates (Ertuğrul & Özçil, 2014; Çakır & Perçin, 2013; Pekkaya & Aktoğan, 2014; Sanjay et al., 2019) and in areas such as transportation, education and health which require decision support (Arıbaş & Özcan, 2016; Yıldırım & Önder, 2015; Özkan, 2007).

However, in architecture or the construction sector there is not much research on TOPSIS. Some examples are: performance evaluation of panel curtain wall systems (İlter, 2016), energy efficiency of a public building renovation and reconstruction (Rasiulis et al., 2016), construction projects and their overall risks under incomplete and uncertain situations (Taylan et al, 2014), and cultural heritage renovation projects in Bulgaria (Tupenaite, 2010).

This research will be an example of TOPSIS application in the field of architecture.

TOPSIS procedure consists of the following steps (Yıldırım & Önder, 2015):

Step 1: Creating a decision matrix for the ranking. The problem of MCDM can be expressed as in the following matrix format (4)

$$
\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ A_{ij} = & \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \end{array} \quad (4)
$$

where

A_{ij} is the decision matrix

$C_1, C_2, \dots, C_n$,, the columns are the criteria by which the alternative performance is measured

a_{ij} is the qualification of the alternative with respect to the criterion C_j

m is the number of the alternatives

n is the number of evaluation criteria

Step 2: Determining the normalized decision matrix and the normalized value r_{ij} is obtained using the formula (5).

$$
r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad (5)
$$

for i=1,2,....,m and j=1,2,....,n

where

a_{ij} and r_{ij} are the original and normalized score of the decision matrix

The standard decision matrix indicated by R is obtained as in (6)

$$
R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \quad (6)
$$

Step 3: Determining the weighted normalized decision matrix (*V*) and weighted normalized value v_{ij}. v_{ij} is obtained using the formula (7).

$$
V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \dots & \dots & \dots & \dots \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & \dots & v_{2n} \\ \dots & \dots & \dots & \dots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix} \quad (7)
$$

where

w_{ij} is the relative weight of the *i*th criterion or attribute

Sum of the weight values w_i should be equal to 1 (8).

$$
\sum_{i=1}^{m} w_i = 1 \quad (8)
$$

Step 4: Calculating the PIS (a*) and NIS (a-). The maximum and minimum values are determined in each column of the weighted normalized decision matrix as (9 and 10)

$$a^{*} = \{v_1^{*}, v_2^{*}, \ldots, v_k^{*}\} \text{ (maximum values)} \quad (9)$$

and

$$a^{-} = \{v_1^{-}, v_2^{-}, \ldots, v_k^{-}\} \text{ (minimum values)} \quad (10)$$

If the target is maximization, maximum values in the column are the ideal solution values and if the target is minimization, minimum values in the column are the ideal solution values. NIS is the value of the opposite target.

Step 5: Calculating the separation measures for each alternative by determining the separation measure value using n-dimensional Euclidian distance method. The separation of each alternative from the ideal solution is given as (11)

$$S_i^{*} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^{*})^2} \quad i=1,2,\ldots,n \quad (11)$$

Similarly, separation from the NIS is given as (12)

$$S_i^{-} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^{-})^2} \quad i=1,2,\ldots,n \quad (12)$$

Step 6: Determining the relative closeness to the ideal solution, and the relative closeness of the alternative C_i^* with respect to S_i^+ and S_i^- is obtained using the formula (13)

$$C_i^{*} = \frac{S_i^{-}}{S_i^{-} + S_i^{*}} \quad (13)$$

and $0 \leq C_i^* \leq 1$

Step 7: Ranking the preference order. The alternative C_i^* closest to 1 indicates greatest relative closeness to the ideal solution.

2.6. Choice theory

Choice theory is an important issue in group decision making. Social choice theory deals with assembling individual preferences over a set of alternatives into a collective decision via a social choice mechanism. The social choice mechanism takes the preferences as input and typically outputs a single alternative as the winner. This theory consists of voting methods and social selection functions (Anshelevich et al., 2015) which have been addressed by many authors who have worked on voting order and social preferences. The most well-known functions can be categorized as; Condorcet's function (Condorcet, 1785), Borda's function (Borda, 1784), Copeland's function (Saari & Merlin, 1996), Nanson's function (Nanson, 1907), Dodgson's function (Dodgson, 1876), and Kemeny's function (Hwang & Lin, 1987).

Condorcet selection procedure is based on the results of one-to-one comparisons between candidates. If a candidate is preferred over all other candidates, it is a Condorcet winner and must be selected (Condorcet, 1785). Borda's function orders the alternatives according to the sums of individual preferences of voters (decision-makers) (Lamboray, 2007). The Copeland Method is the extension of the Borda method. It calculates the number of losses for all alternatives as well. It determines the score by subtracting the losses from the winnings and offers a new order of importance (Saari & Merlin, 1996). Kemeny's rule is also an extension of the principles consisting of linear orders that are closest to the rankings of the profile according to the symmetric difference distance (Lamboray, 2007). In Dodgson's function, candidates are scored in accordance with the smallest number of changes needed in voters' preference orders to create a simple majority winner (Dodgson, 1876). Nanson's function discusses the modification of Copeland method. It deletes only the lowest Borda score candidate(s) at each stage (Hwang & Lin, 1987).

Copeland method

The Copeland method proposed by Copeland at the University of Michigan and later investigated in detail by Saari and Merline (1996) has the advantage of facilitating the analysis of very large data sets. It is rapid, systematic, has simpler mathematical requirements and allows for the possibility of categorical or relative ranking. It has proven to be unsusceptible to variations in the data. So, it can be applied where it is desired to rank objects. It is indicated that it may lose some information during the aggregation, but this disadvantage is observed in other choice theories as well (Al-Sharrah, 2010; Saari & Merlin, 1996).

This aggregation method selects the alternative with the largest Copeland score in pairwise comparisons. The Copeland score for a given alternative is defined as the difference between the number of times the alternative is ranked higher than other alternatives (victories) and the number of times that alternative is ranked lower than other alternatives (defeats) (Çakır, 2015; Çakır, 2017; Hwang & Lin, 1987).

The Copeland method consists of the following steps (Saari & Merlin, 1996):

Step 1: Pairwise comparisons are made between alternatives. The alternative discussed receives “1” votes if it is higher than the others in the ranking and 0 votes if it is lower as in formula (14).

Between c_j and c_k

$$s_{j,k} = \begin{cases} 1 & if\ c_j\ beats\ c_k \\ 1/2 & if\ c_j\ and\ c_k\ are\ tied \\ 0 & if\ c_k\ beats\ c_j \end{cases} \quad (14)$$

Step 2: The Copeland score for each c_j defined as (15);

$$C(j) = \sum_{k \neq j} s_{j,k} \quad (15)$$

Step 3. Consequently, the total order of the objects is evaluated.

In literature, there are some researches where MCDM methods and Copeland method are used together. For instance, Çakır (2015) selected the most appropriate six sigma project by Fuzzy VIKOR, Fuzzy TOPSIS and Fuzzy COPRAS integrating the ranking scores obtained from each method through the Copeland method. Sugiartawan & Hartati (2018) combined AHP and Copeland Model to rank popular tourism objects in Bali. Arslan (2018) integrated TOPSIS, GRA, VIKOR and MOORA methods with the Copeland method to rank countries according to data from 23 OECD member countries. Tajvidi Asr et al. (2015) integrated SAW, TOPSIS, LA (Linear Assignment) methods with the Borda and Copeland techniques to select a proper support system for Beheshtabad water transporting tunnel from among the six proposed support systems. Supçiller and Deligöz (2018) combined AHP, VIKOR, SAW, GRA (Grey Relational Analysis), MOORA, ELECTRE II, M-TOPSIS (Modified TOPSIS) with Borda and Copeland techniques to comprise a solution for a supplier selection problem.

However, these combined methods have not been employed in the field of architecture. This study will contribute to literature in this respect.

3. Study

In this research, 509 non load-bearing masonry interior wall alternatives aiming to maximize sound insulation values have been generated. Then, values of sound insulation, cost, thickness and weight parameters of walls were calculated. According to sound insulation calculation, 54 walls were eliminated for not complying with MN-I C-Class limit of the regulation. So, 455 wall type calculation results were evaluated. A decision matrix representing the values of each criterion with each alternative were formed and analyzed with TOPSIS. All calculations were performed via Microsoft Office Excel.

3.1. TOPSIS method

The application of the method is described below using the formula steps given in section 2.5.1. As Step 1, to create a decision matrix, it is necessary to specify a short code for the walls. In the present study, wall codes were given depending on layers forming wall types as: Construction (Single Wall-SW or Double Wall- DW) – Block Type (Brick or AAC) – Airgap properties – Wall Lining properties. Airgap and wall lining codes are presented in Table 3. Block type codes are given as following:

- BHP: Brick, Horizontally Perforated – Dry Density: 600 kg/m3
- BVPW1: Brick, Vertically Perforated – W Class – Dry Density: 650 kg/m^3
- BVPW2: W Class – Dry Density: 750 kg/m^3
- BVPAB1: Brick, Vertically Perforated – AB Class – Dry Density: 650 kg/m^3
- BVPAB2: Brick, Vertically Perforated – AB Class – Dry Density: 750 kg/m^3

- AACG2: Aerated Autoclaved Concrete – G2 Class – Dry Density: 400 kg/m^3
- AACG3: Aerated Autoclaved Concrete – G3 Class – Dry Density: 500 kg/m^3
- AACG4: Aerated Autoclaved Concrete – G4 Class – Dry Density: 600 kg/m^3

To exemplify, coding for wall types number 241 and 342 is presented in Table 5.

Decision matrix for interior walls is given in Table 6. Since the table will be too long for 455 walls, only some of them are included in the table.

For sample wall number 241 calculations are given in Table 7. As Step 2, to determine the normalized decision matrix, the normalized value r_{ij} was obtained using the formula (5). For sample wall number 241 calculations are given in Table 7. As Step 3, to determine the optimum wall, given weights have a great importance in the criteria. In this study, the importance levels were determined as: sound insulation is first, cost second, weight and thickness equally third (Sound Insulation > Cost > Weight = Thickness). Similar weights can meet these evaluation conditions. Examples of three alternatives that are close to average per each alternative (0,25) were selected. Total weighting is 1 as indicated in formula (8).

Table 5. *Coding examples for wall types numbers 241 and 342.*

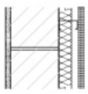
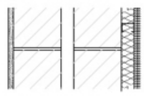
Wall No: 241	Wall No: 342
	
SW-AACG3-10-P7,5-2G	DW-BHP-13,5-a5-P5-2G
Single Wall, 10 cm Aerated Autoclaved Concrete G3 Class – Dry Density: 500 kg/m^3, wall lining with 5 cm rockwool in 7,5 cm airgap (profile)+ double layer gypsum board. Cement plaster on one side.	Double Wall, 13,5 cm Brick, Horizontally Perforated – Dry Density: 600 kg/m^3 5 cm airgap between bricks, wall lining with 5 cm rockwool in 5 cm airgap (profile)+ double layer gypsum board. Cement plaster on one side.

Table 6. *Coding examples for wall types numbers 241 and 342.*

Layer No	Layer Code (construction - block type - block thickness – airgap – profile - gypsum board	Sound Insulation $D_{nT,A}$ (dB)	Cost (EUR)	Weight (m^2/kN)	Thickness (cm)
1	SW-BVPW1 - 30	52	16,30	2,81	34
2	SW-BVPW2 - 30	54	14,80	3,10	34
3	SW-BVPAB1 - 29	52	14,70	2,75	33
.	.	.	.	.	.
.	.	.	.	.	.
117	SW- BVPAB2-29-P7,5-G	62	17,90	2,82	39,75
118	SW- BHP-10-P5-2G	59	15,70	1,25	19,50
.	.	.	.	.	.
.	.	.	.	.	.
241	SW-AACG3-10-P7,5-2G	60	17,00	1,25	22
242	SW-AACG4-10-P5-2G	60	17,10	1,35	19,50
.	.	.	.	.	.
.	.	.	.	.	.
303	SW-AACG4-35-P7,5-2G	66	26,90	2,87	47
304	DW-BHP-10-a2-P5-G	61	19,10	1,81	30,25
.	.	.	.	.	.
.	.	.	.	.	.
342	DW-BHP-13,5-a5-P5-2G	72	21,4	2,42	41,5
343	DW-BHP-13,5-a5-P7,5-2G	74	21,6	2,42	44
.	.	.	.	.	.
.	.	.	.	.	.
454	DW-AACG4-15-a5-P5-2G	73	27,0	2,85	44,5
455	DW-AACG4-15-a5-P7,5-2G	75	27,3	2,85	47

Next steps will be described using Alternative 1 weighting. As Step 4, to find out positive (a*) and negative (a-) ideal solutions, first, minimum and maximum x_{ij} values were calculated for the Alternative 1 criterion weightings. In determining a* value, because sound insulation should be maximized, maximum x_{ij} values were selected. Likewise, because cost, weight and thickness should be minimized, minimum x_{ij} values were selected for a* (Table 7). A- values were taken for the reverse situation. After determining a* and a- values, as in Step 5, separation measures S_i* and S_i- were calculated according to the formulas (11-12). C_i* value was obtained as 0,7441 by formula (13). This is given in Table 8 below.

Optimum Results

Top 10 wall types obtained from the calculations with the Alternative 1-2-3 criteria weights for 455 walls are given in Table 8.

3.2. Analysis and Copeland method

While determining the optimum options, the final decision belongs to the user. In this case, the user can choose any of the rankings of alternatives 1, 2 or 3 and decide. If it is not possible to decide between alternatives, it is feasible to reach a conclusion using social selection functions. In this study, Copeland method was applied to rank the alternatives.

Looking at the findings in Table 8, rankings are quite similar. For these alternatives, Copeland method was applied to the first 6 rankings, the walls with numbers 118,119, 239, 65, 240 and 238. Any number of sequences can be made.

Pairwise comparisons made in accordance with the Copeland method are given in Table 9. In these comparisons, for example, for wall type 118 in alternative 1 it received 1 point because it was superior to the others, but in the alternative 2, it received 0 points because it was not superior to 119. For wall number 240 in alternative 1 it scored 0 on 118 but 1 on 65. There is no relation between alternatives, so none of the candidates is awarded with ½ point.

Table 7. *Example of calculations of sample wall with number 241 and code: SW-AACG3-10-P7,5-2G.*

Calculations	S.I $D_{nT,A}$ (dB)	C. (EUR)	W. (m²/kN)	T. (cm)		
Values obtained by calculations Decision Matrix (4) a_{ij}	60	16,98	1,25	22		
a_{ij}^2	3600	288,24	1,57	484		
$\sqrt{\sum_{i=1}^{m} a_{ij}^2}$ (for m=436 , all walls)	1348,6	434,53	46,26	734,67		
r_{ij} (5)	0,0445	0,0391	0,0271	0,0299		
Criteria Weights for providing Sound Insulation > Cost > Weight = Thickness principle						
w_i *Alternative 1*	*0,35*	*0,25*	*0,20*	*0,20*		
w_i *Alternative 2*	*0,375*	*0,275*	*0,175*	*0,175*		
w_i *Alternative 3*	*0,28*	*0,26*	*0,23*	*0,23*		
For Alternative 1 w_i Criteria Weights:						
v_{ij}	0,0156	0,0098	0,0054	0,0060		
Maximum v_{ij} (of all 436 walls)	0,0195	0,0157	0,0145	0,0128		
Minimum v_{ij} (of all 436 walls)	0,0135	0,0080	0,0046	0,0050		
a^*	0,0195	0,0080	0,0046	0,0050		
a^-	0,0135	0,0157	0,0145	0,0128		
relative closeness to the PIS	$(v_{ij} - v_j^*)^2$				$\sum_{j=1}^{k}(v_{ij} - v_j^*)^2$	(S_i^*)
	1,51548E-05	3,0188E-06	6,6038E-07	1,04E-06	1,98762E-05	0,0045
relative closeness to the NIS	$(v_{ij} - v_j^-)^2$				$\sum_{j=1}^{k}(v_{ij} - v_j^*)^2$	(S_i^-)
	4,3107E-06	3,5443E-05	8,19228E-05	4,63187E-05	0,00017	0,0130
C_i^*						0,7441

Table 8. *Top 10 wall alternatives obtained according to the TOPSIS Method - Weight Alternative 1-2 and 3.*

Alternative 1							
Rank	No	Code	S. I. $D_{nT,A}$ (dB)	C. (m²/EUR)	W. (m²/kN)	T. (cm)	C_i*
1st	118	SW- BHP-10-P5-2G	59	15,7	1,25	19,50	0,7579
2nd	119	SW- BHP-10-P7,5-2G	60	16,0	1,25	22,00	0,7561
3rd	239	SW-AACG2-10-P7,5-2G	60	16,7	1,15	22,00	0,7549
4th	240	SW-AACG3-10-P5-2G	59	16,7	1,25	19,50	0,7473
5th	238	SW-AACG2-10-P5-2G	58	16,4	1,15	19,50	0,7468
6th	65	SW- BHP-10-P7,5-G	57	14,6	1,17	20,75	0,7458
7th	242	SW-AACG4-10-P5-2G	60	17,1	1,35	19,50	0,7441
8th	241	SW-AACG3-10-P7,5-2G	60	17,0	1,25	22,00	0,7441
9th	243	SW-AACG4-10-P7,5-2G	61	17,4	1,35	22,00	0,7396
10th	175	SW-AACG3-10-P7,5-G	57	15,6	1,17	20,75	0,7387
Alternative 2							
Rank	No	Code	S. I. $D_{nT,A}$ (dB)	C. (m²/EUR)	W. (m²/kN)	T. (cm)	C_i*
1st	119	SW- BHP-10-P7,5-2G	60	16,00	1,25	22,00	0,7337
2nd	118	SW- BHP-10-P5-2G	59	15,72	1,25	19,50	0,7336
3rd	239	SW-AACG2-10-P7,5-2G	60	16,67	1,15	22,00	0,7296
4th	65	SW- BHP-10-P7,5-G	57	14,62	1,17	20,75	0,7220
5th	240	SW-AACG3-10-P5-2G	59	16,69	1,25	19,50	0,7203
6th	238	SW-AACG2-10-P5-2G	58	16,38	1,15	19,50	0,7189
7th	241	SW-AACG3-10-P7,5-2G	60	16,98	1,25	22,00	0,7188
8th	242	SW-AACG4-10-P5-2G	60	17,10	1,35	19,50	0,7182
9th	67	SW- BHP-12-P7,5-G	58	14,83	1,31	22,75	0,7167
10th	243	SW-AACG4-10-P7,5-2G	61	17,39	1,35	22,00	0,7155
Alternative 3							
Rank	No	Code	S. I. $D_{nT,A}$ (dB)	C. (m²/EUR)	W. (m²/kN)	T. (cm)	C_i*
1st	118	SW- BHP-10-P5-2G	59	15,72	1,25	19,50	0,8084
2nd	119	SW- BHP-10-P7,5-2G	60	16,00	1,25	22,00	0,8013
3rd	65	SW- BHP-10-P7,5-G	57	14,62	1,17	20,75	0,8012
4th	239	SW-AACG2-10-P7,5-2G	60	16,67	1,15	22,00	0,8004
5th	238	SW-AACG2-10-P5-2G	58	16,38	1,15	19,50	0,7999
6th	240	SW-AACG3-10-P5-2G	59	16,69	1,25	19,50	0,7966
7th	175	SW-AACG3-10-P7,5-G	57	15,60	1,17	20,75	0,7940
8th	173	SW-AACG2-10-P7,5-G	56	15,29	1,07	20,75	0,7935
9th	177	SW-AACG4-10-P7,5-G	58	16,01	1,27	20,75	0,7903
10th	241	SW-AACG3-10-P7,5-2G	60	16,98	1,25	22,00	0,7882

Table 9. *Copeland calculation of wins and defeats with the results.*

No	118			239			119			65			240			238		
	a1	a2	a3	a1	a2	a3	a1	a2	a3	a1	a2	a3	a1	a2	a3	a1	a2	a3
118	---	---	---	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
239	0	0	0	---	---	---	0	0	0	1	1	0	1	1	1	1	1	1
119	0	1	0	1	1	1	---	---	---	1	1	1	1	1	1	1	1	1
65	0	0	0	0	0	1	0	0	0	---	---	---	0	1	1	0	1	1
240	0	0	0	0	0	0	0	0	0	1	0	0	---	---	---	1	1	0
238	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	---	---	---

Calculation Results:

No	118	239	119	65	240	238	Sum	Copeland Ranking
118	---	3	2	3	3	3	14	1st
239	0	---	0	2	3	3	8	3rd
119	1	3	---	3	3	3	13	2nd
65	0	1	0	---	2	2	5	4th
240	0	0	0	1	---	2	3	5th
238	0	0	0	1	1	---	2	6th

Looking at the results presented in Table 9, the candidate with the most points is wall number 118, second candidate is wall number 119 and third candidate is wall number 239.

4. Conclusion

As stated in the Regulation on Protection of Buildings Against Noise, sound insulation should be provided in all kinds of buildings. Since there is a classification in the regulation, it is required to choose the most appropriate type of building element that maximizes sound insulation performance.

However, in order to improve sound insulation performance, acoustic applications like increasing mass or designing double walls affect other important design parameters like cost, weight and thickness that should be minimized. Having conflicting criteria appears to be a design problem for the construction sector. Therefore, multi-criteria decision making (MCDM) methods that allow the best choice to be found among the alternatives in decision-making situations were used in the study. Within MCDM methods TOPSIS method was preferred because it is suitable for large-scale data and identifies the best alternative quickly. In addition, to evaluate several TOPSIS results together and rank objects, Copeland method was applied. This aggregation method selects the alternative with the largest score in pairwise comparisons.

In this research, internal non-load bearing brick and AAC block wall alternatives were examined. Internal wall was designed to be approximately 10m^2 between source and receiver rooms. Wall construction alternatives were formed starting with single wall and developed as double walls and walls with cladding. Brick and AAC types, their thickness and densities were selected from types that are only produced in Turkey and have cost information in the Construction and Installation Unit Prices Book by The Ministry of Environment and Urbanism. The total amount of calculated walls is 509 regarding the number of construction type, density and thicknesses.

Insulation limits for walls were specified considering the source room was highly sensitive to noise (degree I) and the receiver room was moderately noisy (MN). According to the regulation, for Degree I-MN sensitivity noisiness combination, the required limit $D_{nT,A}$ (dB) is 52 dB for C Class. After all parameters were calculated, 54 wall types found to be less than 52 dB were excluded from the analysis. So, a number of 455 walls was analyzed respectively.

Among 455 walls, to choose the optimum wall TOPSIS method was applied. As specified by this method, subjective weight was given to each criterion to emphasize its importance. In the present study, the importance level of sound insulation was considered as the first. Cost was evaluated as second while weight and thickness were equally third (Sound Insulation > Cost > Weight = Thickness). Three different weights meeting this condition were given to parameters and three similar results were found. Accordingly, users could choose of one of these three results. Alternatively, afterwards, to evaluate the alternatives together and rank objects, Copeland method was applied.

According to the Copeland calculation results, optimum wall was found to be as following: the wall number 118, code: SW- BHP-10-P5-2G having section single wall construction made of 10 cm and 600 kg/m^3 dry density horizontally perforated brick, 2 cm 2000 kg/ m^3 cement plaster on one side, wall cladding on the other side consisting of double layer gypsum board 5 cm rockwool inside 5 cm airgap constructed with DU50 and DC50 metal cladding profiles.

The results reveal that co-application of TOPSIS and Copeland method facilitate decision making for architects and engineers at the design stage. The implementation of the optimum walls will not only provide acoustic comfort in buildings but reduce construction costs and contribute to the national economy as well. In this study, interior walls were studied but in future studies this methodology can be used in the construction industry for other selection problems such as choosing exterior walls, glass types, floors, finishing materials etc. among the alternatives. In addition, by changing the criteria weights or by selecting more or different parameters, researchers will be able to obtain different information and results. Especially giving the cost parameter higher weight will prevent large losses in construction budgets.

References

Al-Sharrah, G. (2010). Ranking using the Copeland score: A comparison with the Hasse diagram. *Journal of Chemical Information and Modeling,* 50, 785–791.

Anshelevich, E., Bhardwaj, O.& Postl, J. (2015). Approximating optimal social choice under metric preferences, *Proceedings of the 29th AAAI Conference on Artificial Intelligence,* Austin, Texas, January 25-30.

Arıbaş, M., & Özcan, U. (2016). Akademik araştırma projelerinin AHP ve TOPSIS yöntemleri kullanılarak değerlendirilmesi. *Politeknik Dergisi,* 19 (2),163-173.

Arslan, R. (2018). Çok kriterli karar verme yöntemlerinin karşılaştırılması ve bütünleştirilmesi: OECD verileri üzerine bir uygulama (Doktora tezi). Sivas Cumhuriyet Üniversitesi, Sosyal Bilimler Enstitüsü, Sivas.

Bana e Costa, C.A., De Corte, J.M., & Vansnick, J.C. (2012) MACBETH. *International Journal of Information Technology & Decision Making, 11*(02), 359–87.

Beldek, U. (2009). Design and improvement of multi-level decision-making models (Ph.D. thesis). Middle East Technical University, The Graduate School of Natural and Applied Sciences, Ankara.

Belton, V., & Stewart, T. (2002). *Multiple criteria decision analysis: An integrated approach.* Berlin Heidelberg: Springer Science & Business Media.

Benyoucef, L., Hennet, J.C., & Tiwari, M.K. (Eds.). (2014). *Applications of multi-criteria and game theory approaches: manufacturing and logistics.* London: Springer-Verlag.

Borda, J.C. (1784). *Memoire sur les elections au scrutin.* Paris: Histoire de I'Academie Royaledes Sciences

Brans, J. P., Mareschal, B., & Vincke, P. (1984). PROMETHEE: A new family of outranking methods in multicriteria analysis, *Operational Research,* 3, 477-490.

Brauers, W. K. M. (2004). Optimization methods for a stakeholder society. *A revolution in economic thinking by multiobjective optimization.* Boston, MA: Kluwer.

Brauers, W. K. M., & Zavadskas, E. K. (2006). The MOORA method and its application to privatization in a transition economy. *Control and Cybernetics, 35* (2), 445–469.

Brauers, W. K. M., & Zavadskas, E. K. (2010). Project management by MULTIMOORA as an instrument for transition economies. *Technological and Economic Development of Economy,16*, 5–24.

BSI British Standards Institution. (2015). *Specification for masonry units - Part 4: Autoclaved aerated concrete masonry units* (BS EN 771-4:2011+A1).

CBRT Central Bank of the Republic

of Turkey Head Office. (2019). CBRT Exchange Rates [Website]. Retrieved Sep 18, 2019 from: https://www.tcmb.gov.tr/wps/wcm/connect/en/tcmb+en

CEN European Committee for Standardization. (2016). *Specification for masonry units-Part 1: Clay masonry units* (EN 771- 1+A1).

Condorcet, M. D. (1785). *Essay on the application of analysis to the probability of majority decisions,* Paris: Imprimerie Royale.

Cristobal, S., & Ramon, J. (2012). *Multi criteria analysis in the renewable energy industry,* 43-72. Berlin Heidelberg: Springer Science & Business Media.

Çakır, E. (2015). Bulanık çok kriterli karar verme yöntemlerinin altı sigma projeleri seçiminde uygulanması (Doktora tezi). T.C. Adnan Menderes Üniversitesi, Sosyal Bilimler Enstitüsü, Aydın.

Çakır, E. (2017). Kriter ağırlıklarının SWARA – Copeland yöntemi ile belirlenmesi: bir üretim işletmesinde uygulama. *Adnan Menderes University, Journal of Institute of Social Sciences,*4 (1), 42-56.

Çakır, S., & Perçin, S. (2013). Çok kriterli karar verme teknikleriyle lojistik firmalarında performans ölçümü. *Ege Akademik Bakış,* 13(4), 449-459.

Çatı, K., Eş, A., & Özevin, O. (2017). Futbol takımlarının finansal ve sportif etkinliklerinin Entropi ve Topsis yöntemiyle analiz edilmesi: Avrupa'nın 5 büyük ligi ve süper lig üzerine bir uygulama. *Uluslararası Yönetim İktisat ve İşletme Dergisi,*13 (1),199-222.

Declaration of Council of Ministers. (2018). Decree on Earthquake Hazard Map of Turkey and Parameter Values. *Official Gazette of the Republic of Turkey,* 30364, 18 Mar. (in Turkish).

Dodgson, C. L. (1876). *Method of taking votes on more than two issues.* Oxford: Clarendon Press.

Edwards, W., & Barron, F. H. (1994). SMARTS and SMARTER: Improved simple methods for multi attribute utility measurement. *Organizational Behavior and Human Decision Processes, 60,* 306–325.

Eray, E. (2015). İnşaat sektöründe tedarikçi seçiminde kullanılan çok amaçlı karar destek yöntemlerinin karşılaştırılması (Yüksek Lisans tezi). İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul.

Ertuğrul, İ., & Karakaşoğlu, N. (2008). Banka şube performanslarının VIKOR yöntemi ile değerlendirilmesi. *Endüstri Mühendisliği Dergisi, 20* (1), 19-28.

Ertuğrul, İ., & Özçil, A. (2014). Çok kriterli karar vermede TOPSIS ve VIKOR yöntemleriyle klima seçimi, *Çankırı Karatekin Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 4*(1), 267-282.

Fishburn, P.C. (1967). Letter to the editor-additive utilities with incomplete product sets: application to priorities and assignments. *Operations Research, 15*(3), 537-542.

Hassan, O. (2009). *Building acoustics and vibration: Theory and practice.* Singapore: World Scientific Publishing.

Hwang, C.L., Lai, Y.J., & Liu, T.Y. (1993). A new approach for multiple objective decision making. *Computers and Operational Research, 20* (8), 889–899

Hwang, C.-L., & Lin. M.-J. (1987). *Group decision making under multiple criteria: methods and applications.* Berlin Heidelberg: Springer-Verlag.

Hwang, C. -L., & Yoon, K. (1981). *Multiple attribute decision-making methods and applications: A state of the art survey.* Springer-Verlag: New York.

ISO International Organization for Standardization. (2010). *Acoustics-Laboratory measurement of sound insulation of building elements - Part 5: Requirements for test facilities and equipment* (ISO 10140-5:2010).

INSUL sound insulation prediction software (http://www.insul.co.nz/).

Ishizaka, A., & Nemery, P. (2013). *Multi-criteria decision analysis: Methods and software,* New York: Wiley.

İlter, E. (2016). Gerçek boyutlu cam panel cephe sisteminin uzun dönem taşıyıcılık ve sızdırmazlık performansının değerlendirilmesi (Doktora tezi). İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul.

Karakış, E. (2016). Bankaların ticari kredi verme davranışlarının bulanık mantık TOPSIS ve bulanık analitik hiyerarşi süreci ile incelenmesi (Doktora tezi). Cumhuriyet Üniversitesi, Sosyal Bilimler Enstitüsü, Sivas.

Keeney, R.L., & Raiffa, H. (1976). *Decision making with multiple objec-*

tives preferences and value tradeoffs. New York: Wiley.

KPMG Türkiye (2018). Sektörel Bakış – İnşaat [pdf]. Retrieved Mar 9, 2019 from: https://assets.kpmg/content/dam/kpmg/tr/pdf/2018/01/sektorel-bakis-2018-insaat.pdf

Kuru, A. (2011). Entegre yönetim sistemlerinde çok kriterli karar verme tekniklerinin kullanımına yönelik yaklaşımlar ve uygulamaları (Doktora tezi). T.C. Marmara Üniversitesi, Sosyal Bilimler Enstitüsü, İstanbul.

Lamboray, C. (2007). A comparison between the prudent order and the ranking obtained with Borda's, Copeland's, Slater's and Kemeny's rules, *Mathematical Social Sciences, 54*(1),1-16.

MacCrimmon, K. R., & Rand, C. (1968). *Decision making among multiple-attribute alternatives: A survey and consolidated approach.* Santa Monica, California: Rand Corp.

Malczewski, J., & Rinner, C. (2015). *Multicriteria decision analysis in geographic information science,* Berlin Heidelberg: Springer-Verlag.

Mehta, M., Johnson, J., & Rocafort, J. (1999). *Architectural acoustics: Principles and design.* USA: Prentice Hall.

MoEU Ministry of Environment and Urbanization. (2017). Detailed analysis of construction unit prices [Website]. Retrieved Jan 15, 2018 from: https://birimfiyat.csb.gov.tr/

Mohammadi Dehcheshmeh, A. (2018). Country risk assessment by applying multi-criteria decision-making methods: a case study ranking countries in the Middle East & North Africa (Master thesis). T.C Istanbul Aydın University, Institute of Social Sciences, Istanbul.

Nanson, E. J. (1907). *Methods of elections.* UK: British Government.

Opricovic, S. (1998). *Multicriteria optimization of civil engineering systems* (in Serbian), 302, Belgrade: Faculty of Civil Engineering.

Ömürbek, N., Makas, Y., & Ömürbek, V. (2015). AHP ve TOPSIS yöntemleri ile kurumsal proje yönetim yazılımı seçimi. *Süleyman Demirel Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 1*(21), 59-83.

Özkan, Ö. (2007). Personel seçiminde karar verme yöntemlerinin incelenmesi: AHP, ELECTRE ve TOPSIS örneği (Yüksek Lisans tezi). Dokuz Eylül Üniversitesi, Sosyal Bilimler Enstitüsü, İzmir.

Öztel, A. (2016). Çok kriterli karar verme yöntemi seçiminde yeni bir yaklaşım (Doktora tezi). Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara.

Öztürk, B. (2011). Çok kriterli karar verme tekniklerinden bulanık TOPSIS ve bulanık analitik hiyerarşi süreci (Doktora tezi). Uludağ Üniversitesi, Sosyal Bilimler Enstitüsü, Bursa.

Pekkaya, M., & Aktoğan, M. (2014). Dizüstü bilgisayar seçimi: DEA, TOPSIS ve VIKOR ile karşılaştırmalı bir analiz. *Ekonomik ve Sosyal Araştırmalar Dergisi, 10* (1), 107-125.

Rasiulis, R., Ustinovichius, L., Migilinskas, D., Cepurnaite, J., & Virbickas, A. (2016). Energy efficiency of a public building renovation and reconstruction using base model passive house and BIM technology. *Engineering Structures and Technologies, 7*(3), 114-125.

Regulation on fire protection in buildings. (2007). *Official Gazette of the Republic of Turkey*, 26735, 19 Dec. (in Turkish).

Regulation on protection of buildings against noise. (2017). *Official Gazette of the Republic of Turkey*, 30080, 31 May. (in Turkish).

Roy, B. (1968). Classement et choix en présence de points de vue multiples (la méthode ELECTRE). *La Revue d'Informatique et de Recherche Opérationelle (RIRO),8*, 57–75.

Saari, D., & Merlin, V. (1996). The Copeland method. I. relationships and the dictionary, J*ournal of Economic Theory, 8*, 51–76.

Saaty, T. L. (1988). What is the analytic hierarchy process? In Mitra, G., Greenberg, H.J., Lootsma, F.A., Rijckaert, M.J. & Zimmermann, H.J. (Eds.), *Mathematical models for decision support, 48,* 109–121. Berlin Heidelberg: Springer.

Saaty, T. L. (1996). Decision making with dependence and feedback: The analytic network process: *The organization and prioritization of complexity*. Pittsburgh: RWS Publications.

Saldanlı, A., & Sırma, İ. (2014). TOPSIS yönteminin finansal performans göstergesi olarak kullanılabilirliği.

Marmara Üniversitesi Öneri Dergisi, 11(41),185-202.

Sanjay, M.R., Jawaid, M., Naidu, N.V.R., & Yogesha, B. (2019). TOPSIS method for selection of best composite laminate, In *Modelling of damage processes in biocomposites, fibre-reinforced composites and hybrid composites,* 199-209, US: Woodhead Publishing.

Štreimikienė, D., & Baležentis, A. (2013). Integrated sustainability index: the case study of Lithuania, *Intelektinė Ekonomika, 7* (3), 289-303.

Sugiartawan, P.& Hartati, S. (2018). Group decision support system to selection tourism object in bali using analytic hierarchy process (AHP) and Copeland score model. *3rd International Conference on Informatics and Computing (ICIC),* Palembang, Indonesia, October 17-18.

Supçiller, A. A., & Deligöz, K. (2018). Tedarikçi seçimi probleminin çok kriterli karar verme yöntemleriyle uzlaşık çözümü. *Uluslararası İktisadi ve İdari İncelemeler Dergisi, 18*, 355 – 368.

Tajvidi Asr, E., Hayaty, M., Rafiee, R., Ataie, M., & Jalali, S. E. (2015). Selection of optimum tunnel support system using aggregate ranking of SAW, TOPSIS and LA methods. *International Journal of Applied Operational Research,5* (4), 49-63.

Taylan, O., Bafail, A.O., Abdulaal, R., & Kabli, M.R. (2014). Construction projects selection and risk assessment by fuzzy AHP and Fuzzy TOPSIS methodologies, *Applied Soft Computing, 17,* 105-116.

Tekin, Ö. F., Eşit, M., Kamil B., &Varınca, K. B. (2014). Proposed solutions to environmental concerns in the construction industry: sustainability and green building. *Proceedings of 2nd International Symposium on Environment and Morality,* (651-661). Adıyaman, Turkey, October 24-26.

TGUB Turkish Autoclaved Aerated Concrete Association (http://tgub.org.tr/homeeng).

Thor, J., Ding, S.H., & Kamaruddin, S. (2013). Comparison of multi criteria decision making methods from the maintenance alternative selection perspective. *The International Journal of Engineering And Science (IJES), 2*(6), 27-34.

Toydemir, N., Gürdal, E., & Tanaçan, L. (2000). *Yapı elemanı tasarımında malzeme,* 158. İstanbul: Literatür Yayıncılık.

Triantaphyllou, E. (2000). *Multi-Criteria decision-making methods: a comparative study*. US:Springer.

Tscheikner-Gratl, F., Egger, P., Rauch, W., & Kleidorfer, M. (2017). Comparison of multi-criteria decision support methods for integrated rehabilitation prioritization. *Water, 9*, 68.

TUIK State Institute of Statistics Prime Ministry Republic of Turkey. (2001). Building Census 2000. 24-464, Ankara: State Institute of Statistics Printing Division.

Tupenaite, L. (2010). Multiple criteria assessments of the built and human environment renovation projects (Ph.D. thesis). Vilnius Gediminas Technical University, Technological Sciences, Vilnius.

Velasquez, M., & Hester, P.T. (2013). An analysis of multi-criteria decision making methods, *International Journal of Operations Research, 10* (2), 56 66.

Yazdani-Chamzini, A., Fouladgar, M., Zavadskas, E. K., & Moini, S. H. (2013). Selecting the optimal renewable energy using multi criteria decision making. *Journal of Business Economics and Management, 14* (5), 957-978.

Yıldırım, B.F., & Önder, E. (Eds.). (2015). *Operasyonel, yönetsel ve stratejik problemlerin çözümünde çok kriterli karar verme yöntemleri,* Türkiye: Dora Basım Yayın Dağıtım.

Yoon, K. (1987). A reconciliation among discrete compromise situations. *Journal of Operational Research Society, 38* (3), 277–286.

Zavadskas, E. K., & Antucheviciene, J. (2007). Multiple criteria evaluation of rural building's regeneration alternatives. *Building and Environment, 42,* 436–451.

Zavadskas, E. K., & Turskis, Z. (2010). A new additive ratio assessment (ARAS) method in multicriteria decision-making. T*echnological and Economic Development of Economy, 16* (2), 159–172.

1000minds Ltd. (2017). What is MCDM / MCDA? [Website]. Retrieved May 10, 2017 from: https://www.1000minds.com/sectors/academic/mcdm