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Multiple Attribute Decision-Making Methods Helps in Logically Selection of Concrete Masonry Units

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Abstract: *Concrete Masonry Unit (CMU) is one of the most important building materials used in the construction of walls in place of traditional clay bricks. These CMU are available in various sizes, shapes, and specifications with minor changes. Crushing strength, water absorption, rates, fire-resistant, and many other properties are very important, which are kept in mind while selecting CMU. Engineers, architects, contractors, and owners face problems in making the right choice of CMU so that the quality and economy can be maintained in work. The wrong choice of CMU may lead to bad quality and high cost of the work. Multiple Attribute Decision Making (MADM) methods have been used in many fields of engineering for making the best choice among the available alternatives with minor variations. This paper demonstrates the use of the Simple Additive Weighting (SAW) method, Weighted Product Method (WPM), Analytic Hierarchy Process (AHP), and its version and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in a combination of AHP in the selection of CMU. It is established in this study that these methods are logical and simple in use, rank the alternatives similarly, and can be used successfully for the best choice of CMU.*

Keywords: *Concrete Masonry Unit, Compressive strength, Porosity, Fire rating, Decision-making methods, SAW, WPM, AHP, TOPSIS.*

I. INTRODUCTION

New technologies are evolving without pause, and their application in manufacturing, construction, transportation, medical, irrigation, etc., brings new products with minor and major variations in specifications, materials, colors, aesthetics, etc. Markets are full of varieties of products of all the fields of engineering as well as non-engineering. It becomes very difficult to make the choice of best from the number of alternatives available with very close attributes. Such a situation leads to multiple decision-making problems when one alternative is selected from more than two alternatives with more than two attributes [1]. Many methods with high precision, such as artificial neural network (ANN), fuzzy algorithm, genetic algorithm (GA), goal programming approaches, etc., are available, but these are complicated and require much knowledge.

The construction field is very vast and important because all people of the world require a home first to dwell, all infrastructures like bridges, tunnels, dams, roads, ports, airports, railways, canals, etc. are necessary for the development of the nation at the same time all industries require some buildings or sheds before installation of machines. Different materials such as cement, brick, steel, stone, paints, lime, glass, concrete masonry units (CMU), etc., are required in all kinds of construction, and many varieties of each material are available with different brands, specifications, cost, and qualities. Civil engineers or contractors face problems in making the best choice from the available alternatives of required materials to maintain the economy and best quality in their work. Any kind of mistake in the selection of the best material may lead to high cost and poor quality in the construction. This needs some easy and logically scientific methods or techniques which may help in making the best selection from the available choices.

Many researchers developed various techniques to solve multiple decision-making problems in which available alternatives are ranked in descending order for their choice, so the selector decides his priority according to his circumstances. TOPSIS method demonstrated by Jee and Kang (2000) [2] for material selection involves lengthy calculations if a number of alternatives and attributes are more [3]. Karsak (2002) used distance-based fuzzy theory in a multiple-criteria decision-making method [4.] The fuzzy approach presented by Karsak and Kuzgunkaya (2002) [5] is difficult due to weights representation, fuzzy distribution, and involvement of mathematical equations [6]. Yardakul (2004) [7] used AHP in the selection of machine tools. Many researchers used various approaches of NADM in the selection of ideal flexible manufacturing systems [7]- [12]. Many studies report the use of the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) approach for the selection of optimal objectives in various

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fields [13]. Rao and Patel (2009) [14] demonstrated the improved PROMETHEE in the manufacturing environment. Albayrakoglu (1996) [15] used AHP to justify a new manufacturing technique by proposing a strategic approach. Bayazit (2005) [16] implemented AHP for designing a flexible manufacturing system in a tractor plant. Rao and Padmanabhan (2007) [17] used graph theory and matrix method for the selection of rapid prototyping process. Literature related to MADM shows that the TOPSIS and AHP are the widely used approaches selection of the best alternative from the available choices [18].

Presently buildings are being designed with concrete masonry units (also known as concrete blocks) by design engineers and architects due to high structural capacity. There are many other advantages of CMU when compared to traditional clay bricks are resistance to water, resistance to fire, durability, acoustical advantage, speedy construction, and minimum maintenance. Concrete blocks are the product of cast concrete, e.g., Portland aggregate and cement. Usually, high-density blocks are made from sand and fine gravel. Industrial wastes are generally used as an aggregate for lower-density blocks. Compressive Strength (CS), Water Absorption (WA), Cost (C), Weight (Wt.), and Fire Resistance (FR) are very important parameters or attributes \

that is generally considered while selecting CMU. These parameters change swiftly with a small variation in the quality of materials and composition of ingredients used in the manufacturing of CMU. Many varieties of CMU are available in ever-evolving markets of construction with small variations in the specifications of CMU. Architects, engineers, and contractors engaged in the field of construction face a great challenge in making the right choice of CMU among the available options to meet the highest quality and reasonable cost of the construction.

Literature shows that the MADM methods have not been used in the field of construction for the selection of materials. Even though a large scope for the use of these methods is seen in the selection of construction materials. These methods may also be used in other fields of civil engineering such as water supply, irrigation, surveying, geology, etc. Hence, this study is an attempt to implement MADM methods for the selection of beneficial CMU from the available alternatives with a small change in their attributes. The assigned values of attributes are, for example.

II. MADAM AND METHODOLOGY

A. Normalization of Data

Generally, along with subjective values, the objective values have different units; hence normalization of objectives values is required to the same scale of the subjective values.

B. Value of Attribute

The attribute value Ri of alternatives may be found either from measurement and estimation or from available data. The attribute values may be objective or subjective data. The subjective measures are valued ranked between 0-1 as given in Table 1 [1].

TABLE 1. VALUE OF ATTRIBUTE

A subjective measure of attribute	Assigned value
Exceptionally low	0.0
Extremely low	0.1
Very low	0.2
Low	0.3
Below average	0.4
Average	0.5
Above average	0.6
High	0.7
Very High	0.8
Extremely high	0.9
Exceptionally high	1.0

The normalized value Ri is determined by Rii/ Riu when the attributes are beneficial, i.e., the higher value of the attribute is desirable, while in the case of the non-beneficial attribute, the normalized value Ri is determined by Ril/ Rii, i.e., the lower value of the attribute is desirable.

Where Rii is the intermediate attribute value, Riu is the highest attribute value, and Ril is the lower attribute value.

The relative importance is also assigned to an attribute (rij) for the given problem on a scale between 0-1. If the relative importance value is assigned for the ith attribute as 0.3 and compared with the jth attribute, then the relative importance value of the jth attribute will be 0.7 (rji = 1- rij). The relative importance values can be assigned to the attributes according to six points suggested in Table 2. The scale range may be 1-10, 0-50, 0-100, 1-1000, etc., for obtaining a performance selection index. The highest value of the selection index of the alternative is considered the top choice for the purpose.

TABLE 2. RELATIVE IMPORTANCE OF ATTRIBUTES

Class description	Relative importance rij	rji = 1- rij
Two attributes are equally important	0.5	0.5
One attribute is slightly more important over the other	0.6	0.4
One attribute is strongly more important over the other	0.7	0.3
One attribute is very strongly more important over the other	0.8	0.2
One attribute is extremely important over the other	0.9	0.1
One attribute is exceptionally more important over the other	1.0	0.0

Simple Additive Weighting (SAW), Weighted Product Method (WPM), Analytical Hierarchy Process (AHP), Version of AHP, and TOPSIS method, these five methods of decision making are demonstrated in this study to understand the applicability of MADM methods for selection of best choice of CMU from the available alternatives with multiple characteristics of CMW.

a) Simple Additive Weighting (SAW) Method

SAW method is widely used in decision-making problems because it involves fewer and simple calculations. It is also known as the weighted sum method[19]. SAW method can be applied for any number of attributes of the objective or subjective type after normalizing the data of the decision table.

The weight for the individual attribute is assigned according to the method demonstrated by Edwards et al. (1982) [20]. First, assign 10 points to the attribute of least importance, and then more than 10 points are assigned to the next least important attribute and so on. Points are assigned according to the relative importance of the attributes. Final weights are calculated by normalizing these points

By dividing points of the individual attribute by the sum of all points so that the sum of all weights is 1.

The assessment of each alternative, considering all attributes, is carried out, and the overall performance index (Pi) of each alternative is calculated using Equation 1.

$$Pi = \sum_{j=1}^{M} w_j \, (r_{ij})_{normal} \qquad (1)$$

Where Pi is the overall performance index of the alternative, $(rij)_{normal}$ is the normalized value of rij of the alternative Ai. All Pi values are arranged in descending order, and the alternative with the highest value of Pi is designated as the best or first choice. Second, third, and fourth, etc., choices are designated corresponding to descend values of Pi.

b) Weighted Product Method (WPM)

In this method, the calculation of weights after assessment of relative importance of attribute is similar to the SAW method. All normalized values of alternatives with respect to corresponding attributes are raised to the power of the relative weights of the corresponding attribute. The resulting overall performance index (Pi) of an alternative is calculated by multiplying the performance of each attribute of that alternative using Equation 2.

$$\mathrm{Pi} = \prod_{j=1}^{M} \left[(r_{ij})_{normal} \right]^{wj} \qquad (2)$$

The composite Pi values of all alternatives are arranged in descending order. The alternative with the highest Pi value is taken as the first or best choice, and the second, third and fourth choices of alternatives are reported according to descending order of Pi values.

c) Analytical Hierarchy Process (AHP) method

AHP method performs very well when attributes are objective as well as subjective, even when subjective attributes playing an important role in selection.

Relative importance between attributes in AHP

A method proposed by Satty (2000) [21] of assigning relative importance values between two attributes rij as

1. A pair-wise comparison matrix is constructed on the basis of a relative importance scale. Assign always value 1 to the attribute which is compared to own. Hence all diagonal values are 1 in the pair-wise comparison matrix. Assign values for diagonal attributes such as 3, 5, 7, or 9 as per the judgments such as moderately important, strongly important, very strongly important, or absolutely important, respectively, and 2, 4, 6, and 8 for compromise between previous values. Off-diagonal values in the pair-wise comparison matrix are a pair-wise comparison of attribute i with j; when the total number of attributes are M, then a square matrix $A1_{(MXM)}$ is formed, in which r_{ij} shows the comparative importance of attribute i over attribute j. In matrix A1, $r_{ij} = 1$ and $r_{ji} = 1/rij$, when i = j).

$$
\begin{array}{c c}
 & \begin{array}{ccccccc} \textbf{Attribute } 1 & 2 & 3 & - & - & - & M \end{array} \\
A1_{MxM} = & \begin{array}{c} 1 \\ 2 \\ 3 \\ - \\ - \\ M \end{array}
\left[\begin{array}{cccccccc}
1 & r_{12} & r_{13} & - & - & - & r_{1M} \\
r_{21} & 1 & r_{23} & - & - & - & r_{2M} \\
r_{31} & r_{32} & 1 & - & - & - & r_{3M} \\
- & - & - & - & - & - & - \\
- & - & - & - & - & - & - \\
r_{M1} & r_{M2} & - & - & - & - & 1
\end{array} \right]_{MxM}
\end{array}
$$

2. Now, to check the judgment consistency, the relative normalized weight (wj) of each attribute is found by calculating the first geometric mean of i^{th} row and then normalizing the geometric means of rows in the matrix A1 as expressed by 3 and 4.

$$\mathrm{GMj} = \left[\prod_{j=1}^{M} r_{ij} \right]^{1/M} \qquad (3)$$

$$\mathrm{wj} = \frac{\mathrm{GMj}}{\sum_{j=1}^{M} \mathrm{GMj}} \qquad (4)$$

Matrix of all weights such as $[w_1, w_2, w_3, ...]^T$ is known as matrix A2. This method is easy for finding relative normalized weights and maximum Eigenvalue and to minimize the judgment inconsistency.

3. Matrices A3 and A4 are found as `
   A3 = A1 X A2 and A4 = A3/A2
4. Find Eigenvalue λmax, which is the average of A4.
5. Find Consistency Index CI as
   CI = (λmax - M) / (M - 1)

The smaller value of CI indicates the smaller deviation from consistency; hence CI should be as low as possible.

6. Random Index (RI) is taken from Table 3 for the number of attributes considered in the decision-making problem [17].
7. Determine the Consistency Ratio (CR) = CI / RI. CR value of 0.1 or less indicates appropriate judgment of relative importance and is acceptable.
8. Now the final performance of each alternative is calculated by multiplying the normalized weight (w_j) of each attribute with its corresponding value in a normalized data table.
9. Calculate the sum of all attributes of each alternative to obtain the CMU performance index (Pi) and arrange it in descending order. The highest value is considered the first choice, and the second, third, fourth, etc., choices are according to descending order.

TABLE 3. RANDOM INDEX (RI) VALUES

Attribute	RI
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

d) Multiplicative Analytical Hierarchy process (MAHP) method

This method was proposed by Barzilai and Lootsma (1994) [22] as a version of the AHP method. The normalized value of all attributes for each alternative is raised to the power of the relative normalized weight (w_j) of each attribute obtained in step 2 of the AHP method and multiplied all attributes of all alternatives as done in the WPM method.

e) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method

Hwang and Yoon (1981) developed this method to obtain the solution which remains closest and farthest to the imaginary best and worst solutions, respectively. The TOPSIS process is described in the following steps

Step 1. Obtain the normalized decision matrix Rij, based on Equation 5 from initially normalized data of attributes.

$$R_{ij} = \frac{m_{ij}}{\left[\sum_{j=1}^{M} m_{ij}^2\right]^{\frac{1}{2}}} \quad (5)$$

Step 2. Decide the weights w_j (for j=1,2,3...) based on relative importance of attributes with the condition that $\sum w_j = 1$.

Step 3. Obtain the weighted normalized matrix E_{ij} by multiplying all elements of each column by weight wj of the respective column as below 6.

$$E_{ij} = w_j \, R_{ij} \quad (6)$$

Step 4. Ideal (best) E_j^+ and negative ideal best E_j^- are obtained.

E_j^+ means the ideal (best) value, which is the highest of all values of a considered attribute for all alternatives, while the attribute is beneficial (i.e., the attribute of which the highest value is desired). If the attribute is non-beneficial (the attribute of which the lowest value is desired), then the lowest value is taken as E_j^+.

E_j^- means the negative ideal (worst) value which is the lowest of all values of a considered attribute for all alternatives, while the attribute is beneficial. If the attribute is non-beneficial, then the highest value is taken as E_j^-.

Step 5. Obtain the separation measures F_i^+ and F_i^- of each alternative as per Equation 7 and 8 below from the ideal one obtained in step 4 above.

$$F_i^+ = \left[\sum_{j=1}^{M} \left(E_{ij} - E_j^+\right)^2\right]^{0.5} \quad i = 1, 2, \ldots n \quad (7)$$

$$F_i^- = \left[\sum_{j=1}^{M} \left(E_{ij} - E_j^-\right)^2\right]^{0.5}, \quad i = 1, 2, \ldots n \quad (8)$$

Step 6. Obtain the performance index (Pi) for each alternative as per Equation 9 below

$$Pi = F_i^- / (F_i^+ - F_i^-) \quad (9)$$

Step 7. Arrange all the performance index values (Pi) in descending order, and the highest value will be the first or best choice. The second, third, and other choices will be the other descending values of Pi, respectively.

III. EXAMPLE

Here an example of a selection of CMU is taken to demonstrate the implementation of MADM such as Simple Additive Weighted (SAW), Weighted Product Method (WPM), Analytical Hierarchy Process (AHP), and its version, and TOPSIS methods to check their performance or applicability in the selection of CMU. There are 5 alternatives of CMU and 5 common attributes of each CMU, as shown in Table 4. All the attributes are quantitative data.

TABLE 4. QUANTITATIVE DATA OF ATTRIBUTES OF EXAMPLE

Alternative CMU	Compressive Strength Kg/cm^2 (CS)	Fire Resistance Hours (FR)	Water Absorption % (WA)	Weight Kg (Wt)	Cost Rs (C)
1	410.0	2.5	11	23.0	36.0
2	400.0	2.0	12	22.0	35.0
3	415.0	2.5	9	24.0	38.0
4	390.0	2.5	12	21.0	32.0
5	395.0	3.0	11	23.0	31.0

The applicability of these five methods is explained in the following steps below.

Step 1. Five quantitative attributes, namely Compressive Strength (CS), Water Absorption (WA), Cost (C), Weight (Wt.), and Fire Resistance (FR), of all 5 alternatives are considered in the decision-making problem. Crushing strength (CS) and Fire Resistance (FR) beneficial attribute, i.e., higher values are desired for durability and safety of work, while Water Absorption (WA), Cost (C), Weight (Wt.) are non-beneficial attributes, i.e., their lower values are desired for good quality and economy of work respectively.

Step 2. The units of all five attributes are different hence the values are normalized to bring them on same scale between 0-1. Normalization is carried out for beneficial attributes by dividing all values by highest value, and for non-beneficial attributes, all values are divided by the lowest value as discussed above in methodology. Normalized attribute values are shown in Table 5.

TABLE 5. NORMALIZED DATA

Alternative CMU	Compressive Strength Kg/cm^2 (CS)	Fire Resistance Hours (FR)	Water Absorption % (WA)	Weight Kg (Wt)	Cost Rs (C)
1	0.9879	0.8333	0.8181	0.9130	0.8611
2	0.9638	0.6666	0.7500	0.9545	0.8857
3	1.0000	0.8333e	1.0000	0.8750	0.8157
4	0.9307	0.8333	0.7500	1.0000	0.9687
5	0.9518	1.0000	0.8181	0.9130	1.0000

A. Simple Additive Weighting (SAW)

Step 3. Weight Calculation for each attribute is carried out by assigning 10 points to the least important attribute weight (W), 20 points are assigned to the next least important attribute, fire resistance (FR), 25 points are assigned to water absorption (WA), 30 points are assigned to cost (C) and 50 points are assigned to most important attribute crushing strength (CS). Now, these points separately are divided by the sum of all these points to obtain the relative weight of each attribute as discussed in the methodology part of this method above. The calculation of relative weights is shown in Table 6 below.

Step 4. Weights w_{wt}, w_{fr}, w_{wa}, $w_{c,}$ and w_{cs} are now operated on normalized data of attributes in Table 5 for different alternatives of CMU, as explained in

methodology part of obtaining the performance index of the SAW method. The values of the performance index (Pi) are arranged in descending order and ranked I-V, as shown in Table 7.

TABLE 6. CALCULATION OF WEIGHTS

Attributes in ascending order of importance	Assigned Points
Weight (Wt)	10
Fire Resistance (FR)	20
Water Absorption (WA)	25
Cost (C)	30
Compressive Strength (CS)	50
Total	135
	Weights
Weight (w_{wt})	(10/135) = 0.0740
Fire Resistance (w_{fr})	(20/135) = 0.1481
Water Absorption (w_{wa})	(25/135) = 0.8151
Cost (w_c)	(30/135) = 0.2222
Compressive Strength (w_{cs})	(50/135) = 0.3703

TABLE 7. DETERMINATION OF CMU PERFORMANCE INDEX (SAW METHOD)

Alternatives of CMU	CS	FR	WA	Wt.	Cost	Index	Rank
1	0.3703	0.1234	0.1514	0.0675	0.1917	0.8998	III
2	0.3568	0.0987	0.1388	0.0706	0.1968	0.8617	V
3	0.3703	0.1234	0.1851	0.0647	0.1812	0.9247	II
4	0.3479	0.1234	0.1388	0.0740	0.2152	0.8993	IV
5	0.3524	0.1481	0.1514	0.0675	0.2222	0.9416	I

Order of ranks of all alternatives shows choices are in order as 5-3-1-4-2. This order indicates that the CMU designated as five is the best choice while the CMU designated as two is the last choice.

B. Weighted Product Method (WPM)

Steps 1-3 explained in the SAW method are the same in this method.

Step 4. Weights w_{wt}, w_{fr}, w_{wa}, $w_{c,}$ and w_{cs} are now operated on normalized data of attributes for different alternatives as discussed in the methodology part of this method to obtain the overall performance index of CMU as shown in Table 8.

TABLE 8. DETERMINATION OF CMU PERFORMANCE INDEX (WPM METHOD)

Alternatives of CMU	CS	FR	WA	Wt.	Cost	Index	Rank
1	0.9955	0.9733	0.9635	0.9932	0.9673	4.8928	III
2	0.9864	0.9417	0.9481	0.9965	0.9733	4.8460	V
3	1.0000	0.933	1.0000	0.9901	0.9557	4.9191	II
4	0.9772	0.9733	0.9481	1.0000	0.9929	4.8915	IV
5	0.9818	1.0000	0.9635	0.9932	1.0000	4.9385	I

The above values of the composite performance index (Pi) of all alternatives are arranged in descending order. The highest value of Pi is ranked first, and the lowest value of Pi is ranked last, and other values in between highest and lowest are ranked corresponding to their position in the order, and the final order of ranks is obtained as 5-3-1-4-2. These ranks indicate that CMU designated as five is the first choice, and the CMU designated as 2 is the last or fifth choice. So, the WPM method gives the same order as obtained by the SAW method.

C. Analytical Hierarchy Process (AHP)

Steps 1 and 2 discussed in the SAW method above are the same in this method.

Step 3. A pair-wise comparison matrix is formed by assigning the relative importance of attributes (r_{ij}) as explained in the methodology part of this method. Attribute Crushing Strength (CS) is considered more important than the attribute Fire Resistance (FR) in CMU selection; hence relative importance value of 2 is assigned to CS over FR (i.e., r_{12} = 2), and a relative importance value of 1/2 is assigned to FR over CS (i.e., r_{21} = 1/2). Again Crushing strength (CS) is considered more important than Water Absorption (WA); hence the relative importance value of 1.5 is assigned to WA (i.e., r_{13} = 1.5), and the relative importance value of 1/1.5 is assigned to FR over CS (i.e., r_{31} = 1/1.5). Similarly, relative importance values are assigned among other attributes, as shown in the pair-wise comparison matrix. This assignment of relative importance largely depends on the experience and requirement of the expert. In this decision-making problem, Fire Resistance (FA) has been considered less important to Water Absorption (WA), but some other experts may consider WA less important than FR, so results will be different. Now the relative importance weights for each attribute are calculated as explained in the methodology part of this method.

Step 4. Now Matrix A2, A3, and A4 are found from pairwise matrix as below

Pair-wise matrix

$$A1_{5x5} = \begin{array}{c} \\ CS \\ FR \\ WA \\ Wt \\ C \end{array} \begin{array}{c} \begin{array}{ccccc} CS & FR & WA & Wt & C \end{array} \\ \begin{bmatrix} 1 & 2 & 1.5 & 3 & 1.5 \\ 1/2 & 1 & 1/2 & 1.5 & 1/1.5 \\ 1/1.5 & 2 & 1 & 2 & 1/3 \\ 1/3 & 1/1.5 & 1/2 & 1 & 1/3 \\ 1/1.5 & 1.5 & 3 & 3 & 1 \end{bmatrix} \end{array}$$

$$\Downarrow$$

$$\begin{bmatrix} 13.5000 \\ 00.2500 \\ 00.8888 \\ 00.0370 \\ 09.0000 \end{bmatrix} \xrightarrow{1/5} \begin{bmatrix} 1.6829 \\ 0.7578 \\ 0.9720 \\ 0.5171 \\ 0.5537 \end{bmatrix}$$

Relative normalized weights

$$A2 = \begin{bmatrix} 0.3046 \\ 0.1371 \\ 0.1751 \\ 0.0936 \\ 0.2812 \end{bmatrix} \quad A3 = A1xA2 = \begin{bmatrix} 1.5452 \\ 0.7051 \\ 0.9340 \\ 0.4681 \\ 1.4983 \end{bmatrix} \quad A4 = A3/A2 = \begin{bmatrix} 5.0700 \\ 5.1429 \\ 5.3098 \\ 5.0010 \\ 5.3282 \end{bmatrix}$$

Eigenvalue λmax (average of matrix A4) is found 5.1703. CI is calculated as 0.038. Taking RI = 1.11 from Table III for five attributes, CR = 0.0017, which is very less than the permissible CR value of 0.1. Thus, consistency exists in assigning the relative importance values among the attributes.

Step 5. The relative normalized weights (w_{cs} = 0.3046, w_{fr} = 0.1371, w_{wa} = 0.1759, w_{wt} = 0.0936 , w_c = 0.2812) in matrix A2 are operated by multiplying these weights to corresponding normalized attributes of all alternatives in Table 2. The Performance index (Pi) of all alternatives is calculated as shown in Table 9.

TABLE 9. DETERMINATION OF CMU PERFORMANCE INDEX (AHP METHOD)

Alternatives of CMU	CS	FR	WA	Wt.	Cost	Index	Rank
1	0.3009	0.1142	0.1439	0.0854	0.2421	0.8865	IV
2	0.2935	0.0913	0.1319	0.0893	0.2490	0.8551	V
3	0.3046	0.1142	0.1759	0.0819	0.2293	0.9059	II
4	0.2862	0.1142	0.1319	0.0936	0.2723	0.8982	III
5	0.2899	0.1371	0.1439	0.0854	0.2812	0.9375	I

The Pi values of all alternatives are arranged in descending order, and rank I is assigned to the highest value of Pi, while rank V is assigned to the lowest value of Pi, and other ranks are assigned according to the descending values of Pi. Thus the order of ranks is decided as 5-3-4-1-2. Hence the brick designated as 5 is the first choice, and the brick designated as 2 is the last or fifth choice.

D. Multiplicative Analytical Hierarchy process (MAHP) method (Version of AHP)

In this method, the relative weights (w_{cs} = 0.3046, w_{fr} = 0.1371, w_{wa} = 0.1759, w_{wt} = 0.0936 , w_c = 0.2812) calculated in AHP method have been used and operated on normalized data of Table 5 as operated in WPM method and discussed above in methodology part of this method. Estimated values of composite performance index (Pi) are shown in Table 10.

TABLE 10. DETERMINATION OF CMU PERFORMANCE INDEX (AHP VERSION)

Alternatives of CMU	CS	FR	WA	Wt.	Cost	Index	Rank
1	0.9962	0.9753	0.9653	0.9915	0.9588	0.8915	IV
2	0.9888	0.9459	0.9506	0.9956	0.9964	0.8820	V
3	1.0000	0.9753	1.0000	0.9875	0.9443	0.9094	II
4	0.9812	0.9753	0.9506	1.0000	0.9910	0.9015	III
5	0.9850	1.0000	0.9653	0.9915	1.0000	0.9427	I

From the above values of the CMU performance selection index (Pi), it is clear that the CMU designated as 5 is the first or best choice, and the CMU designated as 2 is the last choice. The order of ranking is similar to the order of ranking obtained in the AHP method. This order of ranking may change if the relative preference is changed by the decision-makers.

E. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method

Step 1. The normalized data given in Table 5 are normalized as explained in methodology above normalized matrix R_{5x5} is prepared as shown below:

$$R_{5x5} = \begin{bmatrix} 0.4560 & 0.4437 & 0.4396 & 0.4380 & 0.4237 \\ 0.4448 & 0.3549 & 0.4030 & 0.4579 & 0.4358 \\ 0.4615 & 0.4437 & 0.5373 & 0.4198 & 0.4014 \\ 0.4337 & 0.4437 & 0.4030 & 0.4798 & 0.4767 \\ 0.4393 & 0.5324 & 0.4396 & 0.4380 & 0.4921 \end{bmatrix}$$

Step 2. Relative importance values are assigned to the attributes and relative importance weights (w_{cs} = 0.3046, w_{fr} = 0.1371, w_{wa} = 0.1759, w_{wt} = 0.0936, w_c = 0.2812) are calculated as calculated in AHP method.

Step 3. The weighted normalized matrix, E_{5x5}, is calculated as shown below:

$$E\,I_{5x5} = \begin{bmatrix} 0.1388 & 0.0608 & 0.0773 & 0.0409 & 0.1191 \\ 0.1354 & 0.0486 & 0.0708 & 0.0428 & 0.01225 \\ 0.1405 & 0.0608 & 0.0945 & 0.0392 & 0.1128 \\ 0.1321 & 0.0608 & 0.0708 & 0.0449 & 0.1340 \\ 0.1338 & 0.0729 & 0.0773 & 0.0409 & 0.1388 \end{bmatrix}$$

Step.4 The ideal (best) and negative ideal (worst) values or obtained from the matrix E_{5x5} obtained in step 3 above.

E_{CS}^{+} = 0.1405 E_{CS}^{-} = 0.1321

E_{FR}^{+} = 0.0729 E_{FR}^{-} = 0.0486

E_{WA}^{+} = 0.0708 E_{WA}^{-} = 0.0945

E_{Wt}^{+} = 0.0392 E_{Wt}^{-} = 0.0449

E_{C}^{+} = 0.1125 E_{C}^{-} = 0.1383

Step 5. Now the separation measures are obtained as discussed in the methodology part from ideal (best) and negative ideal (worst) values obtained in step 4, and these are:

F_1^{+} = 0.01542 F_1^{-} = 0.02955

F_2^{+} = 0.16434 F_2^{-} = 0.02875

F_3^{+} = 0.02661 F_3^{-} = 0.03003

F_4^{+} = 0.02667 F_4^{-} = 0.02700

F_5^{+} = 0.02748 F_5^{-} = 0.03008

Step 6. The relative closeness to the ideal solution or performance index (Pi) of each alternative is calculated as explained in methodology of this method and arranged in descending order as below.

P1= 0.08105, P3= 0.7280, P5= 0.7229, P4= 0.7079 and P2= 0.3856

Here it is clear that the alternative designated as 1 is the first choice and alternative designative as 2 is the last choice. The second, third, and fourth choices are alternatives designated as 3, 5, and 4, respectively.

IV. DISCUSSION

MADM methods have been used for the selection of the best alternative from the available choices of various fields of engineering. But their use in the selection of civil engineering material is not found. SAW, WPM, AHP, and version of AHP are very common and simple methods of MADM used frequently. TOPSIS method has also been used in many multi attributes problems. In this study, SAW, WPM, AHP, MAHP, and TOPSIS methods have been used to demonstrate their applicability in the selection of CMU. These methods can be used for any number of alternatives and attributes of objective or subjective nature.

The assignment of the relative importance to the attributes is very important in the use of these methods, and the results may vary in the same problem using the same method. So, the role of decision-makers is important during assigning the relative importance to the attributes. The knowledge and practical experience of decision-makers play key roles in the use of MADM methods. These methods are logical and easy to use for making a reasonable selection. The TOPSIS method involves some long calculations, and these calculations become lengthier when attributes and alternatives are large in number.

V. CONCLUSIONS

This is the era of science and technology. New developments in science bring fast changes in technology that vibrates the machines to manufacture new products in the field of construction, which are superior, durable, aesthetic, and economic. So, the users need some logical and easy methods of best selection from the available alternatives. SAW, WPM, AHP, MAHP, and TOPSIS methods are demonstrated in this study, considering an example of the selection of best CMU from the five alternatives and five common attributes of each alternative. Results were found to show that SAW and WPM methods rank similar choices of alternatives, while AHP and MAHP give the same order of ranks. The first, second, and fifth choices are the same given by the first four methods. TOPSIS method gives the first choice for the first alternative, while the first-choice given by the first four methods is the fifth alternative. The alternative designated as 2 is the last choice obtained by all the methods. These methods can be used for any type of selection in the field of civil engineering.

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