Nepal Journal of Civil Engineering
Volume: 3(1) March 2023 ISSN: 2773-806X

Application Of MCDM: Sorting Out Retrofitting Process in Column of a Residential RC Building

Ravi Thapa [a], Bharat Mandal [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Author(s): [a] 075msdrm013.ravi@pcampus.edu.np, [b] bharat@ioe.edu.np

Received: 2022-01-14 Final Revision: 2022-03-24 Accepted: 2022-03-25

Abstract
Retrofitting is the process of re-strengthening the structure to make it more resilient to withstand the impact of earthquake. It reduces immediate collapse of the structure or building and improves the functional lifespan of the structure. Gorkha Earthquake 2015 took a massive toll in loss of life and property of people leading to disruption of normal lives of the community. Numerous residential RC buildings were partially or completely damaged in the aftermath. Despite enforcing building codes, by-laws and re-strengthening process, people are still reluctant to retrofit their houses. The paper aims to explore the ongoing process of retrofitting and analyze the decision-making process in accordance with the designer and contractor to sort out their preference over the various retrofitting approaches for the column section of RC building through the application of Multi-Criteria Decision Making Process.

Keywords
Retrofitting, Earthquake, Jacketing, MCDM, AHP, TOPSIS

1. Introduction

1.1 Background

Disasters are the disruptive events causing major impact on human lives and properties as well as the normal functioning of the community. It shows us with characteristics of repeated occurrence and taking its toll on people. Disaster risk management is the application of numerous strategies and policies formulated for the purpose of reducing and managing the risk of the disaster. Retrofitting generally refers to the re-strengthening of the structure for safety after the building is incapable of withstand the seismic force. According to National Reconstruction Authority (2017), retrofitting may be strength enhancement or structural system modification or both which helps in uplifting the existing strength of the building Government of Nepal, National Reconstruction Authority (2017). The techniques are generally based on the building typology, type of elements with their connections and level of damage. The process may also vary in terms of available resources, funds and skilled workmanship. The sole objective of retrofitting is to make the building stronger than before to the design level. When the financial condition and level of damage comes into consideration, retrofitting becomes an easy option rather than reconstruction. However, there have been few numbers of RC residential houses recorded as retrofitted after the disastrous impact of Gorkha Earthquake 2015 so there is need for better understanding of retrofitting processes. Some of the retrofitting processes that are applied in RC buildings of Nepal are RC Jacketing, Steel Jacketing, FRP Jacketing and Composite Jacketing.

Multi-criteria for decision making (MCDM) refers to the study of methods and procedures that analyze a specific problem through several competing criteria. Over the years, it has evolved as an important field of operating research, focusing on problems such as: analysis and evaluation of criteria and alternatives, modeling preferences, developing a decision system that identifies the probable solution to the problem. However, various approaches and technologies have been developed in the field of MCDM to deal with decision problems with conflicting criteria in several domains. This study aims to find out if tools like MCDM can help to sort out the ongoing retrofitting processes and provide a basis for selection of effective options for similar future scenarios.

1.2 Objectives

The study focuses on the application of the MCDM method for the optimal selection of retrofit strategies in the case of RC buildings. The objectives of the study are:

1. To determine the usefulness of the MCDM in retrofitting practices.
2. To validate the usage of MCDM to find the suitability of existing retrofitting practices.

2. Literature Review

The inability of a building to resist the seismicity has led to a need for careful analysis in terms of damage and cost. Retrofitting has become a major part providing a solution to the building needing reinforcing against demolition. Retrofitting of the building is considered feasible when the cost is below 30% of the cost of reconstructing that building. Different studies and analysis have been conducted in regard to the feasibility of the retrofitting in Nepal. A study was conducted by Pradhan et al (2016), on the staff quarter block of Kathmandu University which is a residential RC building with plinth area of 1918.07 sq. ft and of 3 storeys on medium soil where after the Gorkha Earthquake (magnitude of 7.6ML) some cracks on walls and joints was observed. The paper described the vulnerability of the structure and the appropriate retrofitting techniques in terms of strength, stability and economy. Concrete Jacketing was applied in columns, FRP Jacketing was applied in beams and columns, Epoxy injection/ grouting was proposed to seal the crack in walls, columns, beams of the structure Pradhan et al. (2016).

The current practice of sorting out effectiveness of the retrofitting options is generally based on the design parameters and level of damage. However, problem and its complexity range in accordance with the scope and the areas that it covers. There may be numerous elements and attributes that sums up the process. Multi criteria decision making process helps the decision maker in solving the problem of finding the best option from all of feasible alternatives. Decision makers have a major role in expressing their preferences of criteria by providing relative weightage and importance. Technique for order performance by similarity to ideal solution (TOPSIS) is one of known classical MCDM methods for solving a MCDM problem based on the concept of shortest distance with the ideal solution. Zeleny (2011), used the TOPSIS method for ratings and weighing of the criteria Zeleny (2011). Also, Mahmoud (2005), used the very approach in solving multi-objective nonlinear programming problems Abo-Sinna and Amer (2005). A method used by Jahanshahloo et al. (2006), is also feasible to solve problems in fuzzy environments where data from the decision maker cannot be referred Jahanshahloo et al. (2006). Kim et al (2005), used a criteria like usability, thermal comfort, indoor environmental quality and surroundings to model evaluation of housing performance of residential buildings using AHP Kim et al. (2005). The AHP (analytic hierarchy process) uses a hierarchical structure and paired comparison. It is a hybrid process taking several factors in consideration combining both inductive and deductive thinking without syllogism. Saaty (1987), elaborates with an example of Finland where the parliament faced a socio technical problem with intangible criteria Saaty (1987). Their problem with choosing which type of power plant to build was based on factors such as the economy, health, safety and environment of the country. Whereas TOPSIS will be applicable for cases with a large number of criteria and alternatives, especially where objective or quantitative data is given. The main advantage of this method is that it is a simple, rational, comprehensive concept, intuitive and clear logic that represents the reason for human choices, the ease of calculation and good computing efficiency.

MCDM has been applied in numerous streams in aim of better decision making. Bradshaw (2011), used OWA aggregators for the MCDM tool to select retrofitting in terms of time duration and workmanship Bradshaw et al. (2011). The study showed how a decision maker's preference altered the selection of retrofitting techniques. Other studies were conducted to analyze the applicability and effectiveness of the MCDM methods. A study conducted by Caterino (2009), compared decision making methods like Weighted sum and product method, ELECTRE, MAUT, PROMETHEE and VIKOR where the strength and weakness of each approach were pointed out Caterino et al. (2009). Another study was conducted on bridges through MCDM where the criteria for decision making phase of sustainable bridges were conducted through the same approach. Also, the distinction between multi objective and multi attribute decision making was listed out by Vicent (2016) Penadés-Plà et al. (2016).

MCDM was also applied by Gilani (2020), to analyze the sustainability of building facades from social, economic and environmental perspectives Gilani et al. (2020). The stakeholders' preferences were considered and the strengths or weaknesses of the facades were identified. The authors concluded its applicability to private and public stakeholders. In order to improve the energy performance of the structure, Indre (2021), used criteria like efficiency, technology, environment, human health and economic goals were analyzed for selection of insulation materials in buildings Siksnelyte-Butkiene et al. (2021). Methods like TOPSIS, COPRAS, WASPAS and VIKOR were used to solve the issues like reconstruction, demolition and life cycle issues of the building. The sector of logistics and transportation, flood management, water supply, groundwater monitoring and waste water management can also be analyzed including stakeholder's interest and satisfaction. Tools like GIS can also be merged with the MCDM for the planning and management phase. According to Edmundas (2015), projects can be benefitted in selection of appropriate technology with the help of those tools Zavadskas et al. (2015).

This paper includes above processes in terms of comparing the elements that are required for the retrofitting process and analyzing the critical factor among them. To use this model, this study uses a set of criteria and tries to build up the relationship between those criteria. This relationship leads towards the preference of the element where the preference is set through working out those elements in matrices through eigenvalue and eigenvectors. The work is based on various literature regarding similar work done in the past, which is used as a base to formulate the scale and weigh in the criteria to sort out the preference. For the planning and resource allocation among the elements, relative priority weights are required as a guideline to structure and decide the decision problem.

3. Research Methodology

This study is a combination of both qualitative and quantitative research where the former approach is used for data collection through surveys, interviews where a structured questionnaire survey will be used to measure the preference of the decision maker regarding the optimum solution for retrofitting process and the later consists of data analysis by changing the linguistic variables into numeric value. The source of data will be through primary and secondary data collection. The options of the questionnaire are based on the ordinal variables due to which there is no scale of measurement between them. i.e., value 2 does not refer to being double than 1. The Post positivist paradigm is adopted for this research study where the qualitative data achieved through survey are converted to quantitative ones for analyzing relevant equations using manual calculation and software like Microsoft Excel. The paradigm allows accepting the experience, knowledge and perception of the researcher and influencing that it can produce. The decision process is made of the steps on the definition of the set of alternatives for the design of the retrofitting, the selection of the evaluation criteria, the relative weighting of the criteria, the evaluation of the alternatives, the application of the chosen MCDM method to classify the alternatives and identify the best retrofit solution. In addition, a consistent measure of DM judgments ensures that there are no intolerable conflicts between them and that the final decision is logical and is not a result of random prioritization. For the MCDM application included in this paper, a group of alternatives are considered for the column section of a RC building. The decision makers are the professionals and the users who have expertise or experience in R.C.C retrofitting and have been directly or indirectly involved in the process. The alternatives which are used for analysis are A1, A2, A3 and A4 where A1 refers to concrete jacketing, A2 indicates steel jacketing, A3 implies FRP jacketing and A4 refers to composite jacketing (FRP and concrete jacketing). The alternatives which are categorized, rely on the basis of retrofitting processes that are being used in Nepal.

The criteria can generally be defined as different points of view from which the same solution can be evaluated. According to Thermou et al (2004), the criteria can be grouped into two categories: economic/social and technical criteria Thermou et al. (2004). Only the criteria that can have a significant influence on the final decision should be considered. The criteria depend on the specific characteristics of the building and at its destination. Since the building under review (for the purposes of this study) is for residential use and the DM is supposed to be the designer and contractor, the seven criteria ranging from C1 to C7 that are used in this study are based on installation cost, duration of works, functional compatibility, skilled labor requirement, level of damage, aesthetics, and age factor of observation. The

Table 1: Scale of importance (Saaty, 1980)

Intensity of Importance	Definition
1	Equal Importance
3	Moderate Importance of one to another
5	Essential or strong Importance
7	Demonstrated Importance
9	Extreme Importace
2,4,6,8	Intermediate values between the two adjacent judgements
Reciprocal of above	If criterion j compared to k gives of the above, then k, when compared to j, gives its reciprocal

installation cost (C1) was measured based on Nepali rupees per square feet area. Criteria like time duration for construction (C2) and observation (C7) was measured in months. Functional compatibility (C3) was categorized based on the level of satisfaction ranging from no satisfaction to full satisfaction. Level of damage (C5) was measured within the range of low to severe damage. Also, skilled level requirement (C4) was observed as low to high skill level. The visually pleasing aspect after the completion of the retrofitting was measured based on the criteria of aesthetics (C6).

3.1 Weighting the evaluation criteria

Weights will strengthen or strengthen the evaluation alternatively to reflect how many important criteria are relative to others in the best choice of solutions. Therefore, this step, certainly involving DM Choice, needs special attention. The approach used here to calculate the weight from criteria as proposed by Saaty (1980), and is based on comparison of paired criteria and eigenvalue theory Saaty and Vargas (1980). It requires the DM expressing his opinion about pair comparison. In particular, with reference to two generic criteria, DM must define relative interests of one criterion with respect to another. Choose between every possibility. Every choice is a linguistic phrase. Then, by adopting the linear scale, linguistic statements can be converted into a crisp number. Crisp numbers are generally numerical representations of linguistic statements.

Furthermore, discussing the weighting process, let us assume that the owner considers reduction of duration of works (C2) moderately more important than installation cost (C1), then by adopting a linear scale from the Saaty table, it must be assumed to be A_{12} = 1/3. As done by Shapira (2005), after all paired comparisons have been made and the matrix has been filled, measuring consistency from DM ‘s assessment is needed to ensure the stability of the final solution, which should not change for slight modifications of the weight’s values Shapira and Goldenberg (2005). In this case, the level of consistency must be evaluated and then compared to the limit value that is considered acceptable, depending on the number (N) of element compared. First of all, the so-called “Consistency Index” (CI) used by Saaty (1980), has to be calculated Saaty and Vargas (1980). Then CI must be normalized by the specified ”Random Consistency Index” (RCI) as a measure of random consistency on average depending on n (0, 0, 0.58, 0.90, 1.12, 1.24, 1.32, 1.41, 1.45 for n = 1, 2, ..., 9 each). In this way, ”consistency”(CR) ratio is obtained. In general, paired comparisons can be considered consistent enough if CR is less than 5% for n = 3, 9% for n = 4, 10% for $n > 4$. If not, as mentioned, it needs to re-examine paired assessment until acceptable consistency is reached.

3.2 Evaluation and ranking of the retrofit alternatives

The next step of the decision-making procedure consists of evaluating the alternative retrofitting solutions with respect to the considered criteria. All the provided data regarding the information about the alternatives with respect to the criteria is listed out, the data is then converted into normalized value. Normalized value helps to set a standard and bring uniformity in all of the variables provided by the respondents. The ranking of the alternatives is done based on the similarity or closeness with the ideal condition. To determine the closeness, this study adopted the TOPSIS method. It is a technique for order preferences with similarities with the ideal solution (TOPSIS). It was developed by Hwang (1981), and based on the concept of geometric which is the best alternative to have the shortest distance to the positive ideal solution and the farthest distance to the negative ideal solution Hwang et al. (1981). The ranking is then done based on the performance score of the criteria with higher score getting more preferred in the rank.

4. Findings and Discussion

The following findings are the result on the basis of experience of the respondents who have been working

significantly in the field of retrofitting where some are practitioners and others are the policy makers of the sector. The study finalized a questionnaire to determine the alternatives and criteria in order to find the optimum retrofitting process through the comparison between the elements. The building typology and the design framework were described to the responders to streamline their mind frame with the goal of the study. The Analytical Hierarchical Process (AHP) developed by Saaty (1980), was adopted for the pair wise comparison and the scale of 1 to 9 were provided based on the relative importance between the elements Saaty and Vargas (1980). After the survey, the analysis was conducted with the provided data with the eigenvector method. A matrix "A" was formulated based on the relative importance between the elements.

$$A = \begin{bmatrix} 1 & 5 & 3 & 3 & 1 & 5 & 5 \\ 1/5 & 1 & 1/3 & 1 & 1/5 & 1/3 & 3 \\ 1/3 & 3 & 1 & 3 & 1/3 & 3 & 3 \\ 1/3 & 1 & 1/3 & 1 & 1/5 & 3 & 3 \\ 1 & 5 & 3 & 5 & 1 & 5 & 3 \\ 1/5 & 3 & 1/3 & 1/3 & 1/5 & 1 & 3 \\ 1/5 & 1/3 & 1/3 & 1/3 & 1/3 & 1/3 & 1 \end{bmatrix} \quad (1)$$

The weighted normalized pair wise comparison matrix was formulated for the calculation of the criteria weights. The criteria weights thus calculated were:

$$[0.28, 0.06, 0.15, 0.09, 0.29, 0.08, 0.04] \quad (2)$$

The weights then were checked in accordance with the consistency and the maximum principal right eigenvector was calculated i.e., λ_{max}= 7.73. Then the consistency index (C.I) was calculated based on the λ_{max} value. i.e., C.I = 0.12. Finally, the consistency ratio was formulated and derived as 0.09. The value of C.R = 0.09 $<$ 0.1 (i.e., 10%) therefore, the criteria weights derived beforehand were consistent and thus adopted.

Table 2: Random Consistency Index Table

n	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

After the AHP approach, the ranking of the alternatives was determined through the process of technique for order preferences with similarities with the ideal solution (TOPSIS). The concept relies on the relative distance of the solution with the ideal best and ideal worst solution. The performance values of the criteria are extracted from the questionnaire survey and layout in tabular format.

Table 3: Assign performance values

	C1	C2	C3	C4	C5	C6	C7
A1	1500-2000	2-3	25	2	2	1	<1
A2	1500-2000	<1	50	2	2	1	<1
A3	2000-2500	<1	75	3	3	2	<1
A4	2500-3000	2-3	50	3	3	1	<1

As per the decision of the respondents, the installation cost of alternative A1 and A2 used in this study was found to be around Rs 1500-2000 per sq. ft whereas cost of A3 was Rs 2000-2500 per sq. ft and Rs 2500-3000 per sq. ft was cost for alternative A4. The duration of retrofitting for alternatives A1 and A4 were in the range of 2 to 3 months whereas that of A2 and A3 was less than one month. The responders believed that the alternative A3 was functionally highly compatible with the structure whereas A2 and A4 were moderately compatibility and A1 was low in compatibility. The respondents believed that low skilled labor was required in alternatives in alternatives A1 and A2 but the alternatives like A3 and A4 needed high level of skill requirement. The alternatives can be used for low to moderate level of damage and the finished work was rather fairly or unpleasant. However, the observation time of the performance was within a period of two months. After the input of performance value, the study constructs a normalized decision matrix with the following formula developed by Hwang et al. (1981).

$$\overline{X_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (3)$$

Where, X_{ij} is the performance value of each cell.

Table 4: Construct Normalized Decision Matrix

	C1	C2	C3	C4	C5	C6	C7
A1	0.25	0.63	0.32	0.39	0.39	0.37	0.5
A2	0.25	0.31	0.48	0.39	0.39	0.37	0.5
A3	0.51	0.31	0.64	0.58	0.58	0.75	0.5
A4	0.77	0.63	0.48	0.58	0.58	0.37	0.5

The constructed normalized decision matrix is then multiplied with their respective criteria weights which were calculated from the decision matrix of equation (1) to formulate the weighted normalized decision matrix.

Next, the ideal best and ideal worst values are determined based on the weighted normalized value

Table 5: Construct Weighted Normalized Decision Matrix

	C1	C2	C3	C4	C5	C6	C7
A1	0.07	0.04	0.04	0.03	0.11	0.02	0.02
A2	0.07	0.02	0.07	0.03	0.11	0.02	0.02
A3	0.14	0.02	0.09	0.05	0.17	0.05	0.02
A4	0.21	0.04	0.07	0.05	0.17	0.02	0.02

of each element and the selection depends on the criteria. For example, the ideal best value of the cost is the lowest value among the alternatives whereas ideal best value regarding the functional compatibility is selected on the basis of highest value among the alternatives and vice-versa.

Table 6: Ideal best and ideal worst value calculation

	C1	C2	C3	C4	C5	C6	C7
A1	0.07	0.04	0.04	0.03	0.11	0.02	0.02
A2	0.07	0.02	0.07	0.03	0.11	0.02	0.02
A3	0.14	0.02	0.09	0.05	0.17	0.05	0.02
A4	0.21	0.04	0.09	0.05	0.17	0.02	0.02
Vj+	0.07	0.02	0.09	0.03	0.11	0.05	0.02
Vj-	0.21	0.04	0.04	0.05	0.17	0.02	0.02

Now, the Euclidean distance i.e., the shortest distance from the ideal best and ideal worst value are computed using the following formula developed by Hwang et al. (1981).

$$S_i^+ = \left[\sum_{j=1}^{m}(V_{ij} - V_j^+)^2\right]^{0.5} \& S_i^- = \left[\sum_{j=1}^{m}(V_{ij} - V_j^-)^2\right]^{0.5} \quad (4)$$

Table 7: Calculation of Euclidean Distance from Ideal Best and Ideal Worst Value

	C1	C2	C3	C4	C5	C6	C7	S_i^+	S_i^-
A1	0.07	0.04	0.04	0.03	0.11	0.02	0.02	0.05	0.15
A2	0.07	0.02	0.07	0.03	0.11	0.02	0.02	0.03	0.16
A3	0.14	0.02	0.09	0.05	0.17	0.52	0.02	0.09	0.09
A4	0.21	0.04	0.07	0.05	0.17	0.02	0.02	0.16	0.02

Further the performance score of the alternative is calculated based on the Euclidean distance. The formula used in the process developed by Hwang (1981) Hwang et al. (1981) is as follows:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (5)$$

Finally, the ranking of the alternative is done between the alternatives where the ranking is done based on the maximum value among the performance scores. The maximum value is determined as rank 1 and the order goes in descending order of the score. The process of multi criteria decision making thus produced numerical interpretation of linguistic statement where the alternatives were sorted out and ranked based on the performance score. The sorting of the alternatives indicates that the suitability of the application of MCDM in regard to sorting the preference of ongoing retrofitting process whereas checking the consistency level led to logical stability and the result were validated.

Table 8: Alternative Ranking

	Pi	Rank
A1	0.72	2
A2	0.81	1
A3	0.49	3
A4	0.12	4

5. Conclusion

The paper concludes the preference of the decision maker regarding the retrofitting process. According to the analysis, alternative two (A2) i.e., Steel Jacketing is preferred by the respondents over the other alternatives. The ranking is based on the performance score of the alternative and the maximum value among them (i.e., 0.81) is ranked to be most preferred. As per the assigned performance value from the decision maker in Table no 3, the preferred alternative A2 had slight advantage on installation cost and skilled level requirement over alternatives A3 and A4. It had shorter time duration for construction, the level of satisfaction based on the compatibility was higher than other alternatives. As the weightage with respect to pairwise comparison of the criteria provided was more on installation cost, level of damage, skilled level requirement and functional compatibility, the advantage of alternative (A2) led to high performance score and hence ranked as most preferred from the final analysis of Table no 8. The following conclusions can be extracted from the paper:

1. The ranking based on the performance score indicates that sorting of the retrofitting process can be done through the approach of MCDM and most useful in decision making process of retrofit techniques.
2. The data from the respondents being consistent

shows that the linguistic statement can be validated through numerical interpretation where steel jacketing is mostly liked by designer and contractors that is validated through MCDM approach.

3. The analysis and results are based on the decision-making process on the general level. The result may vary if specific analysis of any building is to be performed. The study however tries to bring flexibility during the decision-making process in policy level when there is need of resource allocation during emergency phase.

References

Abo-Sinna, M. A. and Amer, A. H. (2005). Extensions of TOPSIS for multi-objective large-scale nonlinear programming problems, *Applied Mathematics and Computation* **162**(1): 243–256.

Bradshaw, A., Rajeev, P. and Tesfamariam, S. (2011). Multi criteria decision making tool for the selection of seismic retrofitting techniques, *Australian Earthquake Engineering Conference 2011*, Australian Earthquake Engineering Society, pp. 1–8.

Caterino, N., Iervolino, I., Manfredi, G. and Cosenza, E. (2009). Comparative analysis of multi-criteria decision-making methods for seismic structural retrofitting, *Computer-Aided Civil and Infrastructure Engineering* **24**(6): 432–445.

Gilani, G. et al. (2020). MCDM approach for assessing the sustainability of buildings' facades.

Government of Nepal, National Reconstruction Authority (2017). *Repair and Retrofitting Manual for RCC Structure*, Singhadurbar, Kathmandu.

Hwang, C.-L., Yoon, K., Hwang, C.-L. and Yoon, K. (1981). Methods for multiple attribute decision making, *Multiple attribute decision making: methods and applications a state-of-the-art survey* pp. 58–191.

Jahanshahloo, G. R., Lotfi, F. H. and Izadikhah, M. (2006). An algorithmic method to extend TOPSIS for decision-making problems with interval data, *Applied mathematics and computation* **175**(2): 1375–1384.

Kim, S.-S., Yang, I.-H., Yeo, M.-S. and Kim, K.-W. (2005). Development of a housing performance evaluation model for multi-family residential buildings in korea, *Building and environment* **40**(8): 1103–1116.

Penadés-Plà, V., García-Segura, T., Martí, J. V. and Yepes, V. (2016). A review of multi-criteria decision-making methods applied to the sustainable bridge design, *Sustainability* **8**(12): 1295.

Pradhan, P. M., Adhikari, R., Dahal, A., Shrestha, A., Subedi, D. L., Thapa, S. and Kharel, P. (2016). Retrofitting design of Kathmandu University library building after Gorkha earthquake 2015, *Lowland technology international* **18**(2, Sep): 65–74.

Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used, *Mathematical modelling* **9**(3-5): 161–176.

Saaty, T. L. and Vargas, L. G. (1980). Hierarchical analysis of behavior in competition: Prediction in chess, *Behavioral science* **25**(3): 180–191.

Shapira, A. and Goldenberg, M. (2005). AHP-based equipment selection model for construction projects, *Journal of construction engineering and management* **131**(12): 1263–1273.

Siksnelyte-Butkiene, I., Streimikiene, D., Balezentis, T. and Skulskis, V. (2021). A systematic literature review of multi-criteria decision-making methods for sustainable selection of insulation materials in buildings, *Sustainability* **13**(2): 737.

Thermou, G., Elnashai, A., Plumier, A. and Doneux, C. (2004). Seismic design and performance of composite frames, *Journal of constructional steel research* **60**(1): 31–57.

Zavadskas, E. K., Antuchevičienė, J. and Kapliński, O. (2015). Multi-criteria decision making in civil engineering. part ii–applications, *Engineering Structures and Technologies* **7**(4): 151–167.

Zeleny, M. (2011). Multiple criteria decision making (MCDM): From paradigm lost to paradigm regained?, *Journal of Multi-Criteria Decision Analysis* **18**(1-2): 77–89.