4th International Civil Engineering & Architecture Conference
17-19 May 2025, Trabzon, Türkiye

Evaluation of 3D concrete printing production processes with multicriteria Decision-Making methods

Berru İzel Gökgöz *[1], Şeyma Gebel[2], Çağatay Takva[2], Semahat Merve Top[3], Zeynep Yeşim İlerisoy[2]

*[1] OSTIM Technical University, Department of Interior Architecture and Environmental Design, Ankara, Türkiye
[2] Gazi University, Department of Architecture, Ankara, Türkiye
[3] Karabük University, Faculty of Architecture, Department of Architecture, Karabük, Türkiye

Abstract. Recently developed construction technologies have made it possible to carry out processes more efficiently, quickly and sustainably. In this context, 3D concrete printing technology, automation, and robot technologies have emerged. This study aims to verify the reliability of the results obtained through experimental methods in producing different geometric forms in the 3D concrete printing process using multi-criteria decision-making (MCDM) methods. The study's main purpose is to examine the effectiveness of MCDM methods in verifying experimental data and to prevent waste of time and resources in experimental processes. The data obtained in the experiments were analysed using the selected MCDM methods, and it was determined that the circular geometry plan provided the optimum performance in terms of buildability, cost, and mass producibility parameters. MCDM analyses similarly showed that the circular geometry plan was superior regarding these parameters. The results revealed that the selected MCDM methods were broadly consistent with the experimental findings, and it was also determined that the methods were sensitive to different criterion weights and assumptions. This study demonstrates that MCDM methods can effectively support experimental results and serve as a valuable complementary tool in decision-making processes. The findings highlight the effectiveness of using experimental and theoretical approaches in decision-making processes.

Keywords: 3D concrete printing technology; automation; robot technologies; MCDM

1. Introduction

As one of the key technologies of Industry 4.0, additive manufacturing enables the production of products designed in a digital environment using the 3d printing (3DP) method. This technology, first developed in 1983, has become widely adopted in various sectors today, including automotive, aviation, and construction. In the construction industry, 3d printing (3DP) is used as an alternative to traditional molding methods, enabling the production of non-linear, complex architectural designs. This technology offers advantages such as reducing costs, shortening project time and ensuring sustainability by increasing automation and digitalisation in construction processes (Gebel et al., 2024; Takva et al., 2024).

In additive manufacturing processes, the selection of alternative building forms should be considered within the framework of criteria such as manufacturability, cost and sustainability. Multi-criteria decision-making (MCDM) methods can be an effective tool in such decision-making processes, as they save time and resources compared to traditional experimental approaches.

Multi-criteria decision-making (MCDM) methods typically involve processes such as determining alternatives, weighting criteria, and ranking options (Brugha, 2004). Majumder (2015) emphasises in his study that the correct result may not always be achieved in decision-making processes (Majumder, 2015). This study evaluated the similarities and differences between the results obtained using MCDM methods and the findings of a real-life experiment. The study's primary objective is to determine whether the results of an experiment can be accurately predicted using MCDM methods without the need for resources such as time, materials, and labour typically required for experiments.

*Corresponding author, E-mail: berruizel.gokgoz@ostimteknik.edu.tr

https://doi.org/10.31462/icearc2025_a_aen_843

2. Methodology

In this study, the authors' experiment for producing different forms using 3D concrete printing (3DCP) is tested using multi-criteria decision-making methods. Information is diverse, and designers' priorities differ in the field of design (Tan et al., 2021). In MCDM methods, the goal is to optimise the evaluation of experts and decision-making. At the first stage, the parameters to be evaluated will be explained. Then, the criterion weights will be calculated using the Fuzzy AHP method, demonstrating the relevant criteria's importance. At this stage, pairwise comparison matrices are created based on expert assessments. With this evaluation, weights are obtained. After these weights are received, the alternatives will be evaluated with the TOPSIS method, and the resulting ranking will be compared with the actual result. The flow chart for the explained algorithm is shown in Fig. 1.

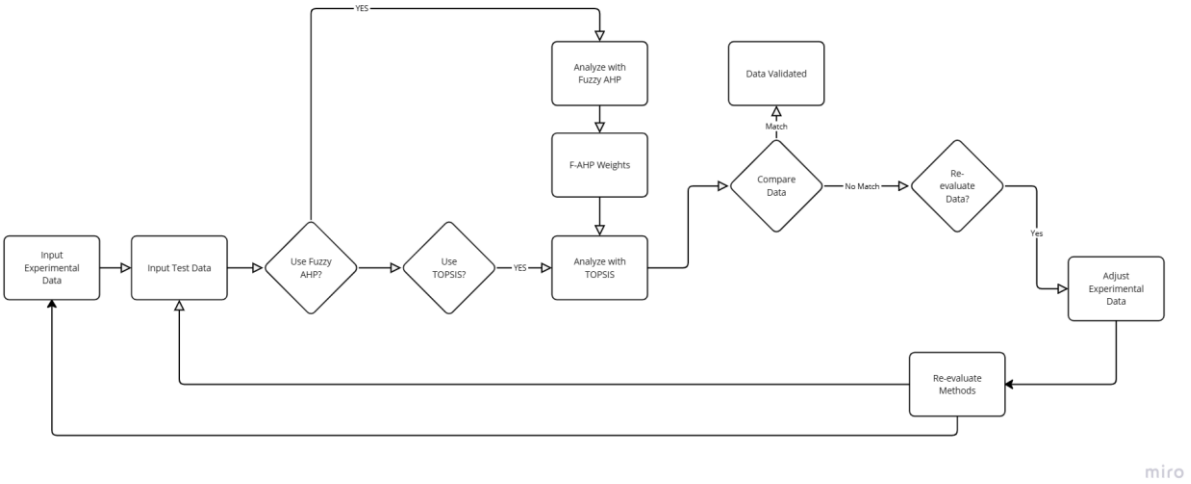


Fig. 1. Flowchart of the study

2.1. Fuzzy AHP

In the analytical hierarchy process, pairwise comparisons contain uncertainty because they are based on expert opinions; therefore, the Fuzzy AHP method is used in the literature to mitigate these situations. In this method, instead of evaluating with numbers (1-3-5-7-9) in AHP, experts are ensured to evaluate using linguistic expressions (Liu et al., 2020). The scale used in creating the fuzzy pairwise comparison matrices for the study is presented in Table 2.

Table 2. Linguistic variables (Huang et al., 2012)

Code	Linguistic Variables	L	M	U
1	Equally important	1	1	1
2	Intermediate value between 1 and 3	1	2	3
3	Slightly important	2	3	4
4	Intermediate value between 3 and 5	3	4	5
5	Important	4	5	6
6	Intermediate value between 5 and 7	5	6	7
7	Strongly important	6	7	8
8	Intermediate value between 7 and 9	7	8	9
9	Extremely Important	9	9	9

The fuzzy AHP method was applied through a series of steps that began with comparing pairs of criteria among experts. First, fuzzy decision matrices were created due to these comparisons and the fuzzy scale in Table 1 was used. Then, the fuzzy weights were normalised by calculating the consistency of the weights. Global fuzzy preference rankings were created for the alternatives, and the results were interpreted to guide the decision process. As a result, the rankings obtained by this method support the decision-making process. The findings obtained through the application of the method revealed the priority criteria for the 3D concrete printing process.

2.2. TOPSIS

The TOPSIS method is a straightforward and comprehensible technique that seeks to identify the alternative that is closest to the ideal solution and the farthest from the negative ideal solution in decision-making processes (Yoon & Hwang, 1995). The steps of the method are as follows: The creation of the decision matrix begins with

normalising this matrix and obtaining the weighted decision matrix by taking into account the weights of the criteria. Then, the distances of each alternative from the ideal and negative ideal solutions are calculated. In the last stage, the relative proximity scores of the alternatives are determined, and the alternative with the highest score is selected as the best option. Due to its ease of application and the fact that its results are not subject to interpretation, the TOPSIS method is widely used in various fields (Fayaz et al., 2023; İlerisoy & Gökgöz, 2023, 2024; Lolli et al., 2022; Wang & Wang, 2014; Xiong et al., 2021).

3. Proposed Framework with Example

In this study, which compares the real-life application of 3DCP technology with the MCDM methods, the effectiveness of the MCDM methods in validating experimental data is measured. The TÜBİTAK project, with code 122M876, is used as experimental data. This experiment aims to identify errors and deficiencies by examining design parameters through models and to reveal the effects of these parameters by comparing them with one another. Building evaluation parameters based on research findings in the literature include comparative analyses of systematically modified design decisions in buildings with the same architectural plan and footprint. These analyses focused on specific structure evaluation criteria for geometric forms derived from 3DP. These are printing time, material usage, mass production, buildability, defect analysis, size consistency and cost criteria. As geometric forms, the square, chamfered square, rectangle, chamfered rectangle, circle, chamfered circle, hexagon, chamfered hexagon, octagon, chamfered octagon, and ellipse were evaluated, and these forms were considered alternatives in this study. The decision tree for this evaluation is given in Fig. 2.

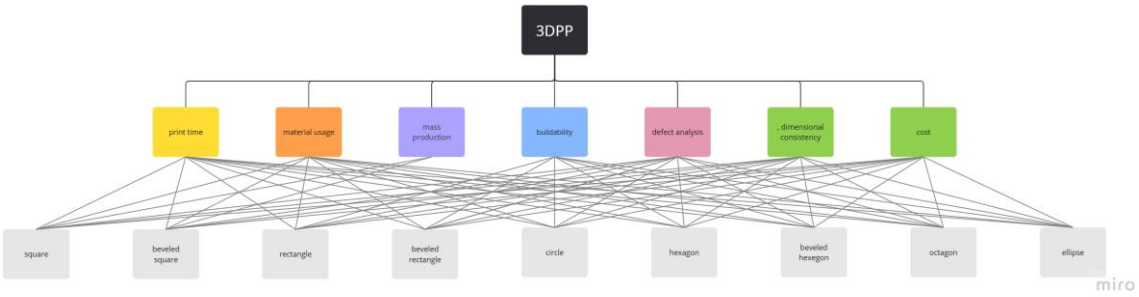


Fig. 2. Decision tree

This hierarchical evaluation was conducted by an expert team comprising five architects and five civil engineers who have specialised studies on the subject. The comparison matrix is presented in Table 1. Accordingly, the criterion weights in the criterion evaluations are given in Table 2.

Table 2. Criteria Weights

Criteria	Printing time	Material usage	Mass production	Buildability	Defect analysis	Dimension consistency	Cost
Weights	0.054	0.081	0.399	0.220	0.032	0.032	0.182

According to these evaluations, it was concluded that mass production was the most important parameter. The mass production parameter is crucial in determining the product's potential for mass production. The sum and analysis of the data obtained from other evaluation criteria help determine the systems suitable for mass production. In this process, the most appropriate mass production method and process should be determined by considering factors such as printing time, material usage, buildability, analysis of potential defects, measurement consistency, and cost. In this context, important factors such as production efficiency, quality standards, and cost-effectiveness are optimised, and successful results are obtained in mass production. The following criteria follow the mass production criterion, respectively: Buildability (0.220), Cost (0.182), Material Use (0.081), Printing Time (0.054), Defect Analysis (0.032), and Dimensional Consistency (0.032).

Buildability is the most critical parameter in evaluating printable mixtures. The extruded filament must maintain its shape without deformation, settle in harmony with the lower layers, gain sufficient stiffness and rapid strength, and form a strong bond between the layers (Ahmed, 2023).

The cost parameter, which ranks third after the buildability criterion, is a critical factor in determining the most economical geometry and is of great importance for applicability and mass production processes. The use of materials is a decisive factor in the printing phase, as the impact of different types and proportions of components on the final 3D printing (3DP) product is significant. Printing time stands out as a dynamic variable that is affected by other parameters and also affects them. Within the scope of defect analysis, the ability of different geometric

forms to reach different layer heights is evaluated. On the other hand, dimensional consistency is an important criterion that examines the difference between input (design) and output (prototype printing) products.

In the evaluation using the TOPSIS method, the expert team evaluated the alternatives on a scale of 1 to 5. A ranking was created according to the criterion weights derived from the fuzzy AHP. Expert evaluation data are presented in Table 3, and normalised data are presented in Table 4.

Table 3. TOPSIS Expert Evaluation

Weights	0.054	0.081	0.399	0.220	0.032	0.032	0.182
Geometric Forms	Printing time	Material usage	Mass production	Buildability	Defect analysis	Dimension consistency	Cost
Square	3	3	3	3	2	3	3
Beveled Square	4	4	4	4	2	3	4
Rectangle	3	3	3	3	2	3	3
beveled rectangle	4	4	4	4	2	3	4
Circle	5	5	5	5	2	3	5
Hexagon	3	3	3	3	2	3	3
beveled hexagon	4	4	4	4	2	3	4
Octagon	3	3	3	3	2	3	3
Beveled Octagon	4	4	4	4	2	3	4
ellipse	5	5	5	4	2	3	5

Table 4. TOPSIS Normalization Data and Sequencing

	S+	S-	C	Rank
Square	0,082185378	0	0,00	7
Beveled Square	0,041092689	0,041092689	0,50	3
Rectangle	0,082185378	0	0,00	7
beveled rectangle	0,041092689	0,041092689	0,50	3
Circle	0	0,082185378	1,00	1
Hexagon	0,082185378	0	0,00	7
beveled hexagon	0,041092689	0,041092689	0,50	3
Octagon	0,082185378	0	0,00	7
Beveled Octagon	0,041092689	0,041092689	0,50	3
ellipse	0,018527342	0,075661411	0,80	2

As a result of these evaluations, considering all the criterion evaluations, it was seen that the best alternative was the circle form. This is followed by ellipse, chamfered octagon, chamfered hexagon, chamfered rectangle, chamfered square, square, rectangle, hexagon and octagon.

When the data obtained from the experiment are analysed, when we look at the printing time and material usage, collapse heights, maximum number of layers during printing and perimeter lengths between square, rectangle, circle and ellipse geometric forms; circle in terms of printing time, circle in terms of material usage, circle in terms of collapse height and circle in terms of number of layers showed the best performance. The results are shown in Fig. 3-4. This shows the accuracy of the study model.



Fig. 3. Collapsed views of square, rectangular, hexagonal and octagonal shapes with right angles and beveled designs and visuals of indestructible geometries



Fig. 4. Collapsed appearances of forms

4. Results and Discussion

This section presents the results obtained with the multi-criteria decision-making methods used in the study and compares them with the experimental results.

Upon examining the findings obtained from this study, it was determined that the mass production parameter was the most important criterion (Fig. 5). This parameter is a comprehensive factor that optimises elements such as production efficiency, quality standards, and cost-effectiveness, and determines the impact of many other criteria. In this context, academicians who expressed their opinions in line with the experiments carried out in the laboratory environment also emphasised that the mass production parameter is the most important criterion. Thus, the criterion evaluation obtained in the multi-criteria decision-making analysis overlapped with the important criteria determined in the experimental environment.

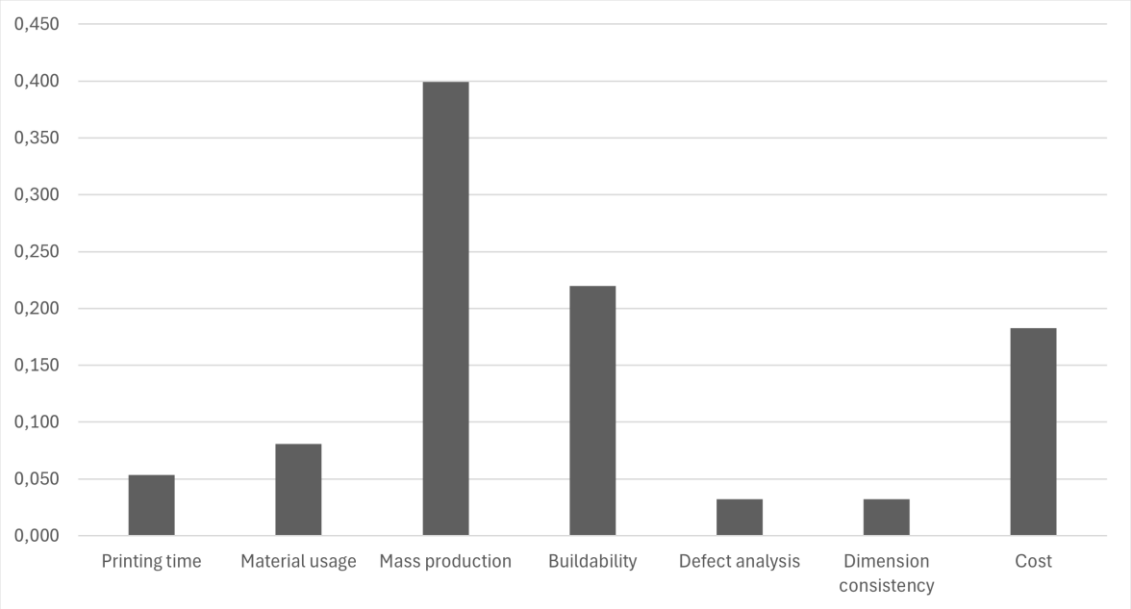


Fig. 5. AHP Results

The buildability parameter is crucial for successful printing. The filament needs to retain its shape, merge well with the layers and harden quickly. Otherwise, the print quality may decrease. In this parameter, a result was obtained that matched the experimental environment.

Printing processes on forms include printing time, material usage, mass production, buildability, defect analysis, and dimension consistency. The circle form got the best results in evaluating the cost criteria, and the presence of the circle form in the experiment shows that the model in this study works (Fig. 6).

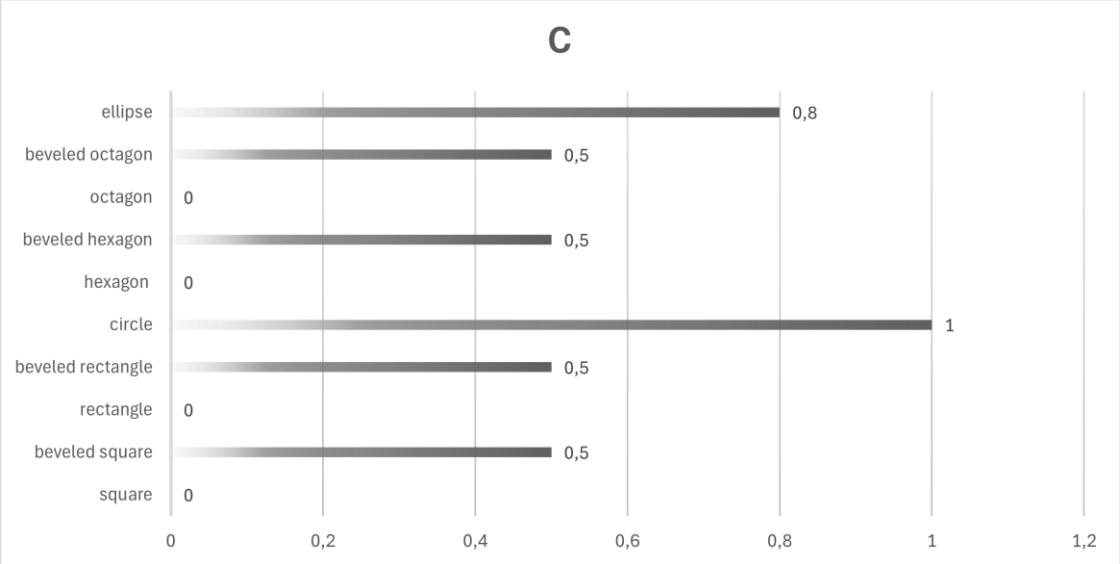


Fig. 6. TOPSIS Results

As a result of these evaluations, it was determined that the most suitable alternative was the apartment form, taking into account all relevant criteria. The circle is followed by an ellipse, a beveled octagon, a beveled hexagon, a beveled rectangle, a beveled square, a square, a rectangle, a hexagon and an octagon, respectively. The most effective criteria for the emergence of these results were mass production, buildability and cost. In the evaluations conducted in the experimental environment, it was found that the circle form exhibited the best performance, particularly when all criteria, including these parameters, were considered. This situation demonstrates that the results obtained using the Multi-Criteria Decision Making (MCDM) method are consistent with experimental studies.

4. Conclusion

This study showed that multi-criteria decision-making methods can evaluate alternative solutions without requiring the use of resources in experimental processes. The results obtained largely align with the experimental findings, indicating that MCDM methods can be a valuable tool in decision support processes. In future studies, the effectiveness of these methods in different decision settings and with more complex criteria may be examined in more detail.

The findings of this study reveal that the most important parameter in the three-dimensional concrete printing process is mass production. Mass production is a critical factor in determining the suitability of the prints for production processes and the efficient operability of the system. When the alternatives were evaluated by experts within the framework of all parameters, it was determined that the best-performing form was the circle. The circular form has demonstrated high performance in all parameters due to its soft lines along its circumference, which enable it to exhibit superior performance compared to other forms.

In this context, the study's findings can be considered an important step in developing alternative approaches to experimental methods in decision-making processes. Experimental studies entail the consumption of resources, such as time, materials, and labour, which can lead to both material and moral losses. Using Multi-Criteria Decision-Making (MCDM) methods, criteria can be weighted, and alternatives can be analysed systematically through expert evaluation questionnaires. Thus, comprehensive and efficient assessments can be carried out without wasting resources.

Acknowledgments

This study was supported by the Scientific and Technological Research Council of Türkiye (TUBITAK) under the Grant Number 122M876.

References

Ahmed, G. H. (2023). A review of “3D concrete printing”: Materials and process characterization, economic considerations and environmental sustainability. *Journal of Building Engineering*, *66*, 105863. https://doi.org/10.1016/j.jobe.2023.105863

Brugha, C. M. (2004). Structure of multi-criteria decision-making. *Journal of the Operational Research Society*, *55*(11), 1156–1168. https://doi.org/10.1057/palgrave.jors.2601777

Fayaz, M., Romshoo, S. A., Rashid, I., & Chandra, R. (2023). Earthquake vulnerability assessment of the built environment in the city of Srinagar, Kashmir Himalaya, using a geographic information system. *Natural Hazards and Earth System Sciences*, *23*(4), 1593–1611. https://doi.org/10.5194/nhess-23-1593-2023

Gebel, Ş., Top, S. M., Takva, Ç., Gökgöz, B. İ., İlerisoy, Z. Y., & Şahmaran, M. (2024). Exploring the role of 3D concrete printing in AEC: Construction, design, and performance. *Journal of Construction Engineering, Management & Innovation*, *7*(3), 229–246. https://doi.org/10.31462/jcemi.2024.03229246

Huang, S., Li, X., & Wang, Y. (2012). A new model of geo-environmental impact assessment of mining: A multiple-criteria assessment method integrating Fuzzy-AHP with fuzzy synthetic ranking. *Environmental Earth Sciences*, *66*(1), 275–284. https://doi.org/10.1007/s12665-011-1237-z

İlerisoy, Z. Y., & Gökgöz, B. İ. (2023). Safety of transportation buildings against vehicle bomb attacks with multi-criteria decision-making. *Open House International*, *48*(3), 576–595. https://doi.org/10.1108/OHI-07-2022-0180

İlerisoy, Z. Y., & Gökgöz, B. İ. (2024). Analysis of earthquake resilience factors for buildings: The case of Istanbul high-rise buildings. *Open House International*, *49*(4), 773–790. https://doi.org/10.1108/OHI-08-2023-0191

Liu, Y., Eckert, C. M., & Earl, C. (2020). A review of fuzzy AHP methods for decision-making with subjective judgements. *Expert Systems with Applications*, *161*, 113738. https://doi.org/10.1016/j.eswa.2020.113738

Lolli, F., Maria Coruzzolo, A., & Balugani, E. (2022). The Indoor Environmental Quality: A TOPSIS-based approach with indirect elicitation of criteria weights. *Safety Science*, *148*, 105652. https://doi.org/10.1016/j.ssci.2021.105652

Majumder, M. (2015). Multi Criteria Decision Making. In M. Majumder (Ed.), *Impact of Urbanization on Water Shortage in Face of Climatic Aberrations* (pp. 35–47). Springer. https://doi.org/10.1007/978-981-4560-73-3_2

Takva, Ç., Top, S. M., Gökgöz, B. İ., Gebel, Ş., İlerisoy, Z. Y., İlcan, H., & Şahmaran, M. (2024). Applicability of 3D concrete printing technology in building construction with different architectural design decisions in housing. *Journal of Building Engineering*, *98*, 111257. https://doi.org/10.1016/j.jobe.2024.111257

Tan, T., Mills, G., Papadonikolaki, E., & Liu, Z. (2021). Combining multi-criteria decision making (MCDM) methods with building information modelling (BIM): A review. *Automation in Construction*, *121*, 103451. https://doi.org/10.1016/j.autcon.2020.103451

Wang, Z.-X., & Wang, Y.-Y. (2014). Evaluation of the provincial competitiveness of the Chinese high-tech industry using an improved TOPSIS method. *Expert Systems with Applications*, *41*(6), 2824–2831. https://doi.org/10.1016/j.eswa.2013.10.015

Xiong, L., Sheng, G., Fan, Z.-M., Yang, H., Hwang, F.-J., & Zhu, B.-W. (2021). Environmental Design Strategies to Decrease the Risk of Nosocomial Infection in Medical Buildings Using a Hybrid MCDM Model. *Journal of Healthcare Engineering*, *2021*, 1–17. https://doi.org/10.1155/2021/5534607

Yoon, K., & Hwang, C.-L. (1995). *Multiple Attribute Decision Making*. SAGE Publications, Inc. https://doi.org/10.4135/9781412985161