MULTI-CRITERIA DECISION-MAKING METHODS APPLIED TO ACHIEVE SUSTAINABLE DESIGN: A SYSTEMATIC REVIEW

Xu, Tianming (1);
Liu, Wei (1);
Zhu, Zicheng (2)

1: King's Collage London;
2: Sartorius Ltd

ABSTRACT

Sustainability is an issue concerned with social, economic and environmental problems. The primary aim of sustainability is to fulfil the needs of the present society without compromising potential needs of future generations. Product design has a significant impact on sustainability, and a sensible decision-making process that considers trade-offs at early design stage is critical to the success of product design that addresses environmental sustainability issues. This study aims to identify and review the decision-making process for environmentally sustainable design. A comprehensive literature review has been performed to establish the trends over the past two decades. The decision-making process for sustainable design has been summarised, and the frequently-used decision-making methods, such as ANP/AHP, TOPSIS, and BWM, have been identified and discussed. A framework for the selection of Multi-criteria Decision-making (MCDM) methods has been developed to aid researchers to select appropriate MCDM methods in sustainable design. In addition, future research opportunities have also been identified.

Keywords: Decision making, Evaluation, Sustainability, Sustainable design, Multi-criteria

Contact:
Xu, Tianming
King's Collage London
United Kingdom
tianming.xu@kcl.ac.uk

Cite this article: Xu, T., Liu, W., Zhu, Z. (2023) 'Multi-Criteria Decision-Making Methods Applied to Achieve Sustainable Design: A Systematic Review', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.273

1 INTRODUCTION

The transformations needed for scope and complexity to achieve the Sustainable Development are unparalleled (Lee et al., 2016). Design process has already been identified as an essential part of circular economy and will have a profound influence on the overall product sustainability(Delaney, Liu, Zhu, Xu, & Dai, 2022; Zhu, Liu, Ye, & Batista, 2022). Designers are also facing new challenges to embrace Sustainable Development aspects into their design. The growing environmental concerns are fundamentally impacting the way that companies design and release new products (Choi, Nies, & Ramani, 2008). Therefore, great responsibilities are facing by the designers to design products under the principle of sustainable design, in order to solve the product sustainability problems (Mihelcic et al., 2008).

This study focused on decision-making in sustainable design. Considering various technical trade-offs at the early stage of design process, researchers involve multi decision-making methods to weigh and integrate sustainable factors in product design, which also refer to product features such as pollutant emissions (Tian, Zhang, Zhou, & Li, 2018), eco-balance (Feng, Kassem, Greenwood, & Doukari), energy efficiency (Baglivo, Congedo, & Fazio, 2014), human health and safety risks (Hoose, Yepes, & Kripka, 2021). Decision-making methods were applied to achieve sustainable design in areas such as product structural and functional (Rossi, Papetti, Marconi, & Germani, 2019), reverse logistics (Yu & Solvang, 2017), material selection (Shaharuzaman, Sapuan, Mansor, & Zuhri, 2019) and waste management (Remery, Mascle, & Agard, 2012). However, different decision-making methods have their own relative merits and adaptability. Many scholars used various methods to support the decision-making in design process to achieve sustainability, but there is no clear framework to select appropriate decision-making methods.

This paper aims to review the state of art decision-making process for sustainable design in new product development. By critically reviewing the process and Multi-criteria Decision-making (MCDM) methods, it will aid towards the understanding of how to conduct a decision-making process and how to choose an appropriate MCDM method for use. The paper therefore will focus on: (a) the research protocol to conduct a decision-making process in sustainable design, (b) any selection principles for MCDM method in sustainable design. This will provide a holistic view of decision-making process for environmentally sustainable design. Section 2 introduces the methodology for this systematic review, which includes the methods adopted for data collection and analysis. Section 3 summarises the flow path and current status of decision-making process. Section 4 proposes a new conceptual framework, considering specific characteristics of study, to facilitate researchers to select appropriate MCDM methods in sustainable design.

2 METHODOLOGY

2.1 Method of data collection

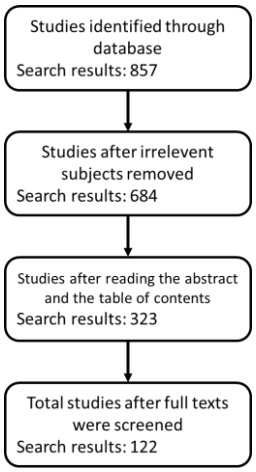

Figure 1. Literature Review Selection Methodology flowchart

The research method employed includes a three-step systematic literature review (SLR) shown in Figure 1. Literature Review Selection Methodology flowchart (Kitchenham et al., 2009). This paper

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press

focuses on the decision-making process of sustainable design, keywords and search terms were selected from the scope of the study, see Table 1. The search string was used to search the titles, abstracts, and keywords of research articles and review articles included in the Scopus and Web of Science databases. The search included all articles published from year 1996 to 2022, which resulted in 857 articles.

Table 1. Keywords for Literature Identification

Search Topics				
Product Design		Circular Economy		Evaluation
product design, design, process design, design development	and	Circular, Circular economy, Environmental sustainability/sustainable,	and	Evaluate/evaluation Design evaluation, Decision-making, Measure/measurement

This study removed the literature that have little relevance to the research subject (for example Material chemistry and agronomy) or written in other languages to clarify the topic of the papers. Thereafter, the number of studies was reduced to 684. The literature was further refined by reading the abstract to ensure the studies were relevant to the research subject. This resulted in 323 studies. After this initial exclusion, a screening of the rest of the articles was performed by reading the full text. The studies are determined by checking whether utilize MCDM methods in sustainable design process. This screening resulted in 122 studies remained.

2.2 Method of data analysis

The data analysis method adopted in this study is Data extraction and synthesis (Tranfield, Denyer, & Smart, 2003). Data analysis is conducted by identifying the key factors of decision-making methods in each study. The factors were identified by searching each paper for word repetitions and key words. All articles were read in full and analysed by the authors to ensure consistency in the analysis.

The following themes were investigated in the analysis: First, what were reasons for applying decision-making methods in the sustainable design process? Second, what were the frequently used decision-making methods? Third, what were the pros and cons of these methods? Fourth, what is the preference of decision-making methods in different subject areas? And fifth, how the methods were selected? These themes were used to guide the analysis of the review and help guide the development of a decision-making framework to aid the researcher to select appropriate MCDM methods to solve the problem in sustainable design.

3 DECISION-MAKING PROCESS FOR SUSTAINABLE DESIGN

The overall decision-making process for sustainable design can be summarised as the workflow shown in Figure 2. This includes (a) The first step is criteria determination, where criteria summarised from literature review and interview should be screened by expert survey. This step aims to find out the primary factors and reduce the workload of calculation, (b) The second step is weight determination. The weight of the criteria should be determined in this step by literature review, survey and expert scoring, (c) The third step is the application of MCDM methods. One or few integrated MCDM methods were conducted in this step, (d) The final step is the output of the decision-making process. The output can be an index, a selection of alternatives or a set of alternatives. This is determined by the MCDM methods selected in step 3.

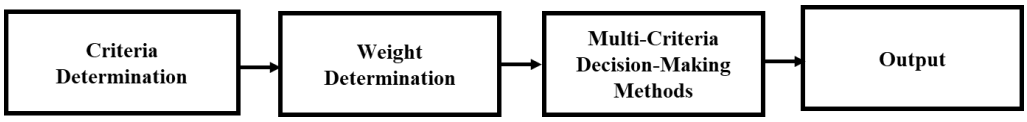

Figure 2. Decision-making process flow path

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press

3.1.1 Criteria determination

Criteria determination should be conducted at the beginning of the research. The criteria were commonly determined by literature review, expert or professional survey. Literature review and survey was conducted to briefly rank the importance of each criterion and reduce their number by selecting the most important from them.

3.1.2 Weight determination

The most widely used method of weight determination is expert scoring (Gu, Wang, Dai, Wei, & Chiang, 2021; Janssen, Chambost, & Stuart, 2009). The opinions of experts were firstly used to rank the determined criteria. Secondly, structured interviews were then conducted to the experts to select from a number of design alternatives. Thirdly, experts and professionals were expected to assign relative scores to each design alternative according to the decision-maker, this was accomplished by another structure-interview. Finally, a survey needed to be completed by the experts or professionals to identify criteria weights. An explanation of the aim of the study and the evaluation criteria are provided for all the respondents. The data obtained from the survey were used to calculate the weights of the criteria.

Fuzzy set is a kind of objects whose membership relations are not accurately defined (Bellman & Zadeh, 1970). Fuzzy sets provide a better realistic representation than classical mathematical binary representation due to (Zadeh, 1975). The degree of membership in fuzzy sets is gradual, which makes the theory highly valuable for expressing the limited level of accuracy in psychological representation. The influence of some decision-making criterion is qualitative and are difficult to be analysed under the typical quantitative method, which requires the introduction of linguistic variables to describe and solve the problems. The fuzzy information is then to be made by using the method of fuzzy mathematics. A total of 19 papers published used Fuzzy set as the weight calculation method in sustainable design in the past 15 years.

3.2 Multi-criteria decision-making methods and output

3.2.1 TOPSIS

TOPSIS is also named as Technique for Order Preference by Similarity to Ideal Solution. TOPSIS is considered to make full use of attribute information, provide the cardinal ranking of alternatives, and do not require to mutually independent attribute preferences (Behzadian, Otaghsara, Yazdani, & Ignatius, 2012). To apply this technique, property values are required to be numeric, monotonously increasing or decreasing, and have commensurable units.

A total of 15 papers was published used TOPSIS as the decision-making method in sustainable design in the past 15 years. Sustainable product design is one of the most frequently applied subject area of TOPSIS on sustainable design, mainly work on the improve of the environmental performance of products at the early stage of product design (Feng et al.; Niero & Kalbar, 2019; Zhang, Dong, Jin, Li, & Ren, 2020).

End-of-life strategy was also a frequently applied subject area for TOPSIS on sustainable design, mainly focus on evaluation on uncertain component end-of-life (EOL) options in the design stage (Ajukumar & Gandhi, 2013; Ma, Kremer, & Ray, 2018; Sabaghi, Mascle, & Baptiste, 2016).

3.2.2 AHP

AHP provides a powerful means of making strategic and sound decisions, it allows decision-makers to employ multiple criteria in a quantitative manner to evaluate potential alternatives and then select the optimal option (Saaty, 1988; Wind & Saaty, 1980). AHP also assists in making decisions that are characterized by several interrelated and often competing criteria, and it establishes priorities amongst decision criteria when set within the context of the decision goal (Saaty, 1990). There are three most prominent justifications why use AHP methods: sample size, high level of consistency and its simplicity of implementation and the availability of user-friendly software, Expert Choice, for analysing AHP data. This provides a structured and analytic, yet simple approach that does not require any special skills from the decision-makers to determine the best solution (Saaty, 2005).

Product sustainable design is a major subject area that AHP is applicated. Sustainable design evaluation of electronic products is the most widely used area. Researches (Darbari, Kannan, Agarwal, & Jha, 2019; Wang, Chan, Lee, & Li, 2015; Yi & Wu, 2021) put forward models and design criteria to

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press

achieve green eco-design and reduce the environmental pressure. It is also common to integrate Fuzzy in product sustainable design (Ali, Paksoy, Torgul, & Kaur, 2020; Chakraborty, Mondal, & Mukherjee, 2017; Palacio, Adenso-Diaz, & Lozano, 2018).
AHP is also widely used in the evaluation of sustainable conceptual design. Researches (Chen, 2016; Y. H. Qi et al., 2006; Shukla, Jangid, Siddh, Soni, & Kumar, 2017) using AHP effectively evaluate various criteria and sub-criteria and weight them are the major research problem. Hassan et al (Hassan, Saman, Sharif, & Omar, 2012), Wang et al (Wang et al., 2015) combine AHP with LCA, measure the environmental and organisational performance of different designs.
Design for end-of-life (Ajukumar & Gandhi, 2013; Chakraborty et al., 2017; Cong, Zhao, & Sutherland, 2019), logistics design (Ali et al., 2020; Palacio et al., 2018), supply design (Darbari et al., 2019) and material selection (Shaharuzaman et al., 2019) were also subject areas in sustainable design that AHP methods were frequently used.

3.2.3 Pareto related method

In some studies, multi-objective optimization must consider the trade-offs between competing objectives before a final single solution can be chosen. As such, multi-objective optimization problems generally result a set of design alternatives that are non-dominated mathematically (Pareto 1927). These are called Pareto solutions, the set of which comprises the Pareto frontier where both objectives are maximized.
LCA was frequently conducted in research using Pareto related methods. Life Cycle Assessment is a tool to assess the potential environmental impacts and resources used throughout a product's life-cycle, i.e., from raw material acquisition, via production and use phases, to waste management (Finnveden et al., 2009). The sustainable design guided by the LCA resulted into a set of design alternatives, which is greatly adaptable for Pareto method (Azapagic & Clift, 1999; Liechty, Mabey, Mattson, Salmon, & Weaver, 2022; H. H. Qi, Lee, Gea, & Asme, 2013).
When considering economic and social sustainability, the results of sustainable design will fall into a trade-off of the three dimensions (Mattson, Lofthouse, Bhamra, & Asme, 2015; Mattson, Pack, Lofthouse, & Bhamra, 2019). Pareto methods can put out a set of design alternatives for the researchers and designers to further selection (Lounis & Daigle, 2013; Martinez, Gonzalez, Hospitaler, & Albero, 2019).

3.2.4 Other methods

In the decision-making process of sustainable design, there are also many other methods that are used in specific research. These methods were not widely used but have good performance for specific subject areas.
Best Worst Method (BWM) was developed by Rezaei (Rezaei, 2015). The main advantage of BWM and the reason for selecting it is that compared to other existing MCDM methods, BWM requires fewer comparative data and leads to more consistent comparisons. For sustainable design, BWM is generally applied in supply chain sustainable design area (Maghsoodi, Mosavat, Hafezalkotob, & Hafezalkotob, 2019; Rezaei, Papakonstantinou, Tavasszy, Pesch, & Kana, 2019). The DEMATEL method was first developed by the research center of the Battle Memorial Institute in 1971, and then it was applied by Gabus and Fontela (1973) to present the cause-effect relationships existing in the complicated systems (Gabus & Fontela, 1972). DEMATEL is a structural method for plotting cause-and-effect diagrams that indicate interdependencies and the degree of influence of factors. VIKOR is also used in sustainable design process for material selection. (Girubha & Vinodh, 2012; Shaharuzaman et al., 2019)

4 SUSTAINABLE DESIGN DECISION- MAKING SELECTION FRAMEWORK

Upon conducting the systematic literature review documented above, the holistic Sustainable design decision-making selection framework was thus developed as depicted in **Figure 3.** Sustainable Design Decision-Making Selection Framework. There are five steps in the framework, with each step investigating the characteristics of the study. Each step will be illustrated in the following sections.

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press

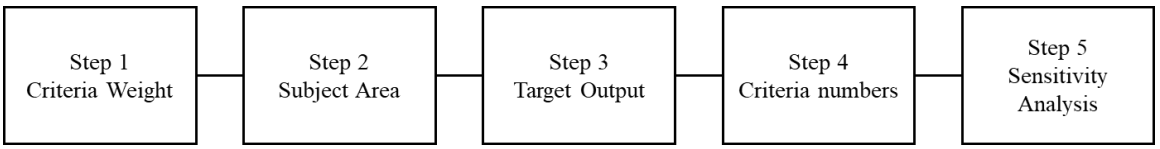

Figure 3. Sustainable Design Decision-Making Selection Framework

4.1 Criteria weight

It is important to get the weight of criteria through expert or experienced professionals. At this step researchers should consider the capability of criteria weight to be evaluated and described quantitively. If so, the weight can be collected by expert or professional scoring. If else, a Fuzzy set method could be helpful to help this process. Criteria is also important to be normalized or scaled when it refers to both quantitively and qualitatively, to integrate them into a same scale (Messac, Ismail-Yahaya, & Mattson, 2003).

4.2 Subject area

Decision-making methods have good consistency with specific subject field. At this step, the subject area of the research should be determined and a list of suitable MCDM can be found out. The specific MCDM method of each subject field is listed in the Table 2 below.

For studies focus on electronic product design. AHP is the most correlated method. In electrical product design, designers need to compare environmental impact of design options in a simple way, which meet the advantage of AHP method.

For other product design, various methods are correlated, however there are still selection principle based on the features of different MCDM methods. TOPSIS is utilized to measure the relative performance of alternatives in the decision of a simple mathematical form. Pareto method solve the problem when a set of design alternatives are needed. BWM is more applicable to studies with less comparative data. VIKOR method is more suitable for product material selection. DEMENTRIAL method has more advantages when criteria have complex cause-effect or interdependent relations.

For conceptual design and design for end-of-life, AHP and Pareto method are most correlated. AHP method is utilized to combines multiple goals into a single goal. Pareto method tends to generate a set of design alternatives. In the field of supply chain design, BWM is mostly used due to the usage practice in previous studies.

Table 2. Statistic of specific MCDM methods for each subject area

Subject Area / MCDM Methods	AHP	TOPSIS	Pareto	BWM	VIKOR	DEMENTRIAL
Product design (electronic)	6					
Product design (others)	2	7	7	3	4	2
Conceptual design	8		10			2
Supply chain design	2	1	5	2		
Design for end-of-life	3	3	5			
logistics design	2		1	1		

4.3 Target output

There are three main styles of output in the review of sustainable design. The first is a sustainable-related index. Secondly is the final score per alternative for selection. Thirdly is a set of optional solutions. Researchers should determine the target output style of the study and select the appropriate method. The specific target output style of each method is sorted out in the Table 3 below.

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press

Table 3. The target output of each MCDM method

MCDM Methods	Index	Alternative Selection	Solutions Set
AHP	√	√	
TOPSIS	√	√	
Pareto			√
BWM		√	
VIKOR		√	
DEMATEL	√	√	

4.4 Criteria size

The criteria size of the research was found to affect the selection of decision-making method. Different MCDM have apparently different appropriate criteria size.

4.5 Sensitivity analysis

A sensitivity analysis is conducted in order to monitor the robustness of solution ranking to changes. The priority ranking of the criteria and sub criteria is highly depended on the experts' judgement. So, to verify the stability in the global ranking, weights of the criteria is changed. Multi experiments should be done by changing their weights. In each experiment, weights of two criteria are interchanged and the rest are kept unchanged. Then see the priority ranking of other criteria and the final ranking of alternatives. If the ranking of other criteria and does not hamper in the ranking of the product alternatives, the process is stable.

5 FUTURE TREND AND OPPORTUNITIES

Firstly, no matter what weight determination method, the weight determination process relies on the experts, which may result in subjective and slightly biased decision making. The information from experts often features with uncertainty and imprecision. Some methods integrating uncertainty theory for evaluating design alternatives need to be further developed. It is needed to apply a new multi-person decision-making approach (MPDM) to obtain weights, broaden the reliability factor. It is also a good solution using statistics instead of expert judgements if conditions allow.

Secondly, it sees a good future to integrate MCDM methods in weight determination and decision-making process. Although most of the reviewed articles use a single MCDM method to analysis, more studies are using integrated MCDM methods with time pass. Considering the integration of different MCDM methods can improve the accuracy of results, which has been proved in studies, further studies should aim on using integrated MCDM methods. However, 16 of the articles reviewed use different MCDM methods separately in weight determination and decision-making process, which are not the application of integrated MCDM methods. The effectiveness and accuracy of different integration MCDM methods still need to study. Current studies lack of theoretical explanation for conducting integrated MCDM methods. Future research should explore whether it is beneficial to integrate more than two MCDM methods. Systematic research on the accuracy impact of different integration MCDM methods should also be conducted. Some other non-MCDM methods mixed with MCDM methods should also be explored in the future. What's more, a trend analysis, which indicates transforms in applied methods in various subject area, can provide more favourable support and foundation for subsequent framework.

Thirdly, a comprehensive sensitivity analysis study regarding weights and final results should be included. More research should be conducted to test the method and more data should be tested om sensitivity analysis. Further case studies also need to be conducted to prove the effectiveness of the selection framework.

6 CONCLUSIONS

This paper presents a systematic review of decision-making process for sustainable design. Through a systematic literature review, 122 related papers were identified and reviewed, during the period of 1999-2021. Our synthesis of the literature shows that researchers applied various MCDM methods to analysis different subject area of sustainable design, model sustainable design enablers and barriers, evaluate and design sustainable design projects or programs, develop systems or strategies for specific

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press

sustainable design programs, and conduct sustainable design performance evaluations. MCDM methods were applied to achieve these purposes.

This study makes some valuable contributions. Firstly, this study summarized the overall decision-making process for sustainable design. The process can be summarized into four steps: criteria determination, weight determination, decision-making process and output. These analyses will help guide researchers conduct decision-making process for sustainable design. Secondly, this study conducted a comprehensive and systematic review of MCDM methods conducted in sustainable design. MCDM methods that were most frequently used, such as AHP, TOPSIS and Pareto related methods, are detailed reviewed, other mentioned MCDM methods such as BWM, DEMATEL and VIKOR are also reviewed combined with specific articles. These analyses will help researchers understand the pros and cons of each MCDM methods and their appropriate application subject areas. Lastly, this research developed a framework for MCDM methods selection. The framework considers the specific characteristics of study and facilitates researchers to select appropriate MCDM methods in sustainable design. The framework aims to help further researchers improve the efficiency and accuracy on decision-making process for sustainable design.

While this study analyzed the identified papers, it also has limitations. This study only considered published journal paper in English. As a result, the findings presented may not be complete. The improvement of integrated MCDM methods still need further research, and a new selection framework for integrated MCDM methods need to be developed.

REFERENCES

Ajukumar, V. N., & Gandhi, O. P. (2013). Evaluation of green maintenance initiatives in design and development of mechanical systems using an integrated approach. *Journal of Cleaner Production*, *51*, 34-46. https://dx.doi.org/10.1016/j.jclepro.2013.01.010

Ali, S. S., Paksoy, T., Torgul, B., & Kaur, R. (2020). Reverse logistics optimization of an industrial air conditioner manufacturing company for designing sustainable supply chain: a fuzzy hybrid multi-criteria decision-making approach. *Wireless Networks*, *26*(8), 5759-5782. https://dx.doi.org/10.1007/s11276-019-02246-6

Azapagic, A., & Clift, R. (1999). The application of life cycle assessment to process optimisation. *Computers & Chemical Engineering*, *23*(10), 1509-1526. https://dx.doi.org/10.1016/s0098-1354(99)00308-7

Baglivo, C., Congedo, P. M., & Fazio, A. (2014). Multi-criteria optimization analysis of external walls according to ITACA protocol for zero energy buildings in the mediterranean climate. *Building and Environment*, *82*, 467-480. https://dx.doi.org/10.1016/j.buildenv.2014.09.019

Behzadian, M., Otaghsara, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, *39*(17), 13051-13069. https://dx.doi.org/10.1016/j.eswa.2012.05.056

Bellman, R. E., & Zadeh, L. A. (1970). Decision-making in a fuzzy environment. *Management science*, *17*(4), B-141-B-164.

Chakraborty, K., Mondal, S., & Mukherjee, K. (2017). Analysis of product design characteristics for remanufacturing using Fuzzy AHP and Axiomatic Design. *Journal of Engineering Design*, *28*(5), 338-368. https://dx.doi.org/10.1080/09544828.2017.1316014

Chen, R. Y. (2016). Feedback-Based Eco-Design for Integrating the Recency, Frequency, and Monetary Value of Eco-Efficiency into Sustainability Management. *Systems*, *4*(3). https://dx.doi.org/10.3390/systems4030030

Choi, J. K., Nies, L. F., & Ramani, K. (2008). A framework for the integration of environmental and business aspects toward sustainable product development. *Journal of Engineering Design*, *19*(5), 431-446. https://dx.doi.org/10.1080/09544820701749116

Cong, L., Zhao, F., & Sutherland, J. W. (2019). A Design Method to Improve End-of-Use Product Value Recovery for Circular Economy. *Journal of Mechanical Design*, *141*(4). https://dx.doi.org/10.1115/1.4041574

Darbari, J. D., Kannan, D., Agarwal, V., & Jha, P. C. (2019). Fuzzy criteria programming approach for optimising the TBL performance of closed loop supply chain network design problem. *Annals of Operations Research*, *273*(1-2), 693-738. https://dx.doi.org/10.1007/s10479-017-2701-2

Delaney, E., Liu, W., Zhu, Z., Xu, Y., & Dai, J. S. (2022). The investigation of environmental sustainability within product design: a critical review. *Design Science*, *8*. https://dx.doi.org/10.1017/dsj.2022.11

Feng, H. B., Kassem, M., Greenwood, D., & Doukari, O. Whole building life cycle assessment at the design stage: a BIM-based framework using environmental product declaration. *International Journal of Building Pathology and Adaptation*. https://dx.doi.org/10.1108/ijbpa-06-2021-0091

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinee, J., Heijungs, R., Hellweg, S., . . . Suh, S. (2009). Recent developments in Life Cycle Assessment. *J Environ Manage*, *91*(1), 1-21. https://dx.doi.org/10.1016/j.jenvman.2009.06.018

Gabus, A., & Fontela, E. (1972). World problems, an invitation to further thought within the framework of DEMATEL battelle institute. *Geneva research centre*.

Girubha, R. J., & Vinodh, S. (2012). Application of fuzzy VIKOR and environmental impact analysis for material selection of an automotive component. *Materials & Design*, *37*, 478-486. https://dx.doi.org/10.1016/j.matdes.2012.01.022

Gu, W., Wang, C., Dai, S. F., Wei, L. R., & Chiang, I. R. (2021). Optimal strategies for reverse logistics network construction: A multi-criteria decision method for Chinese iron and steel industry. *Resources Policy*, *74*. https://dx.doi.org/10.1016/j.resourpol.2019.02.008

Hassan, M. F., Saman, M. Z. M., Sharif, S., & Omar, B. (2012, Jan 13-15). *An integrated MA-AHP approach for selecting the highest sustainability index of a new product.* Paper presented at the International Conference of the Asia-Pacific-Business-Innovation-and-Technology-Management-Society, Pattaya, THAILAND.

Hoose, A., Yepes, V., & Kripka, M. (2021). Selection of Production Mix in the Agricultural Machinery Industry Considering Sustainability in Decision Making. *Sustainability*, *13*(16). https://dx.doi.org/10.3390/su13169110

Janssen, M., Chambost, V., & Stuart, P. (2009, Jun 07-12). *Choice of a Sustainable Forest Biorefinery Product Platform Using an MCDM Method.* Paper presented at the 7th International Conference on the Foundations of Computer-Aided Process Design (FOCAPD), Breckenridge, CO.

Kitchenham, B., Brereton, O. P., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering - A systematic literature review. *Information and Software Technology*, *51*(1), 7-15. https://dx.doi.org/10.1016/j.infsof.2008.09.009

Lee, B. X., Kjaerulf, F., Turner, S., Cohen, L., Donnelly, P. D., Muggah, R., . . . MacGregor, L. S. (2016). Transforming our world: implementing the 2030 agenda through sustainable development goal indicators. *Journal of public health policy*, *37*(1), 13-31.

Liechty, J. C., Mabey, C. S., Mattson, C. A., Salmon, J. L., & Weaver, J. M. (2022). *Trade-Off Characterization Between Social and Environmental Impacts Using Agent-Based Models and Life-Cycle Assessment.* Paper presented at the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Lounis, Z., & Daigle, L. (2013). Multi-objective and probabilistic decision-making approaches to sustainable design and management of highway bridge decks. *Structure and Infrastructure Engineering*, *9*(4), 364-383. https://dx.doi.org/10.1080/15732479.2012.657652

Ma, J. F., Kremer, G. E. O., & Ray, C. D. (2018). A comprehensive end-of-life strategy decision making approach to handle uncertainty in the product design stage. *Research in Engineering Design*, *29*(3), 469-487. https://dx.doi.org/10.1007/s00163-017-0277-0

Maghsoodi, A. I., Mosavat, M., Hafezalkotob, A., & Hafezalkotob, A. (2019). Hybrid hierarchical fuzzy group decision-making based on information axioms and BWM: Prototype design selection. *Computers & Industrial Engineering*, *127*, 788-804. https://dx.doi.org/10.1016/j.eie.2018.11.018

Martinez, S., Gonzalez, C., Hospitaler, A., & Albero, V. (2019). Sustainability Assessment of Constructive Solutions for Urban Spain: A Multi-Objective Combinatorial Optimization Problem. *Sustainability*, *11*(3). https://dx.doi.org/10.3390/su11030839

Mattson, C. A., Lofthouse, V., Bhamra, T., & Asme. (2015, Aug 02-05). *Exploring decision tradeoffs in sustainable design.* Paper presented at the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Boston, MA.

Mattson, C. A., Pack, A. T., Lofthouse, V., & Bhamra, T. (2019). Using a Product's Sustainability Space as a Design Exploration Tool. *Design Science*, *5*. https://dx.doi.org/10.1017/dsj.2018.6

Messac, A., Ismail-Yahaya, A., & Mattson, C. A. (2003). The normalized normal constraint method for generating the Pareto frontier. *Structural and multidisciplinary optimization*, *25*, 86-98.

Mihelcic, J. R., Paterson, K. G., Phillips, L. D., Zhang, Q., Watkins, D. W., Barkdoll, B. D., . . . Hokanson, D. R. (2008). Educating engineers in the sustainable futures model with a global perspective. *Civil Engineering and Environmental Systems*, *25*(4), 255-263. https://dx.doi.org/10.1080/10286600802002981

Niero, M., & Kalbar, P. P. (2019). Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level. *Resources Conservation and Recycling*, *140*, 305-312. https://dx.doi.org/10.1016/j.resconrec.2018.10.002

Palacio, A., Adenso-Diaz, B., & Lozano, S. (2018). A Decision-making model to design a sustainable container depot logistic network: the case of the port of Valencia. *Transport*, *33*(1), 119-130. https://dx.doi.org/10.3846/16484142.2015.1107621

Qi, H. H., Lee, E., Gea, H. C., & Asme. (2013, Aug 04-07). Decision making tool in life cycle assessment for packaging sustainability. Paper presented at the ASME International Design Engineering Technical Conferences / Computers and Information in Engineering Conference (IDETC/CIE), Portland, OR.

Qi, Y. H., Wang, S. W., Pan, J. Q., Liu, Z. F., Zhang, H. C., & Society, I. C. (2006, May 08-11). *Environmental impact assessment method based synthesis weight.* Paper presented at the 14th IEEE International Symposium on Electronics and the Environment (ISEE)/7th Electronics Recycling Summit, San Francisco, CA.

Remery, M., Mascle, C., & Agard, B. (2012). A new method for evaluating the best product end-of-life strategy during the early design phase. *Journal of Engineering Design*, *23*(6), 419-441. https://dx.doi.org/10.1080/09544828.2011.605061

Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega-International Journal of Management Science*, *53*, 49-57. https://dx.doi.org/10.1016/j.omega.2014.11.009

Rezaei, J., Papakonstantinou, A., Tavasszy, L., Pesch, U., & Kana, A. (2019). Sustainable product-package design in a food supply chain: A multi-criteria life cycle approach. *Packaging Technology and Science*, *32*(2), 85-101. https://dx.doi.org/10.1002/pts.2418

Rossi, M., Papetti, A., Marconi, M., & Germani, M. (2019). A multi-criteria index to support ecodesign implementation in manufacturing products: benefits and limits in real case studies. *International Journal of Sustainable Engineering*, *12*(6), 376-389. https://dx.doi.org/10.1080/19397038.2019.1575926

Saaty, T. L. (1988). What is the analytic hierarchy process? In *Mathematical models for decision support* (pp. 109-121): Springer.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9-26.

Saaty, T. L. (2005). *Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks*: RWS publications.

Sabaghi, M., Mascle, C., & Baptiste, P. (2016). Evaluation of products at design phase for an efficient disassembly at end-of-life. *Journal of Cleaner Production*, *116*, 177-186. https://dx.doi.org/10.1016/j.jclepro.2016.01.007

Shaharuzaman, M. A., Sapuan, S. M., Mansor, M. R., & Zuhri, M. Y. M. (2019). Decision Support Strategy in Selecting Natural Fiber Materials for Automotive Side-Door Impact Beam Composites. *Journal of Renewable Materials*, *7*(10), 997-1010. https://dx.doi.org/10.32604/jrm.2019.07529

Shukla, O. J., Jangid, V., Siddh, M. M., Soni, G., & Kumar, R. (2017, Feb 03-05). *Evaluating key factors of sustainable manufacturing in Indian automobile industries using Analytic Hierarchy Process (AHP).* Paper presented at the International Conference on Advances in Mechanical, Industrial, Automation and Management Systems (AMIAMS), Allahabad, INDIA.

Tian, G. D., Zhang, H. H., Zhou, M. C., & Li, Z. W. (2018). AHP, Gray Correlation, and TOPSIS Combined Approach to Green Performance Evaluation of Design Alternatives. *Ieee Transactions on Systems Man Cybernetics-Systems*, *48*(7), 1093-1105. https://dx.doi.org/10.1109/tsmc.2016.2640179

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*(3), 207-222. https://dx.doi.org/10.1111/1467-8551.00375

Wang, X. J., Chan, H. K., Lee, C. K. M., & Li, D. (2015). A hierarchical model for eco-design of consumer electronic products. *Technological and Economic Development of Economy*, *21*(1), 48-64. https://dx.doi.org/10.3846/20294913.2013.876685

Wind, Y., & Saaty, T. L. (1980). Marketing applications of the analytic hierarchy process. *Management science*, *26*(7), 641-658.

Yi, S. L., & Wu, C. F. (2021). Green-Extension Design-A New Strategy to Reduce the Environmental Pressure from the Existing Consumer Electronics. *International Journal of Environmental Research and Public Health*, *18*(18). https://dx.doi.org/10.3390/ijerph18189596

Yu, H., & Solvang, W. D. (2017). A carbon-constrained stochastic optimization model with augmented multi-criteria scenario-based risk-averse solution for reverse logistics network design under uncertainty. *Journal of Cleaner Production*, *164*, 1248-1267. https://dx.doi.org/10.1016/j.jclepro.2017.07.066

Zadeh, L. A. (1975). The concept of a linguistic variable and its application to approximate reasoning—I. *Information Sciences*, *8*(3), 199-249.

Zhang, L., Dong, W. F., Jin, Z. F., Li, X. Y., & Ren, Y. Q. (2020). An integrated environmental and cost assessment method based on LCA and LCC for automobile interior and exterior trim design scheme optimization. *International Journal of Life Cycle Assessment*, *25*(3), 633-645. https://dx.doi.org/10.1007/s11367-019-01691-x

Zhu, Z. C., Liu, W., Ye, S. H., & Batista, L. (2022). Packaging design for the circular economy: A systematic review. *Sustainable Production and Consumption*, *32*, 817-832. https://dx.doi.org/10.1016/j.spc.2022.06.005

https://doi.org/10.1017/pds.2023.273 Published online by Cambridge University Press