# Investigation on Multi-Criteria Decision Making Methods Application in Sustainable Product Design

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## ARTICLE INFO

## ABSTRACT

**Background**: Integrating sustainability development' aspects in the design process is becoming, a growth area in companies. Consequently, sustainable product design has to consider the different aspects of sustainability throughout its life cycle phases in addition of other requirements. This integration is becoming more complicated due the difficulty of managing the constraints and alternatives related to the product and stakeholders needs. This study aims to highlights the most used Multi-Criteria Decision Making (MCDM) tools and methods used in sustainable product design process.

**Contribution**: Product design process involves interesting decisional tasks such as the choice of materials, standard parts, technical solutions. Hence, the contribution of this work is to help designer to adopt relevant MCDM tools and methods that can be integrated to other tools to facilitate and to justify their decisional tasks.

**Method**: Several methods have been affected to solve the problems related to this complexity such as MCDM. A literature review was conducted based on Siencedirect and GoogleScholar articles databases. After filtering more than 200 articles only 62 articles were considered to analyze the correlation between sustainable product design and MCDM.

**Results: C**lassified MCDM use according to the type of choices to achieve SPD goals. This paper allowed us to find matches between MCDM methods and SPD problem. The majority of case studies result show that a large portion of sustainable design methods, techniques, and tools are applied to the sustainable product' along its different life cycle phases

**Conclusion:** It is noticed that the use of MCDM methods are an important outcome in the sustainable product design process and deeply helps designers to make suitable choices. Also, several matches relating MCDM, other methods and sustainable product design sphere are discussed.

## INTRODUCTION

Newsday, the intensity of sustainability or sustainable development is covering the industrial and academic fields. In engineering design, the coupling of sustainability aspects and design requirements throughout the product life cycle phases leads to Sustainable Product Design Process (SPDP) context. Sustainable Product Design (SPD) is getting more intention in the recent research. However, this integration shows an inherent both complexity in the evaluation and the integration of sustainability aspects in the design product process.

Therefore, some studies have proposed and developed some methodologies to help designers to make decision in their choice process. Hence, to solve this complexity a number of methods, tools and techniques are implemented in the SPDP framework. Thus, [1] discussed important technological requirements in product architecture and integrated optimization to realize integrated sustainable design and manufacturing. They introduce a scalable design environment which can convey sustainability principles in the context of product architectural design, manufacturing, assembly, and supply chain decisions to designers. However, [2] proposed a sustainable product design framework incorporating rule-based and model-based methods. Where, Life cycle sustainability assessment (LCSA) method is incorporated into optimization to offer a comprehensive view of sustainability. Afterwards, product design targets and design alternatives are generated using knowledge-base and heuristics to reduce the impacts on hotspots. Then, LCSA or rule-based methods is applied to decide the most sustainable product from the generated product design alternatives. Besides, [3] combined the Pythagorean Fuzzy Set with Analytical Network Process (ANP), Quality Function Deployment (QFD), and Grey Relational Analysis (GRA) approaches to prioritize design requirements of sustainable supply chain (SSC) and to better handle uncertainty in the SSC. Based on the proposed method, the decision-maker can conduct comprehensive analysis to prioritize design requirements (DRs) and design appropriate SSC to fulfill customer requirements (CRs) under uncertain environment. Moreover, [4] analyzed the key factors for achieving sustainable product design in fashion based on the triple bottom line (TBL) framework. They establish a sustainable product development process (SPDP) matrix, which can guide the fashion supply chain members to operate in a sustainable manner during the SPDP. In addition, [5] conducted a literature review to identify various used sustainable product design tools. Further, they ranked the tools using an analytical hierarchy process. The results show that design of sustainability, modular design, and life cycle assessment are the tools that have a significant impact on the improvement of product design sustainability.

In short, this article presents a literature review that can improve the understanding and the usefulness of multi-criteria decision making (MCDM) (tools, methods and techniques) in SPDP. Thus this work is based on a literature review to highlights most used MCDM tools, methods and techniques whish will be later discussed and classified as a part of SPDP.

This article is organized as follow: Section 2 presented a definition of general concepts related to SPD as background. In section 3, the literature review methodology is presented and discussed. Then, a state of art of MCDM methods, tools and techniques applied in the SPD is presented and classified in the section 4. In the section 5, obtained results are discussion and reported. Finally a conclusion and future research are presented in the end.

### Sustainability and Sustainable Products

The most cited definition of sustainability is presented by Brundtland Report where sustainable development is defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]. This

concept is commonly based on three pillars which are environmental, economic and social aspects [7]. Figure 1 presents the different pillars of sustainability.
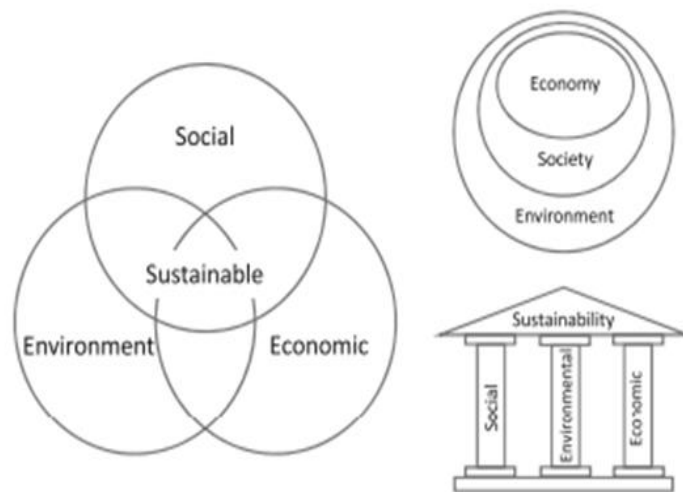


**Figure 1.** Sustainable Development's Pillars

However, [8] have defined the sustainable Product as a 'product that has little impact on the environment, and at the same time, has been designed with consideration of the economic and societal aspects to ensure future benefits'. Moreover, [9] [10] studied sustainable product and identified its factors which are presented in figure 2.



**Figure 2**. Factors of Sustainable Product

**Sustainable Product Design**

According to [11], 'Product design is one of the most important stages in sustainable product development. Consequently, Design affects all stages of product life cycles from extracting raw materials to the end of product life'. Besides, the sustainable design is an extraction and evolution of traditional design approach which involve the concepts of human filed, production, energy, transportation, communication and economy [9]. Furthermore, [12] have described the sustainable design as a design process for a product with considering the environment impact during its entire life cycle. Also, [13] developed a methodology incorporated the sustainability concept into design process.

For SPD techniques, [14] suggested the idea of integrating the pillars of sustainability and the design concepts. On the other hand, [9] have stated that the implementing of sustainability

aspects into the life cycle product design provide an opportunity to reduce a product's negatives impacts on society, environment and economy. In their work, [15] have considered the sustainability in the product design as a part of the wider research and practice of sustainability development. They claimed that the environmentally Sustainable Design (also referred to as: Green Design or Eco-Design) helps products, services and systems to be produced in a more efficient way. It reduces the use of non-renewable resources and minimizes the environmental impact. However, the economic sustainable design "can be achieved by creating products and services that are more economic to produce, transport and use, and better adapted to their needs, i.e. developing countries". Nevertheless, the Social sustainability "is the design for all philosophies, targeting to the minority users, such as disabled and elderly individuals, children and individuals from cultural or linguistic minorities".

## METHOD

A comprehensive literature research was performed to collect the relevant published articles about the sustainable product design in which articles published between 2010 and 2020 are selected. In this framework, we used the following keywords: "sustainable development", "sustainable design", design for sustainability", "sustainable product design". Also, the journal data base "ScienceDirect", and "Google Scholar" were used for our literature review. Figure 3 presents selection steps and exclusion conditions of articles relevant to our topic.
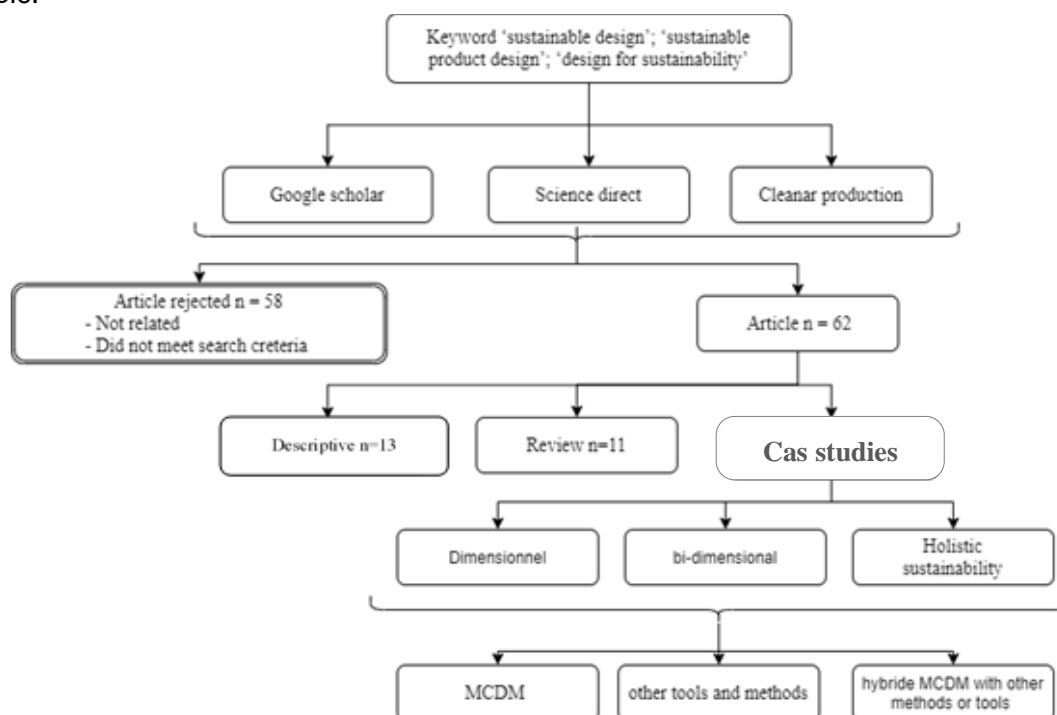


**Figure 3.** Articles Selection Methodology

260 potential papers were initially identified which 198 publication were rejected, because they did not meet our research criteria and 62 papers were included in the present systematic review. Eventually, this 62 contained 13 descriptive papers, 12 reviews and 37 case studies which belong to different sectors. Though, the 37 cases study are grouped according to (type of dimension, the method used and type of methods) which are presented in table 1.

## RESULTS AND DISCUSSION

### Review Data

Table 1 summarizes the studies that take in consideration the different aspects of sustainability and the MCDM methods, techniques and tools and they integration with other tools and methods which are grouped into quantitative one and qualitative one.

**Table 1.** Literature Review Articles Data

| Authors | MCDM | Other Tools or methods | Objectives | Method type | |
|---|---|---|---|---|---|
| | | | | Quantitative | Qualitative |
| Vinodh and Rathod, 2010 | - | ECQFD- LCA | Ensuring a SPD | | X |
| Kyratsis *et al.*, 2012 | - | CAD - SOLDWORKS | Selection of sustainable material | | X |
| Hashim and Dawal, 2012 | - | Kano Model - QFD | Improve the school workshops design (ergonomic) | | X |
| Mosavi, 2013 | MOO | RSO | Selection of sustainable material | | X |
| Bereketli *et al.*, 2013 | FAHP | QFDE | Identify the improvement strategy for SPD | X | X |
| Buchert *et al.*, 2015 | Decision Tree | LCA | Selection the sustainable material | | X |
| Hosseinpour *et al.*, 2015 | - | QFD – LCA | Selection of the best preferment components | X | |
| Younesi and Roghanian, 2015 | FANP - F-DEMATEL | QFDE | Identify the best design criteria | X | X |
| Kulatunga *et al.*, 2015 | AHP - GRA | LCA | Id. the sustainable platform for a product family | X | |
| Anojkumar *et al.*, 2016 | AHP - FAHP PROMETHE | - | Solving material selection problem | X | |
| Huang *et al.*, 2016 | - | Checklist | Construction of a decision model for sustainable servicing design | | X |
| Jahan *et al.*, 2016 | MODM - MADM | - | Selection of sustainable materials | X | |
| Chowdhury *et al.*, 2016 | FAHP | Optimization model – FQFD | Sustainable m-health services design | X | |
| He *et al.*, 2016 | - | LCA | Evaluate the product environmental footprint | X | |
| Polat *et al.*, 2017 | AHP - COPAR | - | Selection of appropriated mechanical design team | X | |
| Karatas, 2017 | - | MPP-WFAD | Selection of company or industry | X | |
| Chandrakumar *et al.*, 2017 | FAHP | - | Selection of sustainable sanitation system design | X | |

| Vicente *et al.*, 2017 | - | Questionnaire | Selection of sustainable wood furniture products | | X |
|---|---|---|---|---|---|
| Sousa-Zomer and Miguel, 2017 | FAHP | Fuzzy QFD | Ranking stakeholder's requirement on PSS Design | X | X |
| Schöggl *et al.*, 2017 | | Checklist | Id. and define the key sustainability performance | | X |
| Badurdeen *et al.*, 2018 | MOO - NSGA-II | | Id of optimal product configuration design | X | |
| Loganathan and Mani, 2018 | VIKOR – PROMETHEE – FAHP– TOPSIS | - | Selection of the sustainable electronic cooling material | X | |
| Babbar and Amin, 2018 | MOP | QFD | Selection of the best suppliers and order allocation | X | X |
| Guini *et al.*, 2018 | ROC - PROMETHEE | - | Choose the best concept of single brake disc | X | |
| Mohebbi *et al.*, 2018 | MMP – Fuzzy Choquet & Sugeno integrals | - | Assessing requirements' abstraction degree in mechatronic systems design | X | |
| Woodhouse *et al.*, 2018 | – | Checklist | Assessing in food processing design sustainability | | X |
| Allaoui *et al.*, 2018 | AHP – OWA – MOO | - | Optimizing agro-food supply chain design | X | X |
| He *et al.*, 2018 | - | Checklist | Mapping from sustainable functional requirements to the design parameters | | X |
| Steenis *et al.*, 2018 | | ANOVA - SPSS | Selection of sustainable packaging design strategy | X | |
| Tao and Yu, 2018 | – | QFD – sustainable value | Selection of sustainable product | X | X |
| Rezaei *et al.*, 2019 | BWM | – | Sustainable product package design | X | |
| Azmi and Kandra, 2019 | – | – | Designing environmentally sustainable mosques | | |
| Sansa *et al.*, 2019 | FANP | SWOT - PESTEL -7 S | Choice of optimal sustainable design scenario | | X |
| Rivera *et al.*, 2019 | – | LCA | Selection innovative solution for food packaging | X | |
| Singh and Sarkar, 2019 | Fuzzy Delphi - DEMATEL | – | Selection of the most significant practices for SPD | X | |
| Mohammed *et* | FAHP – FMOP - | _ | Solving the allocation | X | |

| al., 2019 | TOPSIS | | problem | |
|---|---|---|---|---|
| Bouyarmane and Sallaou, 2019 | _ | LCA | Evaluate the environmental impact during the design phase | X |
| Chunhua *et al.*, 2020 | AHP - Intuitionistic judgment matrix – Morphological matrix | Weighted averaging | Selection the optimal solution principles | X |

**Abbreviation List**:

BWM: Best Worst Method
CAD: Computer Assisted Design
COPAR: Complex Proportional Assessment
DEMATEL: Decision-Making Trial and Evaluation Laboratory
ECQFD: Environmentally Conscious QFD
FAHP: Fuzzy Analytic Hierarchy Process
FANP: Fuzzy Analytic Process
FMOP: Fuzzy Multi-Objectives Programming
GRA: Grey Relational Analysis
LCA: Life Cycle Assessment
MADM: Multi-Attribute Decision-Making
MMP: Multi-Criteria Profile
MODM: Multi-Objective Decision-Making
MOO: Multi-Objective Optimization
MOP: Multi-Objective Programming
MPP-WFAD: Multi-Period Probabilistic Weighted Fuzzy Axiomatic Design

NSGA-II: Non-dominated sorting genetic algorithm II
OWA: Order Weighing Averaging
PESTEL: Political, Economic, Sociological, Technological, Legal and Environmental
PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation
PSS: Product Service System (PSS)
QFDE: Quality function deployment for environment
ROC: Rank Order Centroid
RSO: Reactive Search Optimization
SPD: Sustainable Product Design
SWAT: Strengths, Weaknesses, Opportunities, and Threats
TOPSIS: Technique for Order Preference by Similarity to Ideal Solution
VIKOR: VlseKriterijumska Optimizcija I Kaompromisno Resenje (in Serbian)

Data collected from the table 1 are uploaded in a MS Excel® sheet to perform statistical descriptive analysis. The figure 4 present the distribution of articles per industry sector, we notice that the most important industry sectors are respectively the automotive and furniture with 20% of all study to each sector, the building sector with 18%, the packaging sector with 11% and the food sector with 7%.
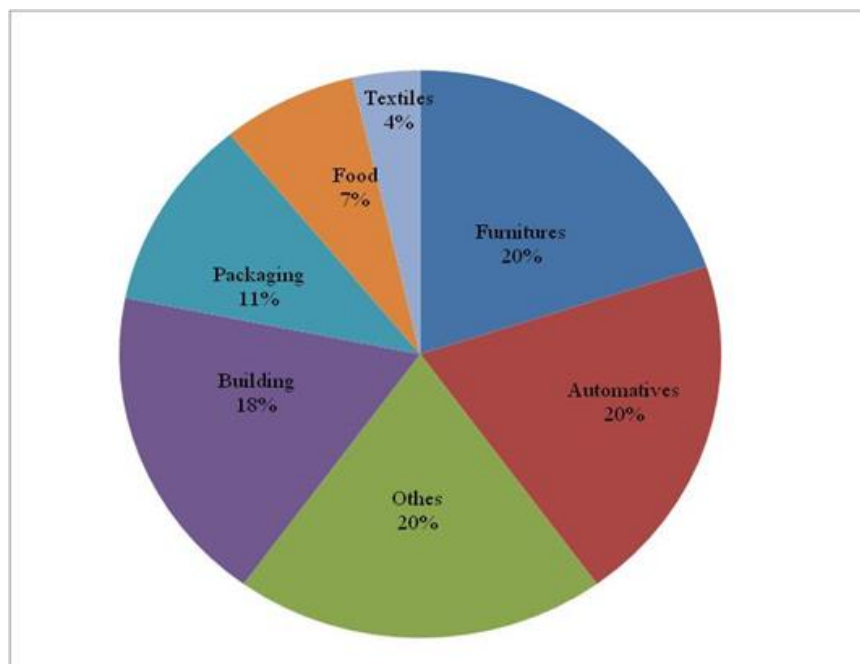


**Figure 4.** Articles Distribution According Industrial Sectors

The figure 5 presents a classification of these studies into three categories are; one-dimensional focus; bi-dimensional focus and the holistic sustainability. We notice that the majority of study the majority of this study focus on one-dimensional (social aspect (one article), economic aspect (4 articles) and environment aspect (9 articles)).
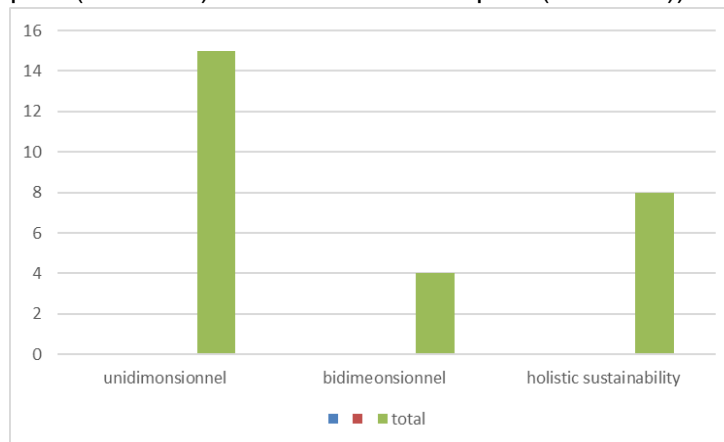


**Figure 5.** Articles Classification According To Sustainability Dimensions

## Design Domain

The use of MCDM methods in SPDP is receiving increasing attention for solving design problems. In this vein, [16] approved that the decision-making methods are an effective support to engineering design. There are few research papers that propose a classification and discussion of MCDM methods in SPD. Hence, [17] classified the MCDM in Multi-Object Decision Making methods (MODM) and Multi-Attribute Decision Making methods (MADM) as mentioned in figure 6. On the other hand, [16] proposed a classification of methods used for solving engineering design problem in automotive sector such as: MCDM; Problem Structuring Method; Decision Making Problem Solving, etc. In this field, authors have approved that the decision-making methods are an effective support to engineering design. Furthermore, [18] presented in heir review a categorization of MCDM methods according their problem-solving technique or their mathematical nature.

- MCDM according to their problem-solving technique: value-based method; outranking method; CBA method
- MCDM according to their mathematical nature: MODM, MADM and a combination of MADM & MODM.

In this literature review, we have grouped the studied articles according the type of choices in SPD (material selection, components selection, technological solution selection and others uses).

## MCDM in Selection Sustainable Components

In this framework, [24] has implemented RSO multi-objective optimization software for selecting the sustainable textiles composites materials. Yet, [25] proposed a hybrid Group Multi-criteria Decision Making (GMCDM) model integrating the Rank Order Centroid (ROC) and the PROMETHEE methods to choose the best industrial performance indicators of single braking disc. However, [26] have used the integration of Environmental Quality Function Deployment (EQFD) and Life Cycle Assessment (LCA) to select sustainable component in product end of life phases. Likewise, [11] have proposed a framework integrating QFD, benchmarking and LCA tools to select the sustainable wheelchair components. Besides, [27] have used BMW method to evaluate the sustainability of packaging design alternatives in food

industry. Conversely, [28] have combined SWOT, 7S and PESTEL methods, to initially identify criteria. Then, they implemented Fuzzy ANP to choose the best optimal among the variety of batteries technologies. But, [29] have proposed a LCA approach to choice the sustainable component of welded sheet during lifecycle phases, such as raw material transformation and manufacturing processes.
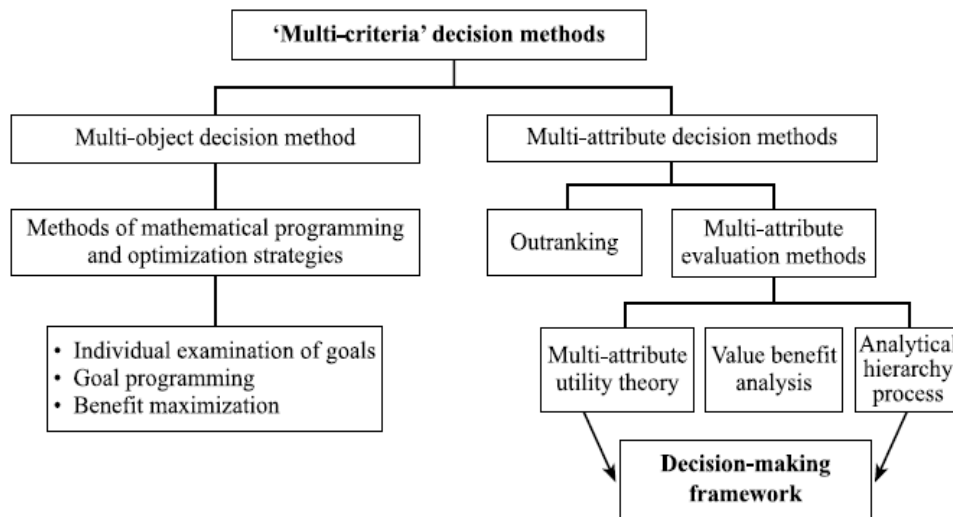


**Figure 6.** Classification of MCDM Methods

**MCDM in Selecting The Sustainable Technological Solution**

In this field, [30] have implemented the Multiperiod Probabilistic Weigthed Fuzzy Axiomatic Design (MPP-WFAD) method to help the designer to select the best stream of income for a long period of times. However, [31] have proposed a hybrid method using Fuzzy DELPHY and DEMATEL for selecting the sustainable eco-design practice in automotive sector. The Fuzzy DELPHY is a qualitative technique implemented for collecting opinions and the DEMATEL is used to obtain the causal relationships between the eco-design practices. Although, [32] have used AHP method for selection the best sustainable system design. On the other hand, [33] have proposed a multi-criteria, multi-objectives optimization problem and the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) to identify the most suited configuration for the toner cartridges. Yet, [34] have presented a new approach based on Multi-Criteria Profile (MCP) and three aggregation techniques, which are Fuzzy logic, Choquet integral and Sugeno integral, for assessing and selecting the best solution of concepts for mechatronic system. Even so, [35] have developed a decision framework integrating techno-environment and circular economy by using the LCA approach to help designer in selecting the suitable innovative solutions of food packaging. Nevertheless, [36] have proposed an integrating multi-criteria decision making model by using AHP, weighting averaging, intuitionistic fuzzy judgment matrix and morphological matrix methods to affect the best choice of spindle system CNC.

**Other Uses**

Besides above presented uses of MCDM in SPD, we find many other uses of these methods. In this perspective, [37] have applied the integration of two multi-criteria decision making methods which are AHP and COPRAS to select the most appropriate mechanical designer company. In addition, [38] have presented the development of a multi-objectives programming model to design a G-resilient supply chain network in solving the allocation

problem of related facilities. Furthermore, [39] have applied the QFDE technique to identify the improvement strategies then they use FAHP to determinate the stakeholder's requirements alternatives to select the most relevant improvements strategies for the hand blander product. Moreover, [40] have integrated the Kano's questionnaire and QFD to improve the design school workshops. Likewise, [41] have proposed an integration of QFDE; DEMATEL and FAHP methods to helps companies to identify the best design criteria. The use of QFDE is to assume the interdependence of costumer attributes, DEMATEL and FAHP are used to find the possible design options. Similarly, [42] have proposed a decision model for sustainable product servicizing by applying the checklist tools. Besides, [43] have proposed a multi-phased QFD based optimization approach in health service design. Also, [44] have integrated the LCA approach in sustainable design process to affect the optimal combinatorial solution in design syntheses approach.

On the other hand, [45] have integrated Fuzzy AHP decision making in the Fuzzy QFD to ranking the influence of stakeholder's requirements on the product services design. Yet, [46] have used a multi-objective model and QFD model for selecting the best supplier and order allocation. However, a checklist tools have been developed by [47] to support the qualitative sustainability in design process in food industry. Additionally, a hybrid methodology using AHP, OWA and MOOM is proposed by [48] to select the sustainable suppliers in agro-food supply chain design. Nevertheless, [49] have implemented the checklist tool to introduces and transform the sustainable functional requirements into design parameters in cleaner production. Although, [50] have applied QFD method for mapping the sustainable value requirements into product engineering characteristics along the whole life cycle of milk maker process.

## CONCLUSION

This paper presents a literature review of articles published along the period 2010-2020 which have treated the SPD concept. It summarizes most used and suited multi-criteria decision-making methods, tools and techniques for solving the SPD problems. Firstly, we have presented the background relate to SPDP supported by the decision-making methods, tools and techniques. Thereafter, we have classified MCDM use according to the type of choices to achieve SPD goals. This literature review allowed us to find matches between MCDM methods and SPD problem. The majority of case studies result show that a large portion of sustainable design methods, techniques, and tools are applied to the sustainable product' along its different life cycle phases. Driving useful metrics form product life cycle, stakeholders' requirements and the sustainability impacts that fits SPDP are challenging tasks. The majority difficulties lie in data collection related to SPDP. The interaction of data affects the implementation of SPD approach. QFD tool play significant role in SPD context. It has the ability to combine product design requirements, and environment, economic and social aspects. Furthermore, it is easily and commonly combined with the multi-criteria decision-making methods. The most past studies focused on the use of AHP and FAHP method to select main SPD parameters. The handle of uncertain data that affect the implementation of SPD is still unsolved. To date, most studies of SPD are focused on environmental aspects assessment while the social aspects are rarely treated as study factors. We notice that the use of MCDM methods presents an important effect in the SPDP and helps designers to make a sustainable choices. Stakeholders' opinion incorporation and conflicting goals are not considered in the majority of studies

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