buildings

MDPI

Review

A Utilitarian Decision—Making Approach for Front End Design—A Systematic Literature Review

Joas Serugga, Mike Kagioglou * and Patricia Tzortzopoulos *

School of Art, Design and Architecture, University of Huddersfield, Huddersfield HD1 3DH, UK; joas.serugga@hud.ac.uk

* Correspondence: m.kagioglou@hud.ac.uk (M.K.); p.tzortzopoulos@hud.ac.uk (P.T.); Tel.: +44-148-447-2289 (M.K.); +44-148-447-2281 (P.T.)

Received: 3 February 2020; Accepted: 16 February 2020; Published: 19 February 2020

check for updates

Abstract: The complexity of construction processes often means interaction between various stakeholders, activities and tasks in order to deliver the expected outcomes. The intensity and dynamics of front-end design (FED) mean decision techniques and methods are important in supporting projects benefits delivery more importantly those based on utility of decision making. This paper explores a new utilitarian decision-making approach based on a systematic literature review of FED decision making. It presents the state of the art in design decision making concepts and analysis of tools over the last 10 years (2009–2019). From a total of 111 peer-reviewed journal papers, fifteen decision-making techniques are identified as dominant in design decision making, broadly grouped in four major categories as explanatory/rational, Multi Criteria Decision Making techniques (MCDM), Hybrid and Visual methods. The review finds that the most applied of the MCDM is Quality Function Deployment (QFD); while among the rational/explanatory techniques is set-based design (SBD). While there is limited application of Multi Attribute Utility Theory (MAUT) in decision making, the paper finds that the robust consistency and structured approach better captures the intricate dynamics of FED; including modelling of the subjectivity, interdependences and uncertainty in design discourse.

Keywords: front end design; multi criteria decision making; utility theory

1. Introduction

The increasing involvement of many stakeholders with varied and sometimes conflicting interests continues to contribute to the complexity of construction processes. This often requires interaction between the various stakeholders, collaboratively in the project processes, activities and tasks in order to deliver the expected outcomes. A lot of the key decision making including management of project requirements, however, is noted to be set in the early project stages [1,2]. Capturing and defining these adequately is key to ensuring the realisation of project benefits. Project benefits are described by authors such as Serra and Kunc [3] as an outcome that creates strategic value as a result of a change process for program and project stakeholders. Such benefits in a front-end design (FED) perspective are intermediate [3]; merely but critically contributing to the end and strategic organizational and project benefits. FED benefits relate as much to the focus of the processes at this stage in embedding value adding project processes during decision-making such as collaborative, integrated and participatory processes for knowledge and information flow and exchanges on the one hand; and management of requirements on the other [4]. The intensity and dynamics of FED, however, mean decision techniques and methods are essential in supporting projects benefits delivery. Design decision making can play an important role in the success of projects as it is central to the transformation of project and stakeholder requirements into design requirements. However, there is little evidence that this understanding is widely shared both in practice and research particularly for front end design (FED). This is even though it is at the FED when vital decision making is taking place that can affect a project's lifecycle performance during this time [1]. Moreover, decision-makers are continually making subjective decisions influenced by their social, economic, environmental, political or technological contexts among others [5,6]. The result is waste and dis-benefits resulting from inefficient and inadequate decision making that ultimately affects requirements management and project processes.

The complexity of construction processes on another hand often means interaction between various stakeholders, various activities and tasks [7–11]; sometimes involving argument, or demonstration in pursuit of interests [12]. These in turn lead to competing and sometimes conflict in requirements [13]. Projects are now expected to deliver expected benefits and impacts that go beyond traditional constraints of time, costs and quality [14]. This suggests that project processes, particularly design decision making, ought to be structured in order that project benefits are realised. This is more acutely important in concept design or rather the project definition stage in lean terms [15].

The dynamic information flow and chaos reported in empirical studies such as that by Austin, Steele [16] in FED suggests that stakeholder collaboration is just as important as structured decision making [13]. According to authors such as Lawson [17] design as a problem-solving endeavour needs to stay in pace with changing user needs and requirements regarding perceived and derived project benefits. Traditional approaches to design processes, therefore, need to be updated to reflect new realities in design; such as for example by augmenting rational (based on reason and logic) processes with newer structured or empirical analytics. Rational approaches can be insufficient in capturing and modelling the complex interdependencies among design and user attributes; and keep pace with the evolving needs of the intrinsically iterative and dynamic nature of FED [18]. In fact, according to Gomes, Tzortzopoulos [19] poor decision practices in design are among the two factors behind conflict among stakeholders; the other, being poor briefs. Both of these can reflect on an inadequate requirements management process and ultimately will contribute to dis-benefits in projects.

It, therefore, follows that alongside a robust stakeholder regime of defining the project's objectives, right at the start, there has to be match in robustness of decision making to better define the project's benefits and outcomes. It is conceivable that hundreds of decisions will have to be made in the course stemming from the many processes, activities and stakeholders required to deliver a typical construction design. Arroyo, Tommelein [20] however argue that decision making in the Architecture, Engineering and Construction (AEC) sector follows neither a structured regime of management nor is there profound understanding of its importance.

As is typical, in construction, complexity means complex decision are never easy to make [21]. There has been a range of tools and methods over the years employed to support design decision making including explanatory/rational methods, Multi Criteria Decision Making (MCDM), hybrid and visual aids. MCDM techniques, generally, use an attribute system to analogise and quantify complex decision making for better analysis using weighting and evaluation.

The fundamental criticism cited in defence of some alternative explanatory/rational and visual techniques mainly MCDM techniques the different results from different methods of the same decision problem [22]. The authors add that it is rather another thing whether in practice, the same decision analysis setting can be replicated for different methods in the same manner and setting for accurate comparison. In defence of MCDM methods however, it can be argued that while these differences do exist, it could suggest instead a case of inconsistency in, or poor application of MCDM rather than MCDM techniques themselves. For example, while the Analytical Hierarchy Process (AHP) that is a basis for much criticism only allows for hierarchical analysis of the attributes that are essentially linear [23,24], the Analytical Network Process (ANP) that is within the same domain allows for analysis of interdependences among attributes [25–27]; something that is essential for the multi-attribute nature of FED. Additionally, important to highlight is the complementarity in many MCDM approaches such as in Quality Function Deployment- Analytical Network Process (QFD)-ANP; [25,28], AHP-MOORA [29], Analytical Hierarchy Process - preference ranking organisation method for enriched evaluation

(AHP-PROMETHEE) [30], QFD-TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) [31], AHP-MAUT (Multi-Attribute Utility Theory) [32] and many others. This allows for the extension of the methodical argument and weaknesses in one by allowing for such things as subjectivity analysis that may not be possible in one technique but in another. This paper, therefore, evaluates and briefly explores the basic principles of some selected MCDM, Explanatory/Rational and Hybrid decision-making techniques alongside some key features important in a FED.

2. Methodology

This study builds on recent emerging research into decision making in AEC sector to support improved delivery of project benefits [33,34]. This research is cast in the perspective of utility theory, an MCDM technique for defining utility of decision making. Authors such as Xiao and Watson [35] and Cook, Greengold [36] firstly highlight the importance of literature reviews as a vital and accepted feature that supports research advancement. The authors argue that reviews present a fundamental link between the present and past research as a basis for new frontiers in the research of a given research area. They add that because of literature reviews, research can benefit from new highlights and breadth of understanding while identifying gaps in present conceptual, theoretical and practice.

According to Paré, Trudel [37] reviews are essential in evaluating the validity and rigour of present research positions against emergent conceptualisations. According to authors, reviews are a basis for building new understanding by identifying weaknesses, gaps and inadequacies in the present research. Xiao and Watson [35] add that rigour and reliability of a literature review, therefore, depends on independent replicability. This means according to the authors that for a systematic review to inform any new frontiers that addresses new hypotheses and theories the process of the review has to have sufficient detail; something that sets them apart from traditional reviews [35]. Above all, the collation of current collective positions and insights is essential to new knowledge. When it is free from bias and chance effects, it gains improved legitimacy for new understanding [34]. Figure 1, therefore, draws to the detailed inclusion/exclusion process for the systematic literature review including the major steps of identifying (searching all potential databases for potential articles for the review), screening (to apply an initial inclusion of articles based on relevance), qualifying (where exclusion criteria is applied to the selected articles) and finally inclusion of appropriate literature based on additional qualifying criteria that would otherwise not be considered in the first place.

2.1. Aim and Research Questions

As the AEC sector continues to explore new frontiers to support improved delivery of project benefits, design decision making has become one of these focus areas. Similarly, there is an increasing recognition of the essential dynamics as a result of the structure and agency influences as understood in the social sciences; that bear down on design processes. It is now accepted that the dynamics of FED and the significant decision making in the processes make impact on the realisation of project benefits. It is similarly recognised that while there exists a significant body of research in design decision making, there is also a lack of converged and coherent approach that fully captures the dynamics of FED. Together with the still limited understanding of the vital role of FED in the delivery of project benefits, this points to the need for new research in this area. This research not only seeks to explore current techniques in design through a state of the art of the key concepts but also attempts to recast these in a utilitarian perspective. To this end, it is aimed the research answers the following research questions.

RQ1—What is the state of the art in design decision making?
RQ2—What techniques and methods are applicable to FED?
RQ3—How do these techniques and methods facilitate utility of decision making in FED?

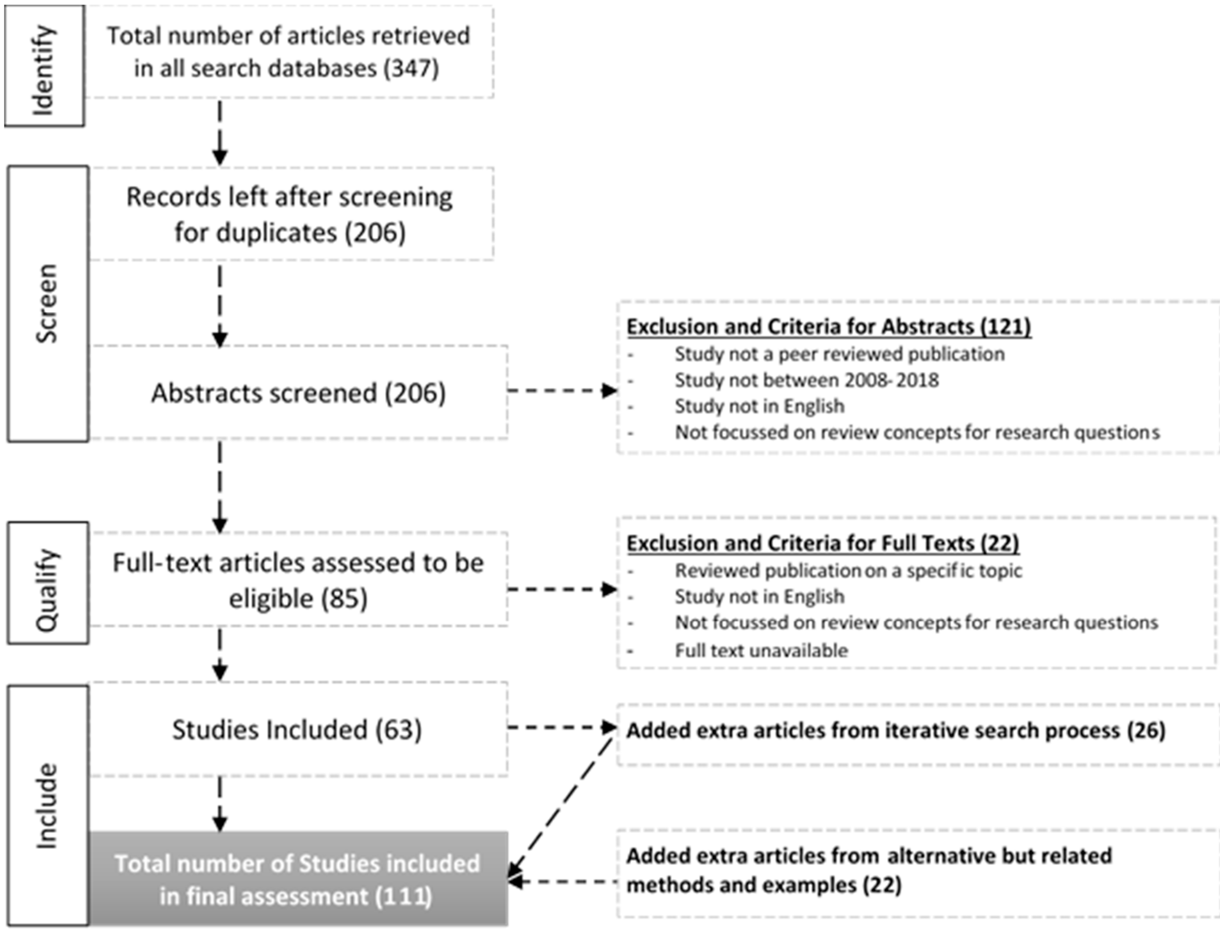

Figure 1. The research approach to include and exclude relevant articles.

2.2. Search Strategy

The Xiao and Watson [35] approach to search is adopted for this research as summarised in Figure 1. Pre-Defined search criteria and objectives are the basis for answering the research questions. This includes defining search spaces and their boundaries in both electronic and print resources. Broadly, the search initially involves retrieving all relevant results from the Web of Science, Google scholar and Scopus the most used databases on decision making in design including, MCDM, MAUT, FED and related variations. These search terms are extracted so they support the research questions. This is followed by snowballing in which other meaningful studies references form part of an expanded search base. Using this approach, it is possible to explore additional studies not identified in the initial search.

The criterion is as follows:

C1—A string of keywords on decision making, including "design decision making" OR "decision making in design".

C2—A string relating to multi-criteria decision making including "MCDM" OR "MADM" OR "MADA" OR "MADM" OR "Utility Theory" OR "Choosing by Advantages" OR "ANP and AHP" OR "QFD".

C3—A string relating to "Front End Design Decision Making" OR "front end planning decision making" OR "early-stage design decision making" OR "conceptual design decision making" OR "conceptual design Stage decision making" OR "Front End decision making".

C1 and C2, C1 and C3 and C1, C2 and C3.

The process illustrated in Figure 1 employs four steps including

(1)–Identification: In which the research establishes all relevant articles. This process searched in databases including Google Scholar, Web of Science and Scopus. Table 1 summarises the key boundaries for search terms that were limited for the years 2009–2019.

Table 1. Criteria for assessment of quality.

Criterion	Grade Criteria	Grade
C1—Clarity of aims and objectives	[1,0.5,0](Yes, Nominally, No)	106 Studies, 95%
C2—Focus and context of research	[1,0.5,0](Yes, Nominally, No)	104 Studies, 94%
C3—Clarity in research findings	[1,0.5,0](Yes, Nominally, No)	103 Studies, 93%
C4—validity and rigour of research	[1,0.5,0](Yes, Nominally, No)	103 Studies, 93%

(2)–Screening: in this stage, the search applies exclusion criteria to the identified results. This includes ensuring that the article is peer-reviewed and that its publication is in the years 2009–2019. Articles not in English are also excluded and similarly those not focussed on the review concepts

(3)–Eligibility: this stage, applies a qualifying criterion for the articles. This includes ensuring that all selected articles are peer-reviewed and focussed on the concepts of this research, are written in English the full text is available and accessible, among others. Full-text scheming aims to reinforce these boundaries for quality and eligibility. High impact peer-reviewed journals articles were selected as high quality and therefore included in the review. Presentations, conference papers, reports and articles from low impact factor publications were deemed unsatisfactory and therefore excluded; and finally

(4)–Inclusion: this stage finally applies an inclusion criterion assessing the most relevant studies that more closely relate to the concepts, that meet the exclusion criteria referenced in the reviewed articles. This is an iterative process that aims to identify any additional relevant articles that for example, employ alternative techniques, methods and cases.

To ensure rigour and validity vital for all literature review, this paper embeds best practice such as (1) a structured research strategy in Figure 1, (2) ensuring independence coding of review articles (Noordzij et al. 2009) and (3) rigorous assessment of quality and rigour of the reviewed studies such as those adopted by Inayat, Salim [38].

An ordinal scale is applied to the criteria in Table 1, to grade the studies and gauge the level of clarity in the aims and objectives of the study and its focus and context concerning the review concepts. Similarly, the grade is the basis for the level of clarity of research findings and validity and rigour of the articles selected. This is a shared process among authors and support team outside of the study to help foster objectivity in the research. For subsequent evaluations, the articles are analysed for each of the four decision-making methods alongside the fifteen decision-making techniques in the selected years of publication. Particular focus is also paid the key concepts and sector and methodology employed for the study as well as any complementary application of additional techniques to the main one.

2.3. Descriptive Analysis

Table A1 is a summary of the key studies highlighting the vital decision-making methods and techniques while the overall results are summarised as follows: Overall, there is a progressive increase in research in decision making over the study period (see Figure 2). Just a handful of the 111 studies are in the years 2009 to 2013. MCDM methods account for much of the later research that appears to hinge on advances in application and research of QFD that dominates in fields of New Product Development (NPD), Engineering design, manufacturing and automotive sectors.

In terms of the breadth of research, the review articles came from 56 different journals reflecting the wide-ranging application of decision-making principles in many sectors of AEC. Table 2 is a summary of the journals with more than two articles. Most identified articles are from the journal of buildings with fourteen articles perhaps reflecting on the emerging focus of design decision making concepts and principles in construction. This is followed by eight articles in the international journal of production research again a reflection of a similar trend in the wider AEC.

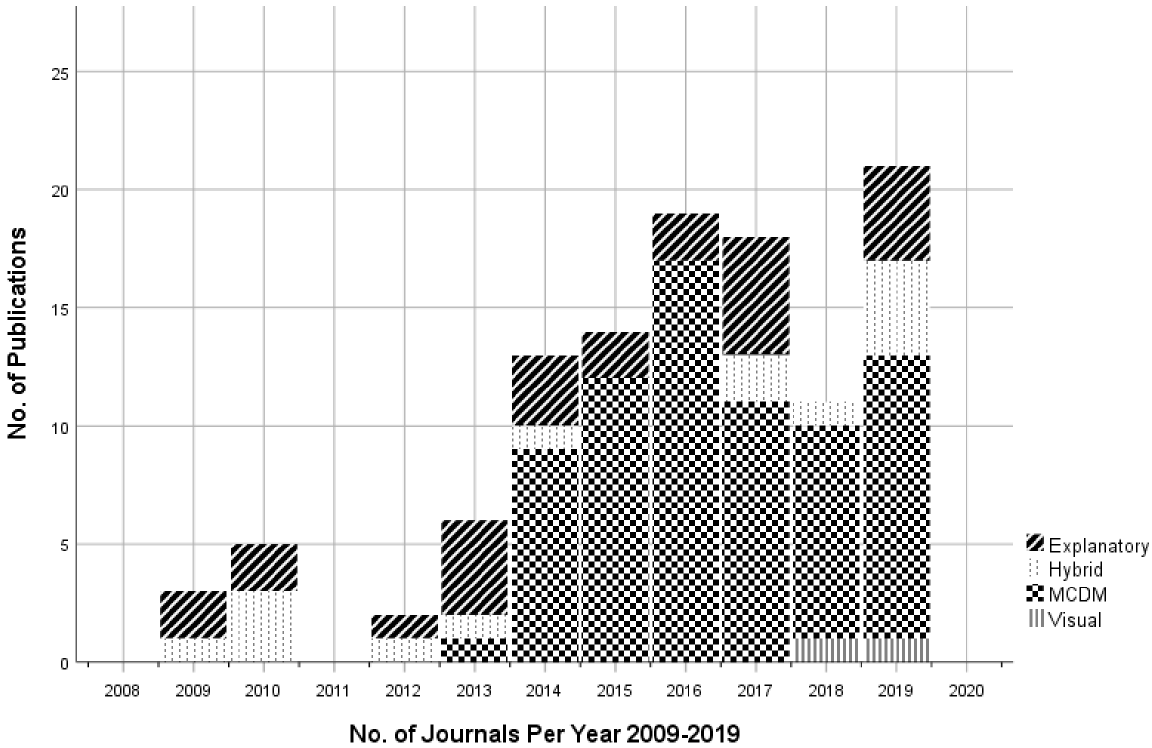

Figure 2. Research in decision making over the study period.

Table 2. Summary of major journal papers.

Journal	Count	%age
Advances in Civil Engineering	2	1.8
Advances in Mechanical Engineering	2	1.8
Concurrent Engineering	2	1.8
Energies	2	1.8
Engineering Applications of Artificial Intelligence	2	1.8
Engineering, Construction and Architectural Management	2	1.8
Environment Systems and Decisions	2	1.8
IEEE Transactions on Systems, Man, and Cybernetics: Systems	2	1.8
International Journal of Advanced Manufacturing Technology	2	1.8
International Journal of Quality and Reliability Management	2	1.8
Journal of Engineering Design	2	1.8
Structural and Multidisciplinary Optimization	2	1.8
Systems Engineering	2	1.8
Automation in Construction	3	2.7
Computers and Industrial Engineering	3	2.7
Energy and Buildings	3	2.7
Neurocomputing	3	2.7
Concurrent Engineering Research and Applications	4	3.6
Decision Science Letters	4	3.6
Mathematical Problems in Engineering	4	3.6
International Journal of Production Research	6	5.4
Journal of Cleaner Production	8	7.1
Buildings	14	12.5
Others	34	30

Further analysis highlights that most of the reviews were from the construction sector (38.5%) followed by NPD and Engineering design at 25.7% and 22%, respectively. These sectors together account for over 86% of the review articles again a reflection on the specific focus of this research. The distribution of articles per sector is summarised in Figure 3.

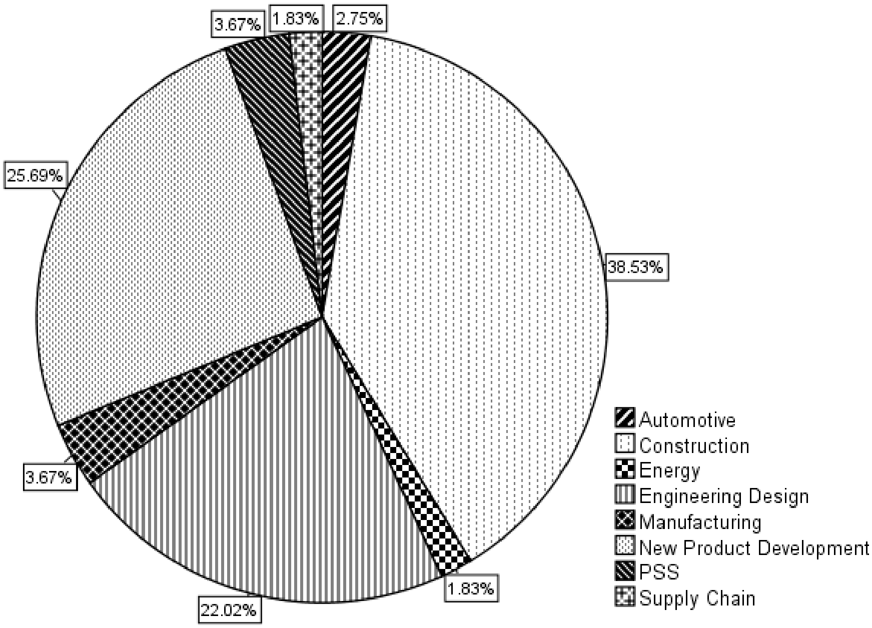

Figure 3. Distribution of review articles per sector.

The distribution of decision-making methods per sector is summarised in Figure 4. A full distribution of decision-making methods is observed only in construction and NPD sectors. The application of explanatory/rational decision-making methods dominates in construction more than in any other sectors (33%). This includes such applications as DQI by Chohan, Irfan [39] for social housing design and Cook, Bose [39] for the study of walkability and accessibility in design. Others include the use of Target Value Design in the design of health facilities using the Last Planner System (LPS) [40], use of explanatory/rational models such as in urban planning and regeneration design [41]. One of the most dominant applications of explanatory/rational decision making in both construction and NPD is seen in set-based design (SBD) either on its own or in hybrid applications [42–47]. Rempling, Mathern [47] successfully investigate the applicability of SBD in structural design in enabling collaborative environments.

Meanwhile, Unal, Miller [44] apply SBD with boundary modelling for the design of seismic resistant structure frames something the authors argue allows design decision making the wider freedom in SBD's ability to support refining and selection of alternatives, and finally Lee, Bae [46] use SBD in conjunction with Building Information Modelling (BIM) and AHP in design of high rise buildings. Hybrid decision-making methods account for 10% of construction decision making as summarised in Figure 5 illustrating the breakdown of all the decision techniques by sector. In addition to SBD based hybrid methods, MCDM based hybrid systems in construction include studies such as Malak Jr, Aughenbaugh [2] in applying SBD and MAUT to extend the former's ability to cope with imprecision and uncertainties in design decision making.

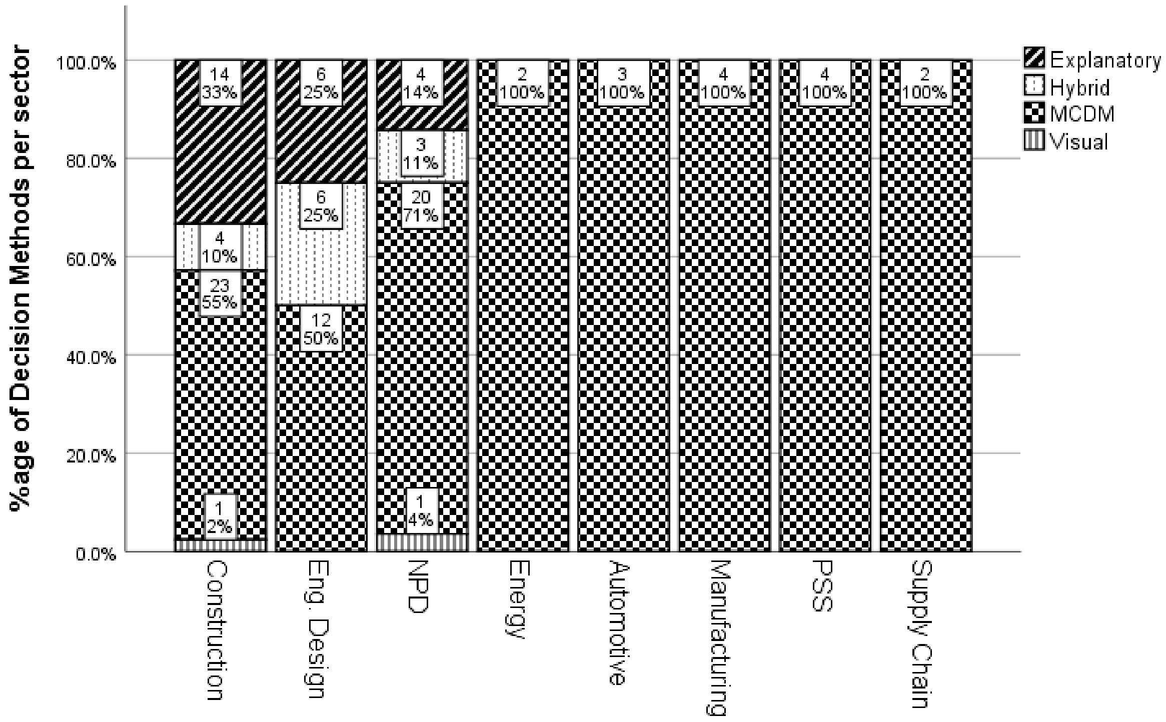

Figure 4. Sector distribution of decision methods.

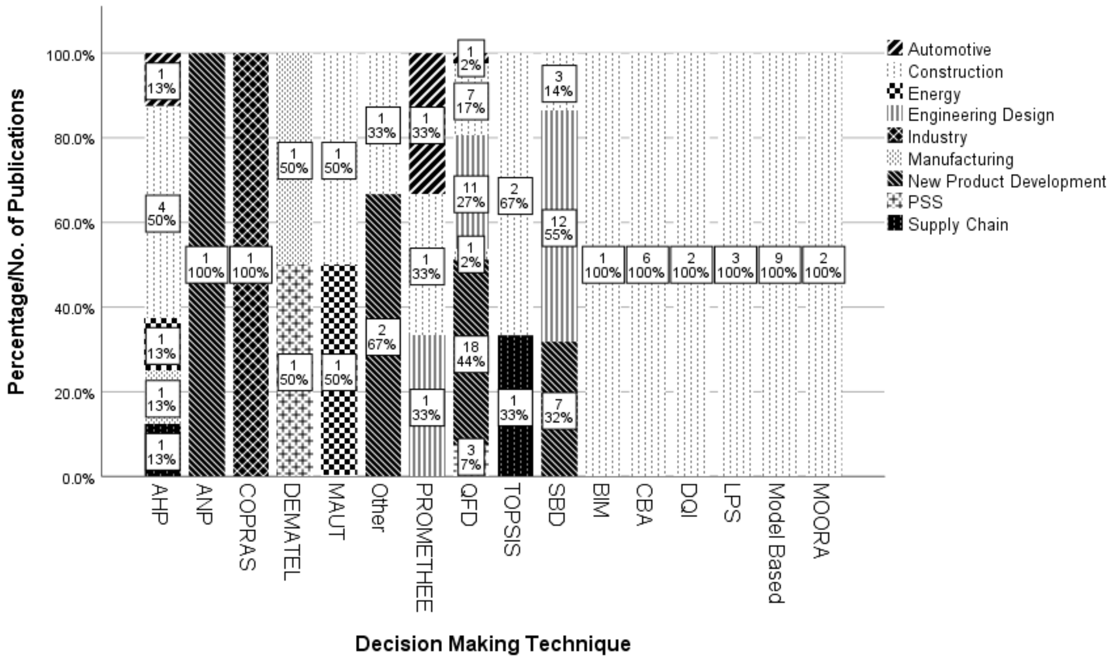

Figure 5. Reviewed decision-making techniques in design.

In Engineering design, unlike in construction and NPD, no visual methods are identified. Half of decision-making is by MCDM while hybrid methods and explanatory/rational each account for a quarter of decision making. The most commonly applied MCDM is QFD found in such applications as in studies of quantification of engineering characteristics by Jia, Liu [48], applications in product design for effective integration of design and specification processes by Jiang, Kwong [49], and in identification of product characteristics for remanufacturing by Zhang, Zhang [50] among others.

Explanatory/rational approaches decision making is seen in applications such as reducing reworks in systems engineering design processes [51].

In other sectors beyond these, MCDM is the only dominant decision-making method identified including in Energy [6,52], Automotive [53,54], Manufacturing [55,56], PSS [57,58] and Supply Chain [59]. In all these latter sectors, it perhaps suggests that the emergent appreciation of the complex dynamics and the need for tools that cope with it are the drivers towards this trend. In construction and NPD, it is noticeable that a mixture of multiple stakeholders, traditional practices and a trend towards newer production processes and philosophies can account for the varied methods in FED decision making practices.

3. Discussion

3.1. Decision-Making Techniques in Design

Over the years, the use of explanatory/rational design decision making has dominated practice. Chen, Kim [60] highlight that with such practices, decision making relies on ad hoc processes lacking consistency. The lack of a structured approach in such decision-making methods also suggests simplistic relationships among attributes and criteria that not only ignores the complex interdependences; but also that sensitivity within data is difficult to assess. Different techniques, particularly in hybrid and MCDM methods, address these limitations differently. Several decision-making methods are widely used in design including MCDM with such techniques as Utility theory, CBA, ANP/AHP, QFD, TOPSIS, PROMETHEE and others [61]; explanatory/rational techniques such as SBD, DQI, Model-Based techniques. Visual techniques are also used as aids in decision making including A3 reports, BIM and LPS. Another type is one that combines a mixture of both MCDM, visual or explanatory/rational techniques called the hybrid type [62,63] and lastly are the statistical aids such as Monte Carlo. Figure 6 captures the full spectrum of decision techniques employed in the review articles. At 22.5%, QFD is the most widely applied technique either on its own or as is usual with complementary techniques. QFD's wide appeal in engineering applications lies in its ability to transform the qualitative user requirements into design requirements via the HoQ (House of Quality) Matrix. Set based design (SBD) is the second most widely applied technique which again has wide applications in engineering design. In SBD, unlike in point-based design, design can concurrently consider alternatives progressively, deferring detailed specifications and decisions until a full understanding of important trade-offs. The decisions are delayed until the last possible moment. While this might apply to some decision-making settings, the empirical position in the Karni and Vierø [64] and Serugga, Kagioglou [65] suggests this may not necessarily improve decision making in all situations due to the resultant complexity in the unawareness in the decision problem. A similar sentiment is seen in model-based decision technique (4.7%) where the various models for decision support lack a unified and consistent approach for decision making while also in the main assuming simplistic relationships among attributes. The other explanatory/rational decision support techniques such as DQI (1.6%), LPS (1.6%), BIM (2.6%) come with similar limitations. Other techniques including statistical such as interpretive structural modelling [63], Graph Theory [52], Spearman's correlation coefficient index [61], Monte Carlo analysis [66]; and Means-End Chain [67] and zero-one goal programming [5] among others account for 19.4%. MCDM techniques and some Hybrid techniques to address some of these limitations. An example is ANP/AHP by Saaty [24] that is one of the most used MCDM accounting for over 12% from the review articles. The difference in the applications is that while in the latter the relationship among attributes is considered linear, in the former, attributes are considered as a network of interdependences [24,68–70]. The criteria and connotative presuppositions in the AHP it is argued are not necessarily representative of the realities of the complexities of decision-making problems such as in FED [71]. In both techniques, decision making requires paired comparison judgments of attributes, defined over a ratio scale [72]. An example is that for two user requirements, a paired comparison judgment is the ordinal advantage of one attribute over the other. This approach means that decision making can organise judgement and preferences in a framework that reflects the dynamics of a decision problem [73].

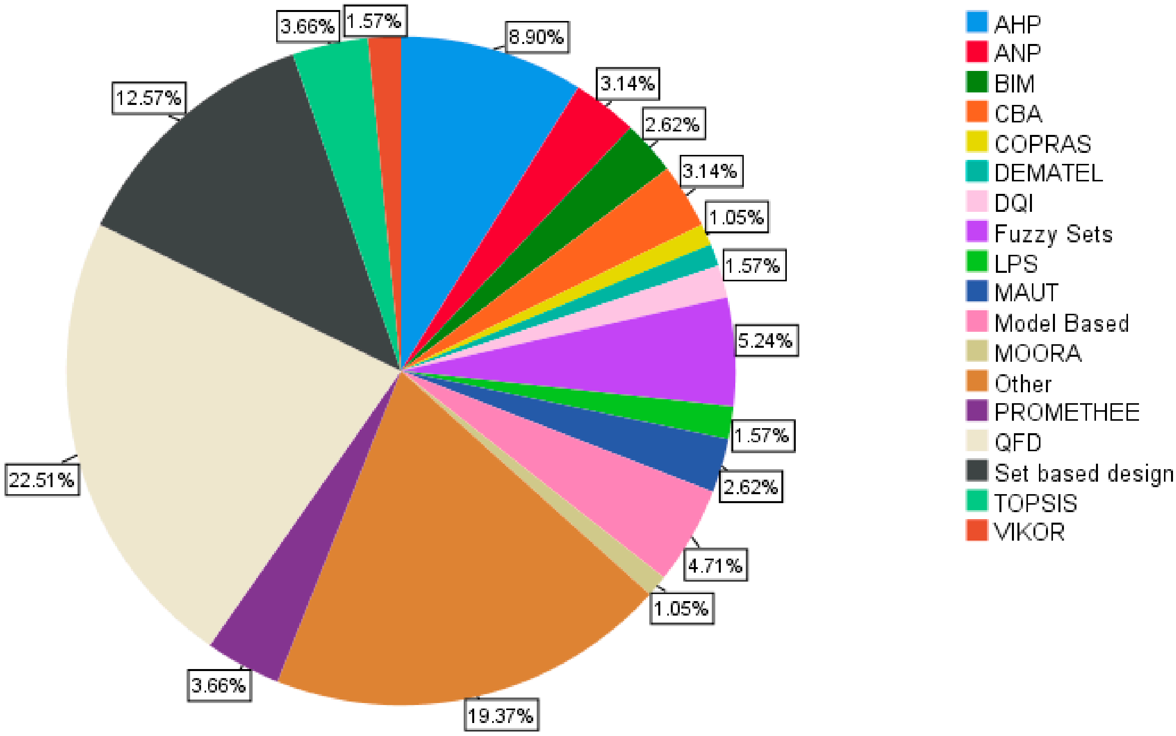

Figure 6. Decision techniques used in the review papers.

TOPSIS is seen in 3.7% of articles and is a technique that aims to evaluate from among the alternatives their distance to the "positive" and "negative" ideal solution [61]. The most preference is that which is closest to the ideal solution and vice-versa [74]. In addition to a simple basis of human representation of decision making, TOPSIS is a flexible approach that allows for complementary tools such as ANP/AHP, fuzzy sets, QFD and the like something that gives it its versatility. Among some of its complementary application is Cho, Chun [75] and Akbaş and Bilgen [31] that both use TPOSIS with QFD. In the latter, the study evaluates construction products through trade-offs of their technical characteristics while in the former, a QFD-TOPSIS application is complemented with the fuzzy sets to select gas fuels. A key element of any MCDM or other technique for that matter is that in bringing structure to FED decision making, it must be repeatable, traceable, consistent and be able to account for the subjective nature of decision making in this stage of design. TOPSIS's versatility means it is able to support most of these attributes, unlike in most of the rational/explanatory, visual or some hybrid techniques.

Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) has also been used in 3.7% of papers and was developed by Brans, Vincke [76]. It is an outranking MCDM technique that has undergone various conceptual adaptations [74]. Part of the appeal for the PROMETHEE is that it can foster confidence through visibility for decision-makers [71] who are able to specify their preference functions [77]. Part of the PROMETHEE adaptations is to address the inherent cumbersomeness in the application of the decision technique in addition to adding the capability of the technique to accommodate decision making with incomplete information. However, authors such as Navarro, Yepes [74] argue that the detailed nature of the mathematical concepts in PROMETHEE means the decision-maker is unable to take advantage of any vantage points in the decision-making process particularly in complex decision problems when this is needed sometimes to take an overall position of the problem. Other studies have found that the technique is also unable to support consideration for any emergent attributes in the process. Any attempt at this drastically changes the decision-making process [74]. Some of its applications have been in the selection of parameter such in choice of siting of electric vehicle charging points [71] and ranking of technical requirements in product design [77]. Choosing by Advantages (CBA) by Suhr [78] is an MCDM technique that uses the advantage of an attribute over the others as a basis for preference and seen in 3.1% of papers. It has been applied widely for its simplicity in such applications as in the selection of design alternatives for energy performance [79].

Other techniques in MCDM include Multi-Attribute Utility Theory (MAUT) that is seen in 2.6% of review papers. In this method, the decision-maker is assumed always to try to maximise their utility in a decision-making problem [2]. It uses a utility function as a basis for assessment of the decision-makers propensity for risk and consistency checking [2,80,81]. VIseKriterijumska Optimizaciji I Kompromisno Resenje (VIKOR) technique in 1.6% of review papers and is similar to TOPSIS in consideration of the preferred attribute basing on its distance from the ideal position [61]. This method is reported to allow for decision making even when the decision-maker is unable to express their preferences at the early stages of decision making [58]. COPRAS is another technique seen in 1% of papers. This is a simple approach based on maximising/minimising criteria values. It has been applied in cases of the right compressor attributes for a textile manufacturer [82]. MOORA is another of the less applied MCDM techniques at 1% and uses a ratio ranking system [61]. The Decision Making Trial and Evaluation Laboratory (DEMATEL) technique, on the other hand, allows for ranking with a requirement on the decision analyst to make any paired comparisons something that brings simplicity to this technique [57].

Table 3. A correlation analysis among key parameters is a correlation analysis between a decision method, technique, sector and methodology of the study. The results indicate no correlation between sector and methodology with a decision-making method. However, a decision-making method strongly correlates with a technique employed (0.02). This finding is in agreement with the Navarro, Yepes [74] results. This is notwithstanding any strong influencing project or context specific factors and parameters such as nature, scope or other constraints dictating on the method and technique to be applied to a specific FED decision making setting.

Table 3. A correlation analysis among key parameters.

Model				**Coefficients** Standardised Coefficients	t	Sig.	95.0% Confidence Interval for B	
				Beta			Lower Bound	Upper Bound
1	(Constant)	1.89	0.23		8.08	0.00	1.43	2.35
	Sector	0.04	0.03	0.14	1.49	0.14	−0.01	0.09
	Decision Technique	0.04	0.02	0.22	2.28	0.02	0.01	0.07
	Methodology	−0.01	0.08	−0.01	−0.07	0.94	−0.16	0.15

Dependent Variable: Decision Method.

This review is exploring the application of decision making in FED. As such, the results contrast with some previous studies such as Navarro, Yepes [74] in not only the broader look at the techniques employed but also in how much they are used such as in Kaya, Çolak [83] TOPSIS, 23%, PROMETHEE 8%, ELECTRE 6%; and TOPSIS, 15.7%, PROMETHEE 8.4%, ELECTRE 7.2% while for Navarro, Yepes [74].

3.2. A Utilitarian Structure of MCDM

The choice of the decision-making method and technique is essential in decision making but so is the appropriate structuring of the decision-making process. Figure 7 captures the essential stages in the structuring of the decision-making problem in MCDM from a MAUT perspective, including pre-analysis, decision analysis and consistency and validation stages.

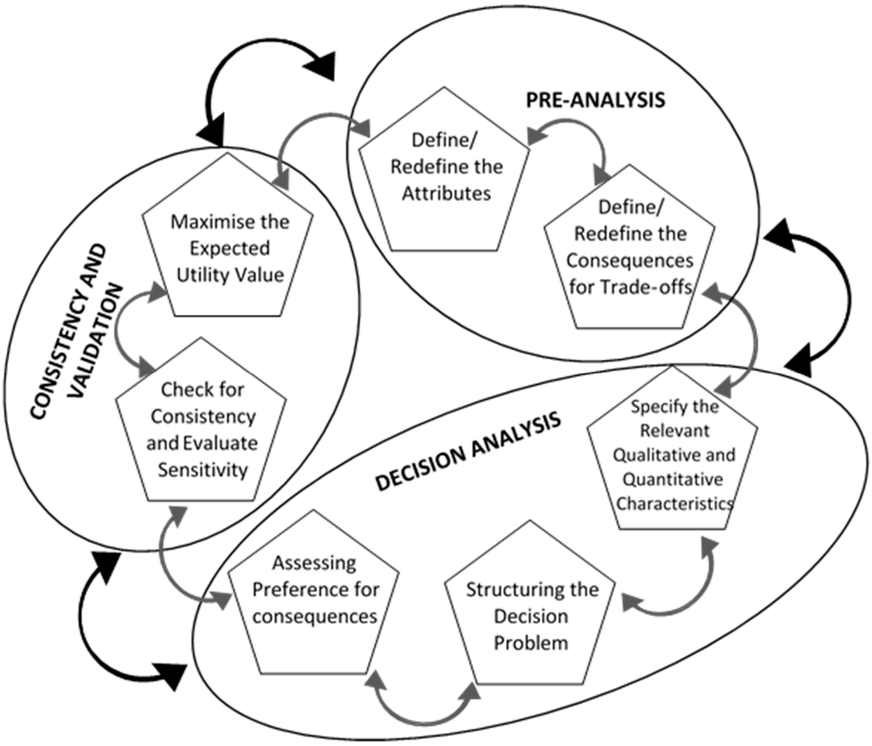

Figure 7. The generic utilitarian decision-making structure.

3.2.1. Pre-Analysis

According to Arroyo, Mourgues [79], MCDM are important for complex decision problems the nature of FED that usually deals with fast-changing and unstructured information. In MCDM, the pre-analysis is an essential step in decision making as it is the process for handling of qualitative data and all pre-analysis processes including selection and defining all the appropriate attributes and criteria [74]. In characterising the problem, in MAUT for example, decision-maker and the analyst roles must be correctly set in such a way that both are well acquainted with the decision problem and that the decision-maker is motivated and ready to consider their consequences carefully and lend effort to the decision making process [80].

Next, the attributes together with their consequences have to be defined. The nature of the decision-maker is quite crucial at this point as characterisation of qualitative data into quantitative data as an essential part of pre-analysis requires expertise and knowledge of the decision problem [74].

In decision making, some attributes such as comfort, energy performance, share market, the extent of emissions performance have to definitively be defined usually through a scale. Other qualitative attributes such as serviceability/maintainability, comfort or aesthetics may, however, be better quantifiable through their lower-level attributes or even proxy attributes [80]. This is the stage when in complex problems, such appropriate techniques such as MAUT or fuzzy linguistics need to be considered. Sousa-Zomer and Cauchick-Miguel [84] in their study of FED processes in sustainable PSS adopt the fuzzy AHP to prioritise stakeholder requirements in QFD. Similarly, Zaim, Sevkli [28] use the fuzzy ANP and QFD to weight for improved ranking of product characteristics in design.

Figure 8 illustrates the relationships between decision methods and techniques. MCDM methods help decision-makers in choosing among complex alternatives through such means as weighting/scaling such as in AHP or QFD [74]; or outranking such as in CBA [79]. Navarro, Yepes [74] and Yoon, Naderpajouh [85] highlight that weighting is an essential step in all MCDM techniques as it is the first step in the conditioning of the criteria for decision analysis. Weighting methods also allow for pairwise comparison of criteria as a basis for later assessments. In MAUT, it is argued that for two attributes A_2 and A_3, it is important to have a perspective of how they not only compare with each other, but also what their contribution is to the utility of say $U(A_2, A_3)$. Using a scaling/weighting constant so that $\sum_{i=1}^{n} k_1 = 1$, for the two attributes A_2 and A_3, the utility will be scaled as $U(A_2, A_3) = k_1 U_{a1}(a_1) + k_2 U_{a2}(a_2)$, where k_1 and k_2 are positive scaling constants and assuming additivity and mutual utility independence of the two attributes.

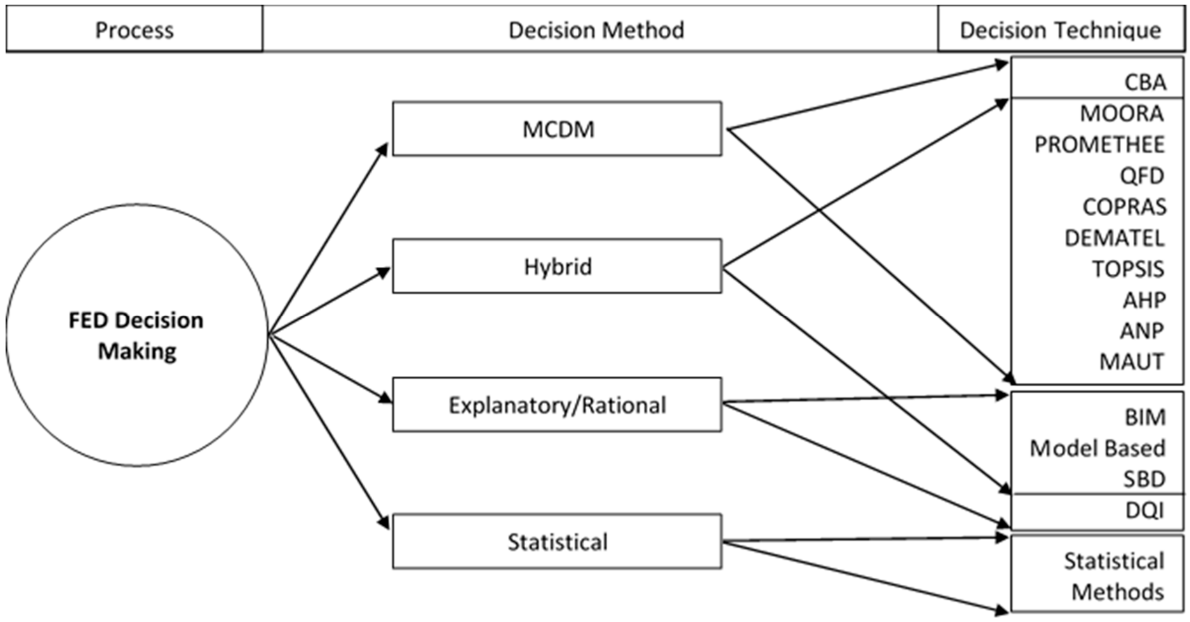

Figure 8. Relationships between design, decision methods and techniques.

This review has sought to present the state of the art in FED decision making looking at the various methods and techniques currently in practice and research. The broadened look at decision making compared to previous studies such as Navarro, Yepes [74] and Kaya, Çolak [83] is reflective of wide range of FED practice in AEC. The results, for example, show that SBD dominates the explanatory/rational method and the review identifies some advances in this technique particularly into hybrid applications with some MCDM techniques. Visual methods have little been explored as; first, there is limited research into these on a broader scale and are limited when dealing with complex design phenomena the nature of FED. These are most dominant in construction (33%) and Engineering Design (25%). Similarly, this research finds little evidence of wide application of hybrid techniques though these present some unique opportunities with their most common applications found in Engineering Design (25%) and only 10% in construction. While MCDM techniques appear to be taking a strong recently in all areas of AEC, these are mainly variants of QFD in the main. It, however, suffices that the dynamics in FED adding to the complexity, chaos and uncertainty during decision making make for a complex decision problem that ultimately requires better tools for better decision making. These positions are perhaps suggestive of the multi-stakeholder nature of AEC design decision making today that often means adoptions of varied techniques and methods.

Some strengths are seen for techniques such as CBA in its collaborative and simplified approach to decision support. However, such approaches assume that expert judgements are crisp which is not always the case. Based on the vagueness and impreciseness from decision-makers that often mean some techniques have adopted fuzzy sets in their corresponding weighting approaches. MAUT, on the other hand, is shown to accommodate the modelling of the subjective views of the decision-maker by allowing for the interaction of the various spaces of attributes. Consistency is seen as a key element in decision making. In explanatory/rational approaches, there is little evidence of a verifiable consistency checking regime. Other MCDM tools such as QFD show no readily adaptable consistency checking in their application while consistency in ANP/AHP has more room to be improved. Complementarity among tools appears to be the trend as a weakness in one technique can be compensated by the strength of another. For example, MAUT is shown to help embed robust consistency checks in decision making through analysing and assessing of the decision maker's utility function. When complemented with such other techniques as QFD, this strength can be brought to decision making.

Regarding uncertainty and subjectivity of FED decision making, Gotzamani, Georgiou [86] highlight that the changing nature of design discourse as a result of changing requirements is something that is essential in design. The authors at the same time note that there is a limited understanding in many current support tools. While subjectivity is addressed in many MCDM tools such as MAUT, its contextual nature during decision making requires more exploration. This extends to quantifiably guiding the quality of decision making based on quantified uncertainty. Similarly, the nature of the changing requirements has not been quantified by any decision technique, something important for FED decision making to help keep it in the currency of the project benefits. Obsolescence of user requirements mean projects particularly those more complex need a way to ensure that as requirements change, design requirements are updated accordingly. None the less, MCDM and hybrid techniques and their principles still present opportunities particularly alongside any explanatory/rational decision-making methods in order to ensure flexibility in project scopes needed for today's complex FED decision making. This appears better reflected in the conceptualisations of MAUT in part due to is complementary nature but also its robust consistency and structuring of the decision problem. This points to the need for new research into new techniques that support complex modelling of attribute interdependences to account for subjectivity of decision-makers; model uncertainty in FED decision making while also attempting to predict any changes in requirements. FED must aim to cope with all these elements in order to deliver the intended project benefits based on the utility of decision making.

Many decision problems in FED, therefore, require trade-offs as a result of the often conflicting and competing attributes which makes the above weighting techniques inadequate [87]. QFD, MAUT and TOPSIS are identified by authors such as Cho, Chun [75] as having the ability to accommodate these trade-offs during decision making.

The QFD technique is particularly useful in transforming the qualitative user requirements into quantitative design requirements [75]. Franceschini, Galetto [88] and Hosseini Motlagh, Behzadian [77] highlight the four essential steps in QFD that employs user requirements throughout the process: (1) The HOQ matrix that relates the user requirements to the design requirements; essentially the relationship between the 'WHATs' and 'HOW's', (2) these are in turn associated with the specification requirements, (3) third is the process of pairwise comparisons relating the subsystems to their production processes in a process deployment matrix, (4) finally is the process and quality control setting the inspection and quality control parameters important for the production process. The technique has been successfully applied in decision making such as in the design of eco-design of new products [84]. Goodfellow, Wortley [10], on the other hand, used QFD to improve social acceptability of large infrastructure designs. Impreciseness and vagueness in FED processes, however, mean QFD is still an insufficient tool on its own for design decision making [58,89].

Eleftheriadis, Duffour [13] report on some notable benefits of QFD in construction including better collaborative environments through improved communication and information transfer among project participants that could positively impact on resource use; and a better understanding of user and design requirements leading to improved decision making among others. The interoperability and complementarity of some of these weighting techniques add to their popularity in design decision making. Several applications have seen QFD naturally combined with the fuzzy sets to address such vagueness and impreciseness [25,86,90–94]. Li and Song [58] for example, successfully use a QFD-VIKOR in product-service planning design by harnessing the compromise ranking list of VIKOR from the ideal position. Gotzamani, Georgiou [86] highlight the changing user as an essential aspect of design rarely considered by many tools. The authors propose the use of QFD with multivariate Markov modelling to cope with the needs of the changing user that ultimately impact on decision making. A fuzzy set according to Jia, Liu [48], in a non-empty set X, a fuzzy set is represented by a pair $\grave{A} := (x, \mu_A(x))$ where x belongs to the set $\grave{A}$, $\mu_A(x)$ the membership function and $\mu_A(x) \in [0,1]$. Triangular fuzzy sets are the most represented of fuzzy numbers and are denoted by $\widetilde{b} = (b_L, b_M, b_H)$ and the membership functions as:

$$\mu_{\tilde{a}}(x) = \begin{cases} \frac{x - b_L}{b_M - b_L}, & if \;\; b_L \leq x \leq b_L \\ \frac{b_H - x}{b_H - b_M}, & if \;\; b_M \leq x \leq b_H \\ 0, & Otherwise \end{cases} \tag{1}$$

3.2.2. Decision Analysis

The key elements here are building on the structuring of the decision problem through such processes as normalisation and aggregation of data. This is a crucial stage in the decision analysis as it brings structure to the quantitative data. Usually, the attributes over which decision making seeks to pronounce itself on are in many different units such as cost, energy, power, decibels and normalisation is the process to bring all these into a uniform dimensionless structure [74]. Normalisation generally takes the form of:

$$\bar{b}_{ij} = \frac{b_{ij}}{\sum_i b_{ij}} \; (i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n) \tag{2}$$

Or it can take the form vector normalisation as:

$$\bar{b}_{ij} = \frac{b_{ij}}{\sqrt{\sum_i b_{ij}^2}} \; (i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n) \tag{3}$$

This basis of normalisation represents a linear form for the b_{ij} attribute of an alternative i over a criterion j. This can then be weighted to draw out any prioritisation using the criterion weight w_j using the relationship $D = \left[d_{ij}\right]_{mbn} = b^*_{ij}.w_j$ where D is the weighted normalised decision matrix, and m the number of alternatives [82,88,95]. Other research has sought to adopt more complex normalisations such as that based on Wasserman [96] as follows;

$$R''_{ij} = \frac{\sum_{k=1}^{n} R_{ik}.\gamma_{kj}}{\sum_{j=1}^{n}\sum_{k=1}^{n} R_{ik}\gamma_{kj}}, \; (i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n) \tag{4}$$

γ_{kj} with a vector space $[-1, 1]$ represents the technical correlation between designs requirements alternative k and j. This normalisation approach is based on the concept of vector space in which attributes are assumed to have potential correlations and interdependences [95]. This means that when $k = j$ then $\gamma_{kj} = 1$; and $\gamma_{kj} = 0$ for any k and j $k \neq j$. From the vector space, it is possible that two design requirements are possibly negatively correlated. This can also mean that decision making processes need to define any conditions and restrictions for the process. This normalisation approach is seen applied in studies such as Li, Tang [91] when it was used to rate engineering characteristics in a probabilistic language method based in a fuzzy QFD, and similarly by Franceschini, Galetto [88] again in combination with QFD. Other applications are found in Chen and Chen [95] in product design, Ko and Chen [97] in new product planning and Ji, Jin [98] in the optimisation of product designs in conjunction with the Kano's Model.

3.2.3. Consistency, Sensitivity and Reiteration

In regard to sensitivity, the decision making processes must assess those attributes and criteria that may be influencing the results significantly [52]; in contributing to the confidence of the analysis [72].

It is therefore an important step multi attribute decision analysis [74]. For Rational/explanatory and visual methods, this can be difficult to achieve in MCDM and some hybrid techniques.

The consideration of sensitivity analysis in certain techniques suggests the acceptance of the subjectivity of decision-makers. Moreover, subjectivity introduces another layer of uncertainty within decision making more acutely for complex and dynamic contexts. In Kültür, Türkeri [1], for example, a sensitivity analysis was used to assess the degree of changes to the orientation to the overall design and performance by individually changing a parameter while keeping the others constant; similar to the approach employed by Rapp, Chinnam [99]. Eleftheriadis, Duffour [13] and Avigad and Moshaiov [100] have separately demonstrated the use of sensitivity analyses in statistical decision techniques such in Evidential Reasoning algorithms and Pareto Analysis, respectively. Additionally, the dynamics of FED and the nature of design in general, mean a lot of decision making will be subjective influencing cognition, shaped by the structure and agency of design. Rational/explanatory and visual techniques show no evidence of accounting for this subjectivity. Some Hybrid and MCDM techniques while attempting to account for subjectivity also assume crispness in the elicitation of expert or user data something that neglects subjectivity. It is, however, vital that decision making accounts for this vagueness to better represent the dynamics and improve the rigour of the results. Recently, many MCDM and Hybrid techniques have applied the fuzzy sets as a way of addressing this [50,59,89,92]; while Grey numbers have also been used [74].

3.3. Restrictions, Conditions and Assumptions in Decision Making

The nature of FED is the inherent interdependence among attributes. This suggests that bounding the decision problem by defining any restrictions, conditions or assumptions is, therefore, important in defining a preference structure. The MAUT understanding of these boundaries is thus essential to highlight. In MAUT, first is the notion of conditional indifference where for attributes X, Y and Z, the marginal rate of substitution of (X, Y) can depend on the value of Z [80]. Some attributes can exhibit dependence relations with others in restricted areas of a decision maker's utility function and in practice, this can be in benefits, opportunities, risks and consequences in all essential elements during trade-offs. If attributes B_1, B_2 and C represent the benefit of attributes 1, 2 and cost of C that is negatively oriented, it can suffice that (B_1, B_2) is preferentially independent of C while (B_1, C) and (B_2, C) may be dependent. In this case, additivity based on the value function (VF) can be summarised as;

$$\begin{aligned} V(X_1,\ X_2,\ \ldots\ldots, X_n) &= \sum_{i=1}^{n} V_i(X_i) \\ V(X_1,\ X_2,\ \ldots\ldots, X_n) &= \sum_{i=1}^{n} \lambda_i V_i(X_i) \end{aligned} \tag{5}$$

when scaled by λ_i.

It can, therefore, follow that dependences can be drawn from this basic structure. One such is preferential independence which follows that given (X_1, X_2, X_3, X_4), if (X_1, X_2) is preferentially independent of (X_2, X_3), The value function can be represented as $V\ (X_1, X_2, X_3, X_4) = Y + V(X_4)$, Where $Y = V(X_1) + V(X_2) + V(X_3)$. In addition, the corollary is that given attributes $(X, Y.Z)$, $V\ (x, y, z) = V_X(x) + \ V_Y(y) + \ V_Z(z)$ and therefore (X, Y) is independent of Z, (X, Z) is independent of Y and (Z, Y) is independent of X.

These conceptualisations are essential aspects in structuring a decision problem by bounding it with any assumptions, restrictions or conditions sufficient for the problem. Additivity among attributes is another of the MCDM and many decision methods such as CBA that is commonly assumed. However, MAUT concepts do help define conditions for it. It thus follows that for attributes $A_1,\ A_2 \ldots,\ A_7$, additive independence can only be assumed if it can be shown that the preference structures over $A_1,\ A_2 \ldots,\ A_7$ depends only on the '*marginal*' rather than their combined '*probability distributions*';

such that $\underline{u(A)} = \sum_{i=1}^{n} u\left(A_i, A_i^{-o}\right) = \sum_{i=1}^{n} k_i u_i(A_i)$. This demonstrates the importance of understanding whether a decision problem is additive, multiplicative, or multilinear and that the conditions relating to preferential or utility independence are explicitly identified and stated to aid decision making.

3.4. Front End Design and MAUT

The design process in FED often deals with sets of incomplete information to inform concepts, attributes and criteria for design decision making [2]. Malak Jr, Aughenbaugh [2] adds that because of the range of stakeholders, this can mean that these parameters can be varying and wide-ranging. In turn, this can correspond to numerous final alternatives. This suggests impreciseness in FED processes. Delivery of intermediate FED benefits means that design decision making ought to capture the subjectivities and uncertainties in the design alternatives and attributes. This places importance in the trade-offs processes in the transformation of attributes through consideration of their consequences This also suggests that it is relevant that qualitative and quantitative characteristics are defined including any restrictions, conditions and assumptions [80]. Some of the quantitative issues the analyst can look at as important to the final decision is defining the boundaries of the attributes.

In a MAUT decision making, Figure 9 represents how the trade-offs process can generically handle design attributes and consequences including the ability to define any boundaries of a design problem. A preference structure representing these trade-offs is built along with the consequences X in a manner that requires design decision making to define a preference for $(X_0,\ X_2)$ or X_1. More generally this follows the form $\langle X_{i+1}, X_{i-1}\rangle$or $X_i;\ i = 1, 2, 3, \ldots, 9$. This is the basis for defining a utility function to capture indifference points for the decision-maker which essentially defines the certainty points $\hat{X}_i$ put more generally as $\hat{X}_i = \langle X_{i+1}, X_{i-1}\rangle$or $X_i;\ i = 1, 2, 3, \ldots, 9$. This definition is also important in establishing uncertainties and subjectivity in decision making based on indifference through a decision maker's risk position, prone, averse or neutral called the risk premium. The difference represents the risk premium $X_i - \hat{X}_i$ using the following relationship;

$$If\ the\ X_i - \hat{X}_i \begin{cases} Increases \\ Decreases \\ Constant \end{cases} then\ the\ DM's\ UF\ is \begin{cases} Increasingly \\ Decreasingly \\ Constantly \end{cases} Risk\ Averse$$

This, however, does not suggest linearity in decision making and neither to the transitivity [80]. How a decision-maker responds in assessing design attributes can be linear so the utility function is $U(x) = -e^{-cx}$; or exponential $U(x) = -e^{-ax} - be^{-cx}$, where $a,\ b,\ c,\ and\ x$ are constants.

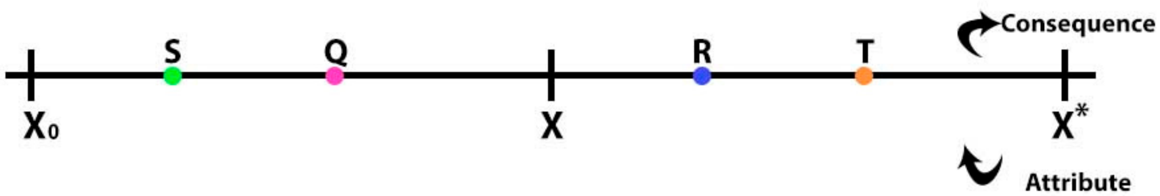

Figure 9. Utilitarian transformation of attributes to consequences.

4. Conclusions

This review has sought to present the state of the art in FED decision making looking at the various methods and techniques currently in practice and research. The broader look at decision making in FED is reflective of broader practice in AEC. The results, for example, show that SBD dominates the explanatory/rational method and the review identifies some advances in this technique particularly into hybrid applications with some MCDM techniques. Visual methods have little been explored as; first, there is limited research into these on a broader scale and are limited when dealing with complex design phenomena the nature of FED. These are most dominant in construction (33%) and

Engineering Design (25%). Similarly, this research finds little evidence of wide application of hybrid techniques though these present some unique opportunities with their most common applications found in Engineering Design (25%) and only 10% in construction. While MCDM techniques appear to be taking a strong recently in all areas of AEC, these are mainly variants of QFD in the main. It, however, suffices that the dynamics in FED adding to the complexity, chaos and uncertainty during decision making make for a complex decision problem that ultimately requires better tools for better decision making. These positions are perhaps suggestive of the multi-stakeholder nature of AEC design decision making today that often means adoptions of varied techniques and methods.

Some strengths are seen for techniques such as CBA in its collaborative and simplified approach to decision support. However, such approaches assume that expert judgements are crisp which is not always the case. Based on the vagueness and impreciseness from decision-makers that often mean some techniques have adopted fuzzy sets in their corresponding weighting approaches. MAUT, on the other hand, is shown to accommodate the modelling of the subjective views of the decision-maker by allowing for the interaction of the various spaces of attributes. Consistency is seen as a key element in decision making. In explanatory/rational approaches, there is little evidence of a verifiable consistency checking regime. Other MCDM tools such as QFD show no readily adaptable consistency checking in their application while consistency in ANP/AHP has more room to be improved. Complementarity among tools appears to be the trend as a weakness in one technique can be compensated by the strength of another. For example, MAUT is shown to help embed robust consistency checks in decision making through analysing and assessing of the decision maker's utility function. When complemented with such other techniques as QFD, this strength can be brought to decision making.

Regarding uncertainty and subjectivity of FED decision making, Gotzamani, Georgiou [86] highlight that the changing nature of design discourse as a result of changing requirements is something that is essential and a mainstay of design. The authors have however noted this as a major limitation in many decision support tools. While subjectivity is addressed in many MCDM tools such as MAUT, its contextual nature during decision making requires more exploration. This extends to quantifiably guiding the quality of decision making based on quantified uncertainty. Similarly, the nature of the changing requirements has not been quantified by any decision technique, something important for FED decision making to help keep it in the currency of the project benefits. Obsolescence of user requirements mean projects particularly those more complex need a way to ensure that as requirements change, design requirements are updated accordingly. None the less, MCDM and hybrid techniques and their principles still present opportunities particularly alongside any explanatory/rational decision-making methods in order to ensure flexibility in project scopes needed for today's complex FED decision making. This appears better reflected in the conceptualisations of MAUT in part due to its complementary nature but also its robust consistency and structuring of the decision problem. This points to the need for new research into new techniques that support complex modelling of attribute interdependences to account for subjectivity of decision-makers; model uncertainty in FED decision making while also attempting to predict any changes in requirements. FED must aim to cope with all these elements in order to deliver the intended project benefits based on the utility of decision making.

This review presents for the first time the state of the art in the broad practice of decision making in FED by analysing the wider application of decision-making techniques and methods. The review however accepts some limitations. First is the inclusion and exclusion criteria that may inadvertently excluded some important studies such as in high end conference publications or those in not in English or indeed keywords that that may have helped add wider value in the review. A second significant limitation is that that relating to influences on decision making such as project context, scope, nature and other project specific constrains and requirements as to the methods and techniques applied. The review finally accepts that in the wider AEC there may not be an awareness let alone the practice of formalised decision making employing such techniques and methods reviewed in this study. This review considers this out of scope and therefore makes no attempt at reviewing any informal decision making in FED in such informal processes. The paper's main contribution therefore is to a new discussion of decision making from a FED perspective by presenting the state of the art in current formalised techniques and methods within the broader research and practice. The review considers important factors as project context, scope, nature and other project specific constrains and requirements as key to decision making in FED. New research is needed to examine their impact on the rigor and robustness of the decision-making methods and techniques in influencing benefits realization in FED including assessing related issues of subjectivity and uncertainty in decision making.

Author Contributions: Conceptualization, J.S., M.K.; methodology, software J.S.; validation, J.S., M.K. and P.T.; formal analysis, J.S.; resources, M.K.; data curation, J.S.; writing—original draft preparation, J.S., M.K.; writing—review and editing, J.S., M.K.; visualization, J.S.; supervision, M.K., P.T.; project administration, M.K., P.T.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Full results of the review papers.

Author	Journal	Decision Method	Sector	Main Technique	Study Type	Technique 2	Technique 3	Technique 4
Alkahtani, Al-Ahmari [101]	Advances in Mechanical Engineering	MCDM	Supply Chain	AHP	Case Study	TOPSIS		
Jalilzadehazhari, Vadiee [102]	Buildings	MCDM	Construction	AHP	Case Study	BIM		
Yoon, Naderpajouh [85]	Journal of Cleaner Production	MCDM	Construction	CBA	Evaluative			
Chen, Ming [57]	Journal of Cleaner Production	MCDM	PSS	DEMATEL	Evaluative	ANP		
D'Agostino, Parker [6]	Energy Strategy Reviews	MCDM	Energy	MAUT	Evaluative			
Chen, Kim [60]	Advances in Civil Engineering	Explanatory	Construction	Model-Based	Case Study			
Kültür, Türkeri [1]	Buildings	Explanatory	Construction	Model-Based	Evaluative			
Zhang, Zhang [50]	Journal of Cleaner Production	MCDM	Engineering Design	QFD	Case Study	Fuzzy sets		
Li, Tang [91]	Computers and Industrial Engineering	MCDM	Engineering Design	QFD	Evaluative	Unigram model		
Zhang, Zhang [50]	Journal of Cleaner Production	MCDM	Engineering Design	QFD	Evaluative	Fuzzy Sets		
Zhang [103]	Journal of Intelligent Manufacturing	MCDM	NDP	QFD	Evaluative	DEA		
Buchanan, Richards [104]	Environment Systems and Decisions	Explanatory	Engineering Design	Set-based design	Evaluative			
Small, Parnell [105]	Journal of Defense Modeling and Simulation	Explanatory	NDP	Set-based design	Evaluative			
Wade, Parnell [106]	Environment Systems and Decisions	Hybrid	Engineering Design	Set based design	Evaluative	probability trees		
Ammar, Hammadi [107]	Concurrent Engineering Research and Applications	Hybrid	NDP	Set-based design		Other		
Rempling, Mathern [47]	Automation in Construction	Hybrid	Construction	Set-based design				
Kabirifar and Mojtahedi [108]	Buildings	MCDM	Construction	TOPSIS	Case Study			

Table A1. *Cont.*

Author	Journal	Decision Method	Sector	Main Technique	Study Type	Technique 2	Technique 3	Technique 4
Navarro, Yepes [74]	Advances in Civil Engineering	MCDM	Construction	TOPSIS	Literature Review	AHP	PROMETHEE	COPRAS
Imran, Khaliq [109]	Decision Science Letters	MCDM	Construction	partial least square structural equation modelling technique	Case Study			
Zanni, Sharpe [110]	Buildings	Visual	Construction	BIM	Evaluative	IDEF		
Lorenzi and Ferreira [111]	International Journal of Quality and Reliability Management	Visual	NDP	A3 Reports	Case Study	FMEA		
Alshamrani, Alshibani [32]	Buildings	MCDM	Construction	AHP	Case Study	MUAT		
Arroyo, Mourgues [79]	Energy and Buildings	MCDM	Construction	CBA	Case Study			
Hashemkhani Zolfani, Pourhossein [112]	Alexandria Engineering Journal	MCDM	Construction	MOORA	Case Study			
Antoniou and Aretoulis [113]	International Journal of Management and Decision Making	MCDM	Construction	PROMETHEE	Case Study			
Eleftheriadis, Duffour [13]	Advanced Engineering Informatics	MCDM	Manufacturing	QFD	Case Study	BIM		
Fargnoli, Costantino [114]	Journal of Cleaner Production	MCDM	NDP	QFD	Case Study			
Liao Wu and Liao [90]	Information Fusion	MCDM	NDP	QFD	Case Study	ORESTE		
Gotzamani, Georgiou [86]	International Journal of Quality and Reliability Management	MCDM		QFD	Evaluative	MMC	AHP	
Eleftheriadis and Hamdy [55]	Buildings	MCDM	Construction	QFD	-	BIM		
Rapp, Chinnam [99]	Systems Engineering	Hybrid	NDP	Set-based design	Comparative Study			
Saaty and De Paola [73]	Buildings	MCDM	Construction	AHP	Evaluative			
Kpamma, Adjei-Kumi [11]	Engineering, Construction and Architectural Management	Explanatory	Construction	CBA	Case Study			
Kamara [115]	Built Environment Project and Asset Management	Explanatory		Design Quality Indicator				
Guarini, Battisti [116]	Buildings	MCDM	NDP	MACBETH	Evaluative	ANP	MUAT	
Della Spina, Lorè [42]	Buildings	Explanatory	Construction	Model-Based	Case Study		-	
Chokhachian, Santucci [117]	Buildings	Explanatory	Construction	Model-Based	Case Study		-	
Fregonara, Giordano [118]	Buildings	Explanatory	Construction	Model-Based	Evaluative		-	
Kang [119]	Energies	Hybrid	Construction	Model-Based	Evaluative		-	
El Sawalhi and El Agha [120]	Journal of Construction in Developing Countries	MCDM	Construction	MUAT	Case Study		-	
Dehe and Bamford [121]	Production Planning and Control	MCDM	Construction	QFD	Case Study		-	
Cho J., Chun J., Kim I., Choi J.	Mathematical Problems in Engineering	MCDM	Engineering Design	QFD	Evaluative	TOPSIS	-	
Liu A., Hu H., Zhang X., Lei D.	IEEE Transactions on Engineering Management	MCDM	NDP	QFD	Evaluative	Fuzzy Sets		-

Table A1. *Cont.*

Author	Journal	Decision Method	Sector	Main Technique	Study Type	Technique 2	Technique 3	Technique 4
Mastura, Sapuan [53]	International Journal of Advanced Manufacturing Technology	MCDM	Automotive	QFD	Evaluative	AHP	-	-
Sousa-Zomer and Cauchick-Miguel [84]	International Journal of Advanced Manufacturing Technology	MCDM	PSS	QFD	Evaluative	AHP	-	-
Moghimi, Jusan [67]	Journal of Building Engineering	MCDM	Construction	QFD	Survey Study	Means-End Chain		-
Singhaputtangkul [122]	Smart and Sustainable Built Environment	MCDM	Construction	QFD	Survey Study		-	-
Chen, Ko [123]	European Journal of Operational Research	MCDM	NDP	QFD	Evaluative	Fuzzy Sets		-
Unal, Miller [44]	Structural and Multidisciplinary Optimization	Hybrid	Construction	Set-based design	Evaluative		-	
Lanjewar, Rao [52]	Decision Science Letters	MCDM	Energy	AHP	Evaluative	Graph Theory	PROMETHEE	
Ignatius, Rahman [25]	Journal of Civil Engineering and Management	MCDM	Construction	AHP	Review	-	-	-
Arroyo, Tommelein [20]	Energy and Buildings	MCDM	Construction	CBA	Case Study		-	-
Arroyo, Fuenzalida [124]	Energy and Buildings	MCDM	Construction	CBA	Survey Study	WRC	-	-
Kundakcı and Işık [82]	Decision Science Letters	MCDM	Industry	COPRAS	Evaluative	MACBETH	-	-
Cattaneo, Giorgi [125]	Buildings	Explanatory	Construction	Model-Based	Evaluative		-	-
Ceballos, Lamata [61]	Progress in Artificial Intelligence	MCDM	Construction	MOORA	Comparative Study	TOPSIS	VIKOR.	
Wu, Yang [71]	Energies	MCDM	Automotive	PROMETHEE	Case Study	ANP	VIKOR.	-
Jia, Liu [49]	International Journal of Production Research	MCDM	Engineering Design	QFD	Case Study	Fuzzy Sets		-
Afshari, Peng [126]	Cogent Engineering	MCDM	NDP	QFD	Evaluative			
Alemam and Li [127]	Concurrent Engineering Research and Applications	MCDM	Engineering Design	QFD	Evaluative			
Li and Song [58]	Mathematical Problems in Engineering	MCDM	PSS	QFD	Evaluative	VIKOR	Rough Numbers	
Wang, Fung [89]	Computers and Industrial Engineering	MCDM	NDP	QFD	Evaluative	Fuzzy Sets		
Wang, You [128]	Symmetry	MCDM	Engineering Design	QFD	Evaluative	QUALIFLEX		
Wey and Wei [5]	Social Indicators Research	MCDM	Construction	QFD	Evaluative	ANP		
Venkata Subbaiah, Yeshwanth Sai [129]	Journal of The Institution of Engineers (India): Series C	MCDM	Engineering Design	QFD	Evaluative	ANP	-	-
Miranda De Souza and Borsato [130]	Journal of Cleaner Production	Explanatory	NDP	Set-based design	Evaluative	Stage-Gate Model		-
Ding, Liang [59]	Mathematical Problems in Engineering	MCDM	Supply Chain	TOPSIS	Case Study		-	-
Tian, Zhang [54]	Advances in Mechanical Engineering	MCDM	Automotive	AHP	Evaluative			-
Yang, Chen [63]	Mathematical Problems in Engineering	MCDM	NDP	ANP	Evaluative	Fuzzy Sets		
Arroyo, Tommelein [23]	Journal of Construction Engineering and Management	MCDM	Construction	CBA	Evaluative	AHP	-	-
Talebanpour and Javadi [56]	Decision Science Letters	MCDM	Manufacturing	DEMATEL	Survey Study	SAW		-
Chohan, Irfan [39]	Open House International	Explanatory	Construction	DQI	Case Study		-	-
Konstantinou [131]	Buildings	Explanatory	Construction	Model-Based	Evaluative		-	-
Hosseini Motlagh, Behzadian [77]	he International Journal of Advanced Manufacturing Technology	MCDM	Engineering Design	PROMETHEE	Evaluative	QFD	-	-
Jiang, Kwong [49]	International Journal of Production Research	MCDM	Engineering Design	QFD	Case Study			

Table A1. *Cont.*

Author	Journal	Decision Method	Sector	Main Technique	Study Type	Technique 2	Technique 3	Technique 4
Franceschini, Galetto [88]	International Journal of Production Research	MCDM	NDP	QFD	Evaluative			
Franceschini, Maisano [72]	Research in Engineering Design	MCDM	NDP	QFD	Evaluative	Yager's algorithm		
Kim, Son [132]	Sustainability (Switzerland)	MCDM	PSS	QFD	Evaluative	AHP		
Luo, Kwong [133]	IEEE Transactions on Systems, Man, and Cybernetics: Systems	MCDM	NDP	QFD	Evaluative	Cluster Analysis		
Singhaputtangkul and Low [134]	Buildings	MCDM	Construction	QFD	Survey Study	Fuzzy Sets		
Yu, Yang [135]	Journal of Cleaner Production	MCDM	NDP	QFD	Case Study			
Jin, Ji [136]	Engineering Applications of Artificial Intelligence	MCDM	NDP	QFD	Comparative Study			
Ochoa [137]	Journal of Cleaner Production	Explanatory	Construction	LPS	Case Study			
Chen and Chen [95]	International Journal of Production Research	MCDM	NDP	QFD	Evaluative			
Goodfellow, Wortley [10]	Process Safety and Environmental Protection	MCDM	Construction	QFD	Evaluative			
Ji, Jin [98]	International Journal of Production Research	MCDM	Engineering Design	QFD	Evaluative	Kano's model		
Liu, Zhou [87]	Neurocomputing	MCDM	NDP	QFD	Evaluative	Fuzzy Sets		
Liu, Zhou [87]	Neurocomputing	MCDM	NDP	QFD	Evaluative	Statistical		
Zaim, Sevkli [28]	Expert Systems with Applications	MCDM	NDP	QFD	Evaluative	AHP		
Zhao, Oduncuoglu [138]	Computers and Industrial Engineering	MCDM	NDP	QFD	Evaluative	functional analysis		
Ko and Chen [139]	International Journal of Production Research	MCDM	NDP	QFD	Evaluative	Fuzzy Sets		
Zhong S., Zhou J., Chen Y.	Neurocomputing	MCDM	Engineering Design	QFD	Evaluative			
Canbaz, Yannou [66]	IEEE Transactions on Systems, Man, and Cybernetics: Systems	Explanatory	Engineering Design	Set-based design	Evaluative	Monte Carlo		
Hannapel and Vlahopoulos [140]	Structural and Multidisciplinary Optimization	Hybrid	Engineering Design	Set-based design	Evaluative			
Kennedy, Sobek Ii [51]	Systems Engineering	Explanatory	Engineering Design	Set-based design	Evaluative	Design Structure Matrix		
Jain and Raj [141]	Global Journal of Flexible Systems Management	MCDM	Manufacturing	AHP	Survey Study	TOPSIS	PROMETHEE	
Cook, Bose [39]	Landscape Journal	Explanatory	Construction	DQI	Case Study			
Al-Ashaab, Golob [42]	Concurrent Engineering	Explanatory	NDP	Set-based design	Evaluative			
Wang, Yannou [142]	Engineering with Computers	Hybrid	NDP	Set-based design	Evaluative			
Yannou, Yvars [45]	Journal of Engineering Design	Explanatory	NDP	Set-based design	Evaluative			
Thomson, Austin [143]	Engineering, Construction and Architectural Management	Explanatory	Construction	Model-Based	Evaluative			
Rybkowski, Shepley [40]	Health Environments Research and Design Journal	Explanatory	Construction	LPS	Evaluative	Set-Based Design		
Lee, Bae [47]	Automation in Construction	Hybrid	Construction	Set-based design	Case Study	AHP		
Sacks, Radosavljevic [144]	Automation in Construction	Explanatory	Construction	Last Planner System		BIM		

Table A1. *Cont.*

Author	Journal	Decision Method	Sector	Main Technique	Study Type	Technique 2	Technique 3	Technique 4
Inoue, Nahm [145]	Concurrent Engineering Research and Applications	Hybrid	Engineering Design	Set-based design	Evaluative			
Qureshi, Dantan [143]	Engineering Applications of Artificial Intelligence	Explanatory	Engineering Design	Set-based design	Evaluative			
Shahan and Seepersad [144]	Concurrent Engineering Research and Applications	Hybrid	Engineering Design	Set-based design	Evaluative	Trial-and-Error Design Process		
Avigad and Moshaiov [100]	journal of Engineering Design	Hybrid		Set-Based Design	Evaluative	Pareto Analysis		
Avigad and Moshaiov [44]	Journal of Engineering Design	Explanatory	Engineering Design	Set-based design	Evaluative			
Malak Jr, Aughenbaugh [2]	CAD Computer Aided Design	Hybrid	Engineering Design	Set based design	Evaluative	MAUT		
Singer, Doerry [145]	Naval Engineers Journal	Explanatory	Engineering Design	Set based design	Evaluative			

References

1. Kültür, S.; Türkeri, N.; Knaack, U. A holistic decision support tool for facade design. *Buildings* **2019**, *9*, 186. [CrossRef]
2. Malak, R.J., Jr.; Aughenbaugh, J.M.; Paredis, C.J. Multi-attribute utility analysis in set-based conceptual design. *Comput.-Aided Des.* **2009**, *41*, 214–227. [CrossRef]
3. Serra, C.E.M.; Kunc, M. Benefits realisation management and its influence on project success and on the execution of business strategies. *Int. J. Proj. Manag.* **2015**, *33*, 53–66. [CrossRef]
4. Serugga, J.; Kagioglou, M.; Tzortzopoulos, P. Value Generation in Front-End Design of Social Housing with QFD and Multiattribute Utility Theory. *J. Constr. Eng. Manag.* **2020**, *146*, 04020019. [CrossRef]
5. Wey, W.M.; Wei, W.L. Urban Street Environment Design for Quality of Urban Life. *Soc. Indic. Res.* **2016**, *126*, 161–186. [CrossRef]
6. D'Agostino, D.; Parker, D.; Melià, P. Environmental and economic implications of energy efficiency in new residential buildings: A multi-criteria selection approach. *Energy Strategy Rev.* **2019**, *26*, 100412. [CrossRef]
7. Ballard, G.; Koskela, L. Rhetoric and design. In Proceedings of the19th International Conference on Engineering Design, Seoul, Korea, 19–22 April 2013.
8. Koskela, L. Where rhetoric and lean meet. In Proceedings of the 23rd Annual Conference of the International Group for Lean Construction, Perth, Australia, 29–31 July 2015.
9. Koskela, L.; Ballard, G. The two pillars of design theory: Method of analysis and rhetoric. In Proceedings of the International Conference on Engineering Design, ICED13, Seoul, Korea, 19–22 August 2013.
10. Goodfellow, M.J.; Wortley, J.; Azapagic, A. A system design framework for the integration of public preferences into the design of large infrastructure projects. *Process. Saf. Environ. Prot.* **2014**, *92*, 687–701. [CrossRef]
11. Kpamma, Z.E.; Adjei-Kumi, T.; Ayarkwa, J.; Adinyira, E. Participatory design, wicked problems, choosing by advantages. *Eng. Constr. Archit. Manag.* **2017**, *24*, 289–307. [CrossRef]
12. Buchanan, R. Declaration by design: Rhetoric, argument, and demonstration in design practice. *Des. Issues* **1985**, *2*, 4–22. [CrossRef]
13. Eleftheriadis, S.; Duffour, P.; Mumovic, D. Participatory decision-support model in the context of building structural design embedding BIM with QFD. *Adv. Eng. Inform.* **2018**, *38*, 695–711. [CrossRef]
14. Sapountzis, S.; Harris, K.; Kagioglou, M. *Benefits Management and Benefits Realisation—A Literature Review*; HaCIRIC, The University of Salford: Greater Manchester, UK, 2008.
15. Ballard, G. The Lean Project Delivery System: An Update. *Lean Constr. J.* **2008**, 1–19.
16. Austin, S.; Steele, J.; Macmillan, S.; Kirby, P.; Spence, R. Mapping the conceptual design activity of interdisciplinary teams. *Des. Stud.* **2001**, *22*, 211–232.
17. Lawson, B. *How Designers Think: The Design Process Demystified*; Architectural Press: New York, NY, USA, 2005.

18. Austin, S.; Baldwin, A.; Li, B.; Waskett, P. Analytical design planning technique (ADePT): A dependency structure matrix tool to schedule the building design process. *Constr. Manag. Econ.* **2010**, *18*, 173–182. [CrossRef]
19. Gomes, D.; Tzortzopoulos, P.; Kagioglou, M. Socio-Constructivist Account of Collaboration in Concept Design. In Proceedings of the 25th Annual Conference of the International Group for Lean Construction, Heraklion, Greece, 9–12 July 2017; pp. 301–308.
20. Arroyo, P.; Tommelein, I.; Ballard, G.; Rumsey, P. Choosing by advantages: A case study for selecting an HVAC system for a net zero energy museum. *Energy Build.* **2016**, *111*, 26–36. [CrossRef]
21. Brownley, C.W. *Multi-objective Decision Analysis: Managing Trade-offs and Uncertainty*; Business Expert Press: New York, NY, USA, 2013.
22. Arroyo, P.; Tommelein, I.; Ballard, G. Deciding a sustainable alternative by 'choosing by advantages' in the AEC industry. In Proceedings of the 20th Annual Conference of the International Group for Lean Construction, San Diego, CA, USA, 18–20 July 2012.
23. Arroyo, P.; Tommelein, I.; Ballard, G. Comparing AHP and CBA as decision methods to resolve the choosing problem in detailed design. *J. Constr. Eng. Manag.* **2014**, *141*, 04014063. [CrossRef]
24. Saaty, T.L. Making and validating complex decisions with the AHP/ANP. *J. Syst. Sci. Syst. Eng.* **2005**, *14*, 1–36. [CrossRef]
25. Ignatius, J.; Rahman, A.; Yazdani, M.; Šaparauskas, J.; Haron, S.H. An integrated fuzzy ANP–QFD approach for green building assessment. *J. Civ. Eng. Manag.* **2016**, *22*, 551–563. [CrossRef]
26. Dağdeviren, M.; Yüksel, İ. A fuzzy analytic network process (ANP) model for measurement of the sectoral competititon level (SCL). *J. Expert Syst. Appl.* **2010**, *37*, 1005–1014. [CrossRef]
27. Cheng, E.W.; Li, H.; Yu, L. The analytic network process (ANP) approach to location selection: A shopping mall illustration. *J. Constr. Innov.* **2005**, *5*, 83–97. [CrossRef]
28. Zaim, S.; Sevkli, M.; Camgöz-Akdağ, H.; Demirel, O.F.; Yayla, A.Y.; Delen, D. Use of ANP weighted crisp and fuzzy QFD for product development. *J. Expert Syst. Appl.* **2014**, *41*, 4464–4474. [CrossRef]
29. Akkaya, G.; Turanoğlu, B.; Öztaş, S. An integrated fuzzy AHP and fuzzy MOORA approach to the problem of industrial engineering sector choosing. *Expert Syst. Appl.* **2015**, *42*, 9565–9573. [CrossRef]
30. Macharis, C.; Springael, J.; Brucker, K.D.; Verbeke, A. PROMETHEE and AHP: The design of operational synergies in multicriteria analysis: Strengthening PROMETHEE with ideas of AHP. *Eur. J. Oper. Res.* **2004**, *153*, 307–317. [CrossRef]
31. Akbaş, H.; Bilgen, B. An integrated fuzzy QFD and TOPSIS methodology for choosing the ideal gas fuel at WWTPs. *Energy* **2017**, *125*, 484–497. [CrossRef]
32. Alshamrani, O.; Alshibani, A.; Alogaili, M. Analytic hierarchy process & multi attribute utility theory based approach for the selection of lighting systems in residential buildings: A case study. *Buildings* **2018**, *8*, 73. [CrossRef]
33. Navarro-Martinez, D.; Loomes, G.; Isoni, A.; Butler, D.; Alaoui, L. Boundedly rational expected utility theory. *J. Risk Uncertain.* **2019**, *57*, 199–223. [CrossRef]
34. Reim, W.; Parida, V.; Örtqvist, D. Product–Service Systems (PSS) business models and tactics—A systematic literature review. *J. Clean. Prod.* **2015**, *97*, 61–75. [CrossRef]
35. Xiao, Y.; Watson, M. Guidance on conducting a systematic literature review. *J. Plan. Educ. Res.* **2019**, *39*, 93–112. [CrossRef]
36. Cook, D.J.; Greengold, N.L.; Ellrodt, A.G.; Weingarten, S.R. The relation between systematic reviews and practice guidelines. *Ann. Intern. Med.* **1997**, *127*, 210–216. [CrossRef] [PubMed]
37. Paré, G.; Trudel, M.-C.; Jaana, M.; Kitsiou, S. Synthesizing information systems knowledge: A typology of literature reviews. *Inf. Manag.* **2015**, *52*, 183–199.
38. Inayat, I.; Salim, S.S.; Marczak, S.; Daneva, M.; Shamshirband, S. A systematic literature review on agile requirements engineering practices and challenges. *Comput. Hum. Behav.* **2015**, *51*, 915–929. [CrossRef]
39. Chohan, A.H.; Irfan, A.; Awad, J. Development of quality indicators of housing design (QIHD), an approach to improve design quality of affordable housing. *Open House Int.* **2015**, *40*, 10–17.
40. Cook, J.A.; Bose, M.; Marshall, W.E.; Main, D.S. How does design quality add to our understanding of walkable communities? *Landsc. J.* **2013**, *32*, 151–166. [CrossRef]
41. Rybkowski, Z.K.; Shepley, M.M.; Ballard, H.G. Target value design: Applications to newborn intensive care units. *Health Environ. Res. Des. J.* **2012**, *5*, 5–22. [CrossRef]

42. Della Spina, L.; Lorè, I.; Scrivo, R.; Viglianisi, A. An integrated assessment approach as a decision support system for urban planning and urban regeneration policies. *Buildings* **2017**, *7*, 85. [CrossRef]
43. Unal, M.; Miller, S.W.; Chhabra, J.P.S.; Warn, G.P.; Yukish, M.A.; Simpson, T.W. A sequential decision process for the system-level design of structural frames. *Struct. Multidiscip. Optim.* **2017**, *56*, 991–1011. [CrossRef]
44. Yannou, B.; Yvars, P.A.; Hoyle, C.; Chen, W. Set-based design by simulation of usage scenario coverage. *J. Eng. Des.* **2013**, *24*, 575–603. [CrossRef]
45. Lee, S.-I.; Bae, J.-S.; Cho, Y.S. Efficiency analysis of Set-based Design with structural building information modeling (S-BIM) on high-rise building structures. *Autom. Constr.* **2012**, *23*, 20–32. [CrossRef]
46. Rempling, R.; Mathern, A.; Ramos, D.T.; Fernández, S.L. Automatic structural design by a set-based parametric design method. *Autom. Constr.* **2019**, *108*, 1–10. [CrossRef]
47. Jia, W.; Liu, Z.; Lin, Z.; Qiu, C.; Tan, J. Quantification for the importance degree of engineering characteristics with a multi-level hierarchical structure in QFD. *Int. J. Prod. Res.* **2016**, *54*, 1627–1649. [CrossRef]
48. Jiang, H.; Kwong, C.K.; Liu, Y.; Ip, W.H. A methodology of integrating affective design with defining engineering specifications for product design. *Int. J. Prod. Res.* **2015**, *53*, 2472–2488. [CrossRef]
49. Zhang, X.; Zhang, S.; Zhang, L.; Xue, J.; Sa, R.; Liu, H. Identification of product's design characteristics for remanufacturing using failure modes feedback and quality function deployment. *J. Clean. Prod.* **2019**, *239*, 117967. [CrossRef]
50. Kennedy, B.M.; Sobek, D.K.; Kennedy, M.N. Reducing rework by applying set-based practices early in the systems engineering process. *Syst. Eng.* **2014**, *17*, 278–296. [CrossRef]
51. Lanjewar, P.; Rao, R.; Kale, A.; Taler, J.; Ocłoń, P. Evaluation and selection of energy technologies using an integrated graph theory and analytic hierarchy process methods. *Decis. Sci. Lett.* **2016**, *5*, 237–348. [CrossRef]
52. Mastura, M.T.; Sapuan, S.M.; Mansor, M.R.; Nuraini, A.A. Conceptual design of a natural fibre-reinforced composite automotive anti-roll bar using a hybrid approach. *Int. J. Adv. Manuf. Technol.* **2017**, *91*, 2031–2048. [CrossRef]
53. Tian, G.; Zhang, H.; Jia, H.; Liu, Y.; Xu, G.; Wang, J. Automotive style design assessment and sensitivity analysis using integrated analytic hierarchy process and technique for order preference by similarity to ideal solution. *Adv. Mech. Eng.* **2016**, *8*, 1–10. [CrossRef]
54. Eleftheriadis, G.; Hamdy, M. The impact of insulation and HVAC degradation on overall building energy performance: A case study. *Buildings* **2018**, *8*, 23. [CrossRef]
55. Talebanpour, R.; Javadi, M. Decision-making for flexible manufacturing systems using DEMATEL and SAW. *Decis. Sci. Lett.* **2015**, *4*, 363–372. [CrossRef]
56. Chen, Z.; Ming, X.; Zhang, X.; Yin, D.; Sun, Z. A rough-fuzzy DEMATEL-ANP method for evaluating sustainable value requirement of product service system. *J. Clean. Prod.* **2019**, *228*, 485–508. [CrossRef]
57. Li, X.; Song, W. A Rough VIKOR-Based QFD for Prioritizing Design Attributes of Product-Related Service. *Math. Probl. Eng.* **2016**, *2016*, 9642018. [CrossRef]
58. Ding, T.; Liang, L.; Yang, M.; Wu, H. Multiple attribute decision making based on cross-evaluation with uncertain decision parameters. *Math. Probl. Eng.* **2016**, *2016*, 4313247. [CrossRef]
59. Chen, X.; Kim, T.W.; Chen, J.; Xue, B.; Jeong, W. Ontology-based representations of user activity and flexible space information: Towards an automated space-use analysis in buildings. *Adv. Civ. Eng.* **2019**, *2019*, 3690419. [CrossRef]
60. Ceballos, B.; Lamata, M.T.; Pelta, D.A. A comparative analysis of multi-criteria decision-making methods. *Prog. Artif. Intell.* **2016**, *5*, 315–322. [CrossRef]
61. Trivedi, A.; Singh, A. A hybrid multi-objective decision model for emergency shelter location-relocation projects using fuzzy analytic hierarchy process and goal programming approach. *Int. J. Proj. Manag.* **2017**, *35*, 827–840. [CrossRef]
62. Yang, L.-R.; Chen, J.-H.; Wang, X.-L. Assessing the effect of requirement definition and management on performance outcomes: Role of interpersonal conflict, product advantage and project type. *Int. J. Proj. Manag.* **2015**, *33*, 67–80. [CrossRef]
63. Karni, E.; Vierø, M.-L. Awareness of unawareness: A theory of decision making in the face of ignorance. *J. Econ. Theory* **2017**, *168*, 301–328. [CrossRef]
64. Serugga, J.; Kagioglou, M.; Tzortzopoulos, P. A Predictive Method for Benefits Realisation through Modelling Uncertainty in Front End Design. In Proceedings of the 27th Annual Conference of the International Group for Lean Construction (IGLC), Dublin, Ireland, 1–7 July 2019.

65. Canbaz, B.; Yannou, B.; Yvars, P.A. Resolving design conflicts and evaluating solidarity in distributed design. *IEEE Trans. Syst. Man Cybern. Syst.* **2014**, *44*, 1044–1055. [CrossRef]
66. Moghimi, V.; Jusan, M.B.M.; Izadpanahi, P.; Mahdinejad, J. Incorporating user values into housing design through indirect user participation using MEC-QFD model. *J. Build. Eng.* **2017**, *9*, 76–83. [CrossRef]
67. Saaty, T.L. Decision making—The analytic hierarchy and network processes (AHP/ANP). *J. Syst. Sci. Syst. Eng.* **2004**, *13*, 1–35. [CrossRef]
68. Saaty, T.L. *Decision Making with Dependence and Feedback: The Analytic Network Process*; RWS Publications: Pittsburgh, Pennsylvania, 2001.
69. Saaty, T.L. Fundamentals of the analytic network process. In Proceedings of the 5th International Symposium on the Analytic Hierarchy Process, Kobe, Japan, 12–14 August 1999.
70. Wu, Y.; Yang, M.; Zhang, H.; Chen, K.; Wang, Y. Optimal site selection of electric vehicle charging stations based on a cloud model and the PROMETHEE method. *Energies* **2016**, *9*, 157. [CrossRef]
71. Franceschini, F.; Maisano, D.; Mastrogiacomo, L. Customer requirement prioritization on QFD: A new proposal based on the generalized Yager's algorithm. *Res. Eng. Des.* **2015**, *26*, 171–187. [CrossRef]
72. Saaty, T.; De Paola, P. Rethinking design and urban planning for the cities of the future. *Buildings* **2017**, *7*, 76. [CrossRef]
73. Navarro, I.J.; Yepes, V.; Martí, J.V. A Review of Multicriteria Assessment Techniques Applied to Sustainable Infrastructure Design. *Adv. Civ. Eng.* **2019**, *2019*, 6134803. [CrossRef]
74. Cho, J.; Chun, J.; Kim, I.; Choi, J. Preference evaluation system for construction products using QFD-TOPSIS logic by considering trade-off technical characteristics. *Math. Probl. Eng.* **2017**, *2017*, 9010857. [CrossRef]
75. Brans, J.-P.; Vincke, P.; Mareschal, B. How to select and how to rank projects: The PROMETHEE method. *Eur. J. Oper. Res.* **1986**, *24*, 228–238. [CrossRef]
76. Hosseini Motlagh, S.M.; Behzadian, M.; Ignatius, J.; Goh, M.; Sepehri, M.M.; Hua, T.K. Fuzzy PROMETHEE GDSS for technical requirements ranking in HOQ. *Int. J. Adv. Manuf. Technol.* **2015**, *76*, 1993–2002. [CrossRef]
77. Suhr, J. *The Choosing by Advantages Decisionmaking System*; Greenwood Publishing Group: Westport, CT, USA, 1999.
78. Arroyo, P.; Mourgues, C.; Flager, F.; Correa, M.G. A new method for applying choosing by advantages (CBA) multicriteria decision to a large number of design alternatives. *Energy Build.* **2018**, *167*, 30–37. [CrossRef]
79. Keeney, R.L.; Raiffa, H. *Decisions with Multiple Objectives: Preferences and Value Trade-Offs*; Cambridge University Press: Cambridge, UK, 1976.
80. Serugga, J.; Kagioglou, M.; Tzortzopoulos, P. Decision Making: Value Generation in Front End Design using Quality Function and Utility Theory. In Proceedings of the CIB World Building Congress, Hong Kong, China, 17–21 June 2019.
81. Kundakcı, N.; Işık, A. Integration of MACBETH and COPRAS methods to select air compressor for a textile company. *Decis. Sci. Lett.* **2016**, *5*, 381–394. [CrossRef]
82. Kaya, İ.; Çolak, M.; Terzi, F. Use of MCDM techniques for energy policy and decision-making problems: A review. *Int. J. Energy Res.* **2018**, *42*, 2344–2372. [CrossRef]
83. Sousa-Zomer, T.T.; Cauchick-Miguel, P.A. Proposal of a hotspot-based approach to identifying social impacts along the product-service systems life cycle in the early design phases. *Procedia CIRP* **2017**, *64*, 85–90. [CrossRef]
84. Yoon, S.; Naderpajouh, N.; Hastak, M. Decision model to integrate community preferences and nudges into the selection of alternatives in infrastructure development. *J. Clean. Prod.* **2019**, *228*, 1413–1424. [CrossRef]
85. Gotzamani, K.; Georgiou, A.; Andronikidis, A.; Kamvysi, K. Introducing multivariate Markov modeling within QFD to anticipate future customer preferences in product design. *Int. J. Qual. Reliab. Manag.* **2018**, *35*, 762–778. [CrossRef]
86. Liu, Y.; Zhou, J.; Chen, Y. Using fuzzy non-linear regression to identify the degree of compensation among customer requirements in QFD. *Neurocomputing* **2014**, *142*, 115–124. [CrossRef]
87. Franceschini, F.; Galetto, M.; Maisano, D.; Mastrogiacomo, L. Prioritisation of engineering characteristics in QFD in the case of customer requirements orderings. *Int. J. Prod. Res.* **2015**, *53*, 3975–3988. [CrossRef]
88. Wang, Z.; Fung, R.Y.K.; Li, Y.L.; Pu, Y. A group multi-granularity linguistic-based methodology for prioritizing engineering characteristics under uncertainties. *Comput. Ind. Eng.* **2016**, *91*, 178–187. [CrossRef]
89. Wu, X.; Liao, H. An approach to quality function deployment based on probabilistic linguistic term sets and ORESTE method for multi-expert multi-criteria decision making. *Inf. Fusion* **2018**, *43*, 13–26. [CrossRef]

90. Li, S.; Tang, D.; Wang, Q. Rating engineering characteristics in open design using a probabilistic language method based on fuzzy QFD. *Comput. Ind. Eng.* **2019**, *135*, 348–358. [CrossRef]
91. Liu, A.; Hu, H.; Zhang, X.; Lei, D. Novel Two-Phase Approach for Process Optimization of Customer Collaborative Design Based on Fuzzy-QFD and DSM. *IEEE Trans. Eng. Manag.* **2017**, *64*, 193–207. [CrossRef]
92. Büyüközkan, G.; Güleryüz, S. Extending Fuzzy QFD Methodology with GDM Approaches: An Application for IT Planning in Collaborative Product Development. *Int. J. Fuzzy Syst.* **2015**, *17*, 544–558. [CrossRef]
93. Chen, L.H.; Chen, C.N. Normalisation models for prioritising design requirements for quality function deployment processes. *Int. J. Prod. Res.* **2014**, *52*, 299–313. [CrossRef]
94. Wasserman, G.S. On how to prioritize design requirements during the QFD planning process. *IIE Trans.* **1993**, *25*, 59–65. [CrossRef]
95. Ko, W.-C.; Chen, L.-H. An approach of new product planning using quality function deployment and fuzzy linear programming model. *Int. J. Prod. Res.* **2014**, *52*, 1728–1743. [CrossRef]
96. Ji, P.; Jin, J.; Wang, T.; Chen, Y. Quantification and integration of Kanos model into QFD for optimising product design. *Int. J. Prod. Res.* **2014**, *52*, 6335–6348. [CrossRef]
97. Rapp, S.; Chinnam, R.; Doerry, N.; Murat, A.; Witus, G. Product development resilience through set-based design. *Syst. Eng.* **2018**, *21*, 490–500. [CrossRef]
98. Avigad, G.; Moshaiov, A. Set-based concept selection in multi-objective problems involving delayed decisions. *J. Eng. Des.* **2010**, *21*, 619–646. [CrossRef]
99. Alkahtani, M.; Al-Ahmari, A.; Kaid, H.; Sonboa, M. Comparison and evaluation of multi-criteria supplier selection approaches: A case study. *Adv. Mech. Eng.* **2019**, *11*, 1687814018822926. [CrossRef]
100. Jalilzadehazhari, E.; Vadiee, A.; Johansson, P. Achieving a trade-off construction solution using BIM, an optimization algorithm, and a multi-criteria decision-making method. *Buildings* **2019**, *9*, 81. [CrossRef]
101. Zhang, X. User selection for collaboration in product development based on QFD and DEA approach. *J. Intell. Manuf.* **2019**, *30*, 2231–2243. [CrossRef]
102. Buchanan, R.K.; Richards, J.E.; Rinaudo, C.H.; Goerger, S.R. Integrating set-based design into cost analysis. *Environ. Syst. Decis.* **2019**, *39*, 111–117. [CrossRef]
103. Small, C.; Parnell, G.S.; Pohl, E.; Goerger, S.R.; Cilli, M.; Specking, E. Demonstrating set-based design techniques: An unmanned aerial vehicle case study. *J. Def. Model. Simul.* **2019**. [CrossRef]
104. Wade, Z.; Parnell, G.S.; Goerger, S.; Pohl, E.; Specking, E. Convergent set-based design for complex resilient systems. *Environ. Syst. Decis.* **2019**, *39*, 118–127. [CrossRef]
105. Ammar, R.; Hammadi, M.; Choley, J.Y.; Barkallah, M.; Louati, J.; Haddar, M. Narrowing the set of complex systems' possible design solutions derived from the set-based concurrent engineering approach. *Concurr. Eng. Res. Appl.* **2019**, *27*, 233–248. [CrossRef]
106. Kabirifar, K.; Mojtahedi, M. The impact of Engineering, Procurement and Construction (EPC) phases on project performance: A case of large-scale residential construction project. *Buildings* **2019**, *9*, 15. [CrossRef]
107. Imran, M.; Khaliq, M.; Mahbubul Hye, A.K.; Ekareesakul, K. Influence of risk factors on construction firm project success in Pakistan. *Decis. Sci. Lett.* **2019**, *8*, 285–294. [CrossRef]
108. Zanni, M.; Sharpe, T.; Lammers, P.; Arnold, L.; Pickard, J. Developing a methodology for integration of whole life costs into BIM processes to assist design decision making. *Buildings* **2019**, *9*, 114. [CrossRef]
109. Lorenzi, C.I.; Ferreira, J.C.E. Failure mapping using FMEA and A3 in engineering to order product development: A case study in the industrial automation sector. *Int. J. Qual. Reliab. Manag.* **2018**, *35*, 1399–1422. [CrossRef]
110. Hashemkhani Zolfani, S.; Pourhossein, M.; Yazdani, M.; Zavadskas, E.K. Evaluating construction projects of hotels based on environmental sustainability with MCDM framework. *Alex. Eng. J.* **2018**, *57*, 357–365. [CrossRef]
111. Antoniou, F.; Aretoulis, G.N. Comparative analysis of multi-criteria decision making methods in choosing contract type for highway construction in Greece. *Int. J. Manag. Decis. Mak.* **2018**, *17*, 1–28.
112. Fargnoli, M.; Costantino, F.; Di Gravio, G.; Tronci, M. Product service-systems implementation: A customized framework to enhance sustainability and customer satisfaction. *J. Clean. Prod.* **2018**, *188*, 387–401. [CrossRef]
113. Kamara, J.M. Maintaining focus on clients' requirements using the DQI tool: Towards a requirements-oriented project process. *Built Environ. Proj. Asset Manag.* **2017**, *7*, 271–283. [CrossRef]

114. Guarini, M.R.; Battisti, F.; Chiovitti, A. Public initiatives of settlement transformation: A theoretical-methodological approach to selecting tools of multi-criteria decision analysis. *Buildings* **2017**, *8*, 1. [CrossRef]
115. Chokhachian, A.; Santucci, D.; Auer, T. A human-centered approach to enhance urban resilience, implications and application to improve outdoor comfort in dense urban spaces. *Buildings* **2017**, *7*, 113. [CrossRef]
116. Fregonara, E.; Giordano, R.; Ferrando, D.G.; Pattono, S. Economic-environmental indicators to support investment decisions: A focus on the buildings' end-of-life stage. *Buildings* **2017**, *7*, 65. [CrossRef]
117. Kang, H. Development of an nearly Zero Emission Building (nZEB) life cycle cost assessment tool for fast decision making in the early design phase. *Energies* **2017**, *10*, 59. [CrossRef]
118. El Sawalhi, N.I.; El Agha, O. Multi-attribute utility theory for selecting an appropriate procurement method in the construction projects. *J. Constr. Dev. Ctries.* **2017**, *22*, 75–96. [CrossRef]
119. Dehe, B.; Bamford, D. Quality Function Deployment and operational design decisions—A healthcare infrastructure development case study. *Prod. Plan. Control.* **2017**, *28*, 1177–1192. [CrossRef]
120. Singhaputtangkul, N. A decision support tool to mitigate decision-making problems faced by a building design team. *Smart Sustain. Built Environ.* **2017**, *6*, 2–18. [CrossRef]
121. Chen, L.H.; Ko, W.C.; Yeh, F.T. Approach based on fuzzy goal programing and quality function deployment for new product planning. *Eur. J. Oper. Res.* **2017**, *259*, 654–663. [CrossRef]
122. Arroyo, P.; Fuenzalida, C.; Albert, A.; Hallowell, M.R. Collaborating in decision making of sustainable building design: An experimental study comparing CBA and WRC methods. *Energy Build.* **2016**, *128*, 132–142. [CrossRef]
123. Cattaneo, T.; Giorgi, E.; Ni, M.; Manzoni, G.D. Sustainable development of rural areas in the EU and China: A common strategy for architectural design, research practice and decision-making. *Buildings* **2016**, *6*, 42. [CrossRef]
124. Afshari, H.; Peng, Q.; Gu, P. Reducing effects of design uncertainties on product sustainability. *Cogent Eng.* **2016**, *3*, 1231388. [CrossRef]
125. Alemam, A.; Li, S. Matrix-based quality tools for concept generation in eco-design. *Concurr. Eng. Res. Appl.* **2016**, *24*, 113–128. [CrossRef]
126. Wang, Z.L.; You, J.X.; Liu, H.C. Uncertain quality function deployment using a hybrid group decision making model. *Symmetry* **2016**, *8*, 119. [CrossRef]
127. Venkata Subbaiah, K.; Yeshwanth Sai, K.; Suresh, C. QFD–ANP Approach for the Conceptual Design of Research Vessels: A Case Study. *J. Inst. Eng. India Ser. C* **2016**, *97*, 539–546. [CrossRef]
128. De Souza, V.M.; Borsato, M. Combining Stage-Gate™ model using Set-Based concurrent engineering and sustainable end-of-life principles in a product development assessment tool. *J. Clean. Prod.* **2016**, *112*, 3222–3231. [CrossRef]
129. Konstantinou, T. A methodology to support decision-making towards an energy-efficiency conscious design of residential building envelope retrofitting. *Buildings* **2015**, *5*, 1221–1241. [CrossRef]
130. Kim, S.; Son, C.; Yoon, B.; Park, Y. Development of an innovation model based on a service-oriented product service system (PSS). *Sustainability* **2015**, *7*, 14427–14449. [CrossRef]
131. Luo, X.G.; Kwong, C.K.; Tang, J.F.; Sun, F.Q. QFD-based product planning with consumer choice analysis. *IEEE Trans. Syst. Man Cybern. Syst.* **2015**, *45*, 454–461. [CrossRef]
132. Singhaputtangkul, N.; Low, S.P. Modeling a decision support tool for buildable and sustainable building envelope designs. *Buildings* **2015**, *5*, 521–535. [CrossRef]
133. Yu, S.; Yang, Q.; Tao, J.; Xu, X. Incorporating quality function deployment with modularity for the end-of-life of a product family. *J. Clean. Prod.* **2015**, *87*, 423–430. [CrossRef]
134. Jin, J.; Ji, P.; Liu, Y.; Johnson Lim, S.C. Translating online customer opinions into engineering characteristics in QFD: A probabilistic language analysis approach. *Eng. Appl. Artif. Intell.* **2015**, *41*, 115–127. [CrossRef]
135. Ochoa, J.J. Reducing plan variations in delivering sustainable building projects. *J. Clean. Prod.* **2014**, *85*, 276–288. [CrossRef]
136. Zhao, S.; Oduncuoglu, A.; Hisarciklilar, O.; Thomson, V. Quantification of cost and risk during product development. *Comput. Ind. Eng.* **2014**, *76*, 183–192. [CrossRef]
137. Hannapel, S.; Vlahopoulos, N. Implementation of set-based design in multidisciplinary design optimization. *Struct. Multidiscip. Optim.* **2014**, *50*, 101–112. [CrossRef]

138. Jain, V.; Raj, T. Ranking of flexibility in flexible manufacturing system by using a combined multiple attribute decision making method. *Glob. J. Flex. Syst. Manag.* **2013**, *14*, 125–141. [CrossRef]
139. Wang, J.; Yannou, B.; Alizon, F.; Yvars, P.A. A usage coverage-based approach for assessing product family design. *Eng. Comput.* **2013**, *29*, 449–465. [CrossRef]
140. Thomson, D.S.; Austin, S.A.; Mills, G.R.; Devine-Wright, H. Practitioner understanding of value in the UK building sector. *Eng. Constr. Archit. Manag.* **2013**, *20*, 214–231. [CrossRef]
141. Sacks, R.; Radosavljevic, M.; Barak, R. Requirements for building information modeling based lean production management systems for construction. *Autom. Constr.* **2010**, *19*, 641–655. [CrossRef]
142. Inoue, M.; Nahm, Y.-E.; Okawa, S.; Ishikawa, H. Design support system by combination of 3D-CAD and CAE with preference set-based design method. *Concurr. Eng.* **2010**, *18*, 41–53. [CrossRef]
143. Qureshi, A.J.; Dantan, J.Y.; Bruyere, J.; Bigot, R. Set-based design of mechanical systems with design robustness integrated. *Int. J. Prod. Dev.* **2014**, *19*, 64–89. [CrossRef]
144. Shahan, D.; Seepersad, C.C. Implications of alternative multilevel design methods for design process management. *Concurr. Eng. Res. Appl.* **2010**, *18*, 5–18. [CrossRef]
145. Singer, D.J.; Doerry, N.; Buckley, M.E. What Is Set-Based Design? *Nav. Eng. J.* **2009**, *121*, 31–43. [CrossRef]