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CIVIL ENGINEERING, BUILDING TECHNOLOGY, AND SUSTAINABLE DECISION-MAKING

[1] Pragyan Priyadarshini, [2]Aditya Roy*
[1] Professor, Dept. of Civil Engineering, NIT BBSR,*
Asst. Professor Dept. of Civil Engineering, HIT, BBSR
[1]pragyanpriyadarshini@thenalanda.com,royaditya09@gmail.com*

Abstract: Fundamental scientific developments and multiple-criteria decision-making (MCDM) theories can promote sustainable decision-making in civil engineering, construction, and building technology. The goal of the present study is to provide a comprehensive overview of the state of the art in terms of theoretical methodologies that are used to support sustainable evaluation and selection procedures in civil engineering. Only works cited in the Clarivate Analytic Web of Science core collection database are included in the review. The review will examine how articles on MCDM innovations and applications have been dispersed by period of publication, by author countries and institutions, and by journals since the focus is on multiple-criteria decision-making. It presents a thorough study of journal articles published in 2015–2017 in two Web of Science categories: engineering civil and construction building technology. The articles are organised by study areas, issues that are examined, and methods that are applied in making decisions. The current review paper's findings demonstrate that MCDM applications have been steadily increasing, especially over the last three years, demonstrating the significant potential and opportunities for using MCDM methods for sustainable decision-making in civil engineering, construction, and building technology. **Keywords:** civil engineering; construction building technology; sustainability; decision-making; MCDM; literature review

1. Introduction

Fundamental scientific developments are the foundation of civil engineering. Theoretical techniques based on the fundamental sciences, such as mathematics, physics, and chemistry, are used in the design and construction of engineering structures and buildings. A number of review papers addressing the advancements in these fields of fundamental sciences and its application in civil engineering as well as in building and construction have been written throughout the last five years (2013–2017). On the basis of chemistry [1], physics [2], and other natural sciences [3], optimizations "inspired by nature" were developed. Applications of central force metaheuristic optimization [6], simulated annealing [5], and gravitational search algorithms [4] are presented as nature-inspired conceptual frameworks in engineering. Vibration control and building and engineering structure health monitoring are receiving a lot of attention [7–11], including bridges [12,13] and high-rise buildings [14–16]. A thorough analysis of tuned mass dampers for the reduction of structural vibration was given [17].

Continuing our overview of review articles, a number of review articles have been published to address specific civil engineering issues and information technology applications to assist in solving engineering problems. The usage of support vector machines in structural engineering was presented [18,19]. Neurocomputing, in terms of the application of artificial neural networks for civil infrastructure optimization, monitoring and control is reviewed [20]. A review of how automation in construction operations was applied and automated equipment was incorporated in building construction phases [21] is presented. Transportation systems and transport technologies are systematically assessed in [22].

As sustainable development is becoming more relevant, more and more publications are being published related to sustainability in construction (Figure 1). Sustainable, innovative and efficient structural design [23,24], sustainable building design [25], including sustainability in high-rise building design [26], and integrated planning for sustainable building [27] is acknowledged, as well as a model for the structural health monitoring of high-rise buildings [28], and the vibration control of smart structures [29] were discussed, including sustainability aspects. Sustainable urban design [30] is no less important for assuring overall sustainability. Ceravolo et al. [31] describe a methodology for assessing the time-dependent structural performance of electric road infrastructures. Katsigarakis et al. [32] present a sense–think–act methodology for intelligent building energy management. Wang and Szeto [33] present a multiobjective environmentally sustainable road network design using Pareto optimization. Wang et al. [34] present a multi-objective path optimization for critical infrastructure links with consideration of seismic resilience. Bozza et al. [35] advocate alternative resilience indices for city ecosystems subject to natural hazards. Cahill et al. [36] study the effect of road surface, vehicle and device characteristics on energy harvesting from bridge–vehicle interactions.

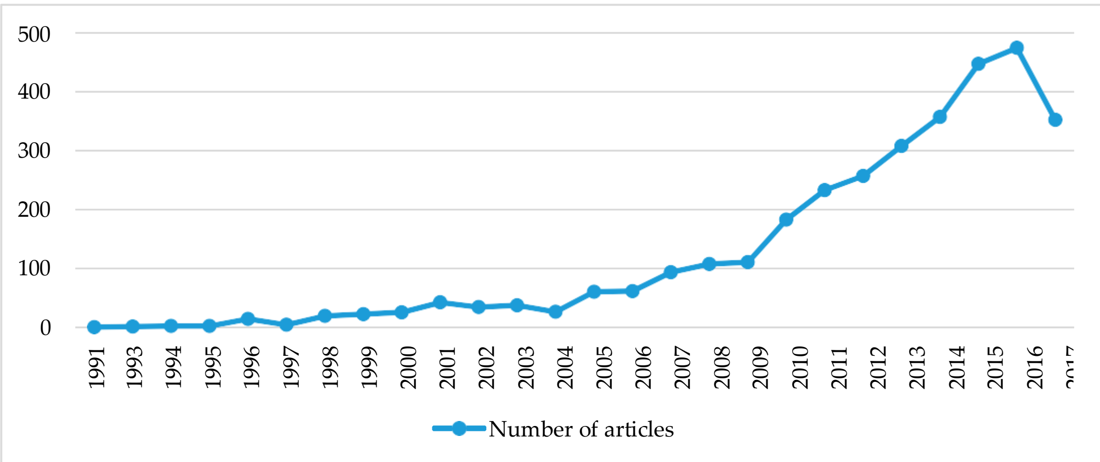

Figure 1. Number of publications on the topic “sustainability” in civil engineering and construction building technology Web of Science categories (Web of Science core collection database, 15 October 2017).

In applying the principles of sustainability, besides technological and economic aspects, environmental and social aspects also need to be considered. Accordingly, when choosing the most effective project decisions, everyone is faced with the need to evaluate the performance of a number of criteria. Mixed information and a wide variety of information types can be managed by applying multi-criteria decision analysis methods [37]. Multiple-criteria decision-making (MCDM) methods cover a wide range of somewhat distinct approaches. The methods can be broadly classified into two categories: discrete MADM (multi-attribute decision-making) methods and continuous MODM (multi-objective decision-making) methods. This classification has risen from two schools of thought regarding what human choice is based on: a French school and an American school. The French school mainly promotes the outranking concept for evaluating discrete alternatives. The American school

is based on multi-attribute value functions and multi-attribute utility theory. Lately multiple-criteria decision-making (MCDM) methods have been increasingly applied (Figure 2), combining MODM and MADM techniques.

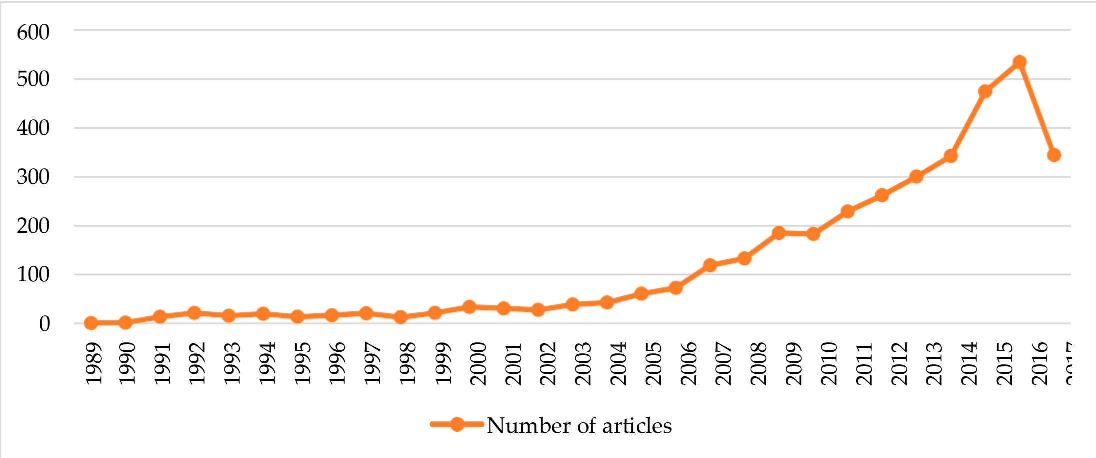

Figure 2. Number of publications on the topic "MCDM" in Web of Science core collection database (15 October 2017).

There are not many review articles aimed at analyzing MCDM (including MODM and MADM) for civil engineering applications. A very comprehensive paper was published by Kabir et al. [38]. Jato-Espino et al. [39] published a review article where an overview of the most widely-applied multi-criteria techniques and the main applications of the techniques to construction was provided.

Zavadskas et al. [40,41] reviewed the development of MCDM methods from 1772 to 2015. The first publication on multiple-criteria methods is considered a letter written by Franklin [42]. Pareto [43] publications played a particularly important role. Several Nobel prizes were

awarded to Debrese (1959), Frisch (1969), Samuelson (1970), Arrow (1972), Nash (1994), Kantorovich and Koopmans (1975), Dantzig (1976), Sen (1998). The work of Simon (1978) [44] played a special role in the most up-to-date MCDM theory. Other important contributions were made by Saaty [45], Zeleny [46], Zadeh [47]. Zadeh [47] introduced the fuzzy sets theory. In 2015, Herrera-Viedma, a well-known scholar in the field of MCDM, prepared a special issue [48] devoted to the fifty-year theory of Zadeh. Kou and Ergu [49] prepared a special issue devoted to Satty's 90th anniversary and an overview article for pairwise comparison matrixes in multi-criteria decision-making [50]. Later Zavadskas et al. reviewed applications of MCDM methods in civil engineering until 2015 [40,41]. Applications in particular civil engineering areas were summarized in a number of papers. In 2016, Zavadskas et al. [51] reviewed the application of hybrid MCDM (HMCDM) methods in engineering. This article also gave an overview of the historical development of MCDM and the main publications on this topic. The focus of the article was on a broad overview, i.e., engineering applications on the whole, not focusing on building and construction. In another review article, Zavadskas et al. [52] presented a comprehensive analysis of the application of HMCDM methods for sustainability problems, including technology or product development/selection, personnel selection and company management, site selection, supply chains, etc. Yi and Wang [53] presented a multi-objective mathematical programming approach for construction laborer assignment with equity consideration. Pons et al. [54] published an article devoted to the application of MCDM methods for the assessment of sustainability in architectural and engineering design; Penades-Pla et al. [55] overviewed the sustainable design of bridges. Keshavarz Ghorabaee et al. [56] provided a broad overview of the application of MCDM methods in supply chains. Si et al. [57] reviewed the application of MCDM methods for the assessment of green technologies. Decision-making for green building, sustainable design, and energy related
problems were overviewed [58,59]. Cerveira et al. [60] discussed wind farm distribution network optimization. These published review articles well illustrate the current state of the art in solving sustainability issues in civil engineering by applying MCDM, including MADM and MODM, methods. The whole and continuously increasing number of publications applying MCDM in civil engineering, construction and building technology is presented in Figure 3.

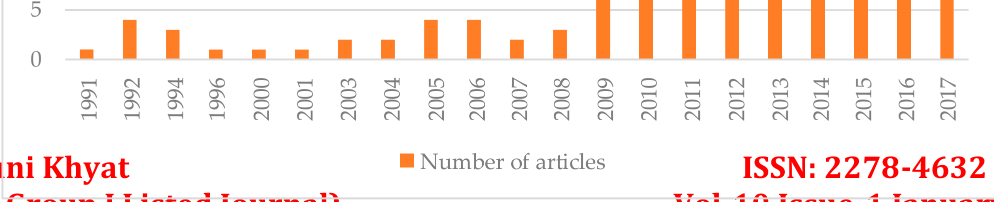

Figure 3. Number of publications on the topic "MCDM" in civil engineering and construction building technology Web of Science categories (Web of Science core collection database, 15 October 2017).

In addition, review articles focusing on the development of MCDM techniques also play an important role. Broad MADM and fuzzy MADM overviews were presented by Mardani et al. [61,62], Kahraman et al. [63], Antucheviciene et al. [64]. Zavadskas et al. [65] and Behzadian et al. [66] reviewed TOPSIS (technique for order of preference by similarity to ideal solution) method. Development of the VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje (in Serbian), which means multicriteria optimization and compromise solution) method was presented by Mardani et al. [67]. Balezentis and Balezentis [68] reviewed the MULTIMOORA (multiobjective optimization by ratio analysis plus full multiplicative form) method. Behzadian et al. [69] discussed numerous developments and applications in various areas of PROMETHEE (preference ranking organization method for enrichment evaluations) method. Yang et al. [70] discussed multiobjective inventory routing with uncertain demand using population-based metaheuristics. Pan et al. [71] presented a region division-based diversity maintaining approach for many-objective optimization. Marttunen et al. [72] reviewed combinations of methods and structuring challenges for multiple-criteria decision analysis in practice. The books, summarizing the MCDM methodology, and published by Tzeng [73–75], Kou et al. [76], Bisdorff et al. [77], and Liu [78] also play an important role. These publications facilitate the work of researchers and the ability to orient themselves in choosing the methods.

In the next section, MCDM applications in civil engineering and construction building technology are reviewed in terms of the distribution of papers by years, countries, institutions, and journals. Detailed analysis of the latest articles (2015–2017) in terms of application domains, analyzed problems and MCDM methods applied is provided in Section 3.

2. Research Methodology and Preliminary Results

The search in the online Web of Science core collection database was made on 15 October 2017. The research procedure is presented in Figure 4. The search was made on the topic "MCDM". From all the documents identified (3571), a total of 2605 articles were identified, including research articles and reviews, and excluding proceedings papers and book chapters.

A search for MCDM applications in civil engineering and construction building technology Web of Science categories identified 195 papers, including 160 research articles and review articles.

This search revealed that MCDM methods were applied by researchers from over 100 institutions in 91 countries all over the world and in more than 100 research areas, while MCDM in the Web of Science categories of civil engineering and construction building technology was applied by researchers from 34 countries (Figure 5). It is worth mentioning that the leading three countries were Iran, the USA and Lithuania. The leading university was Vilnius Gediminas Technical University, Lithuania (30 articles), followed by the University of Tehran, Iran (17 articles), as presented in Table 1.

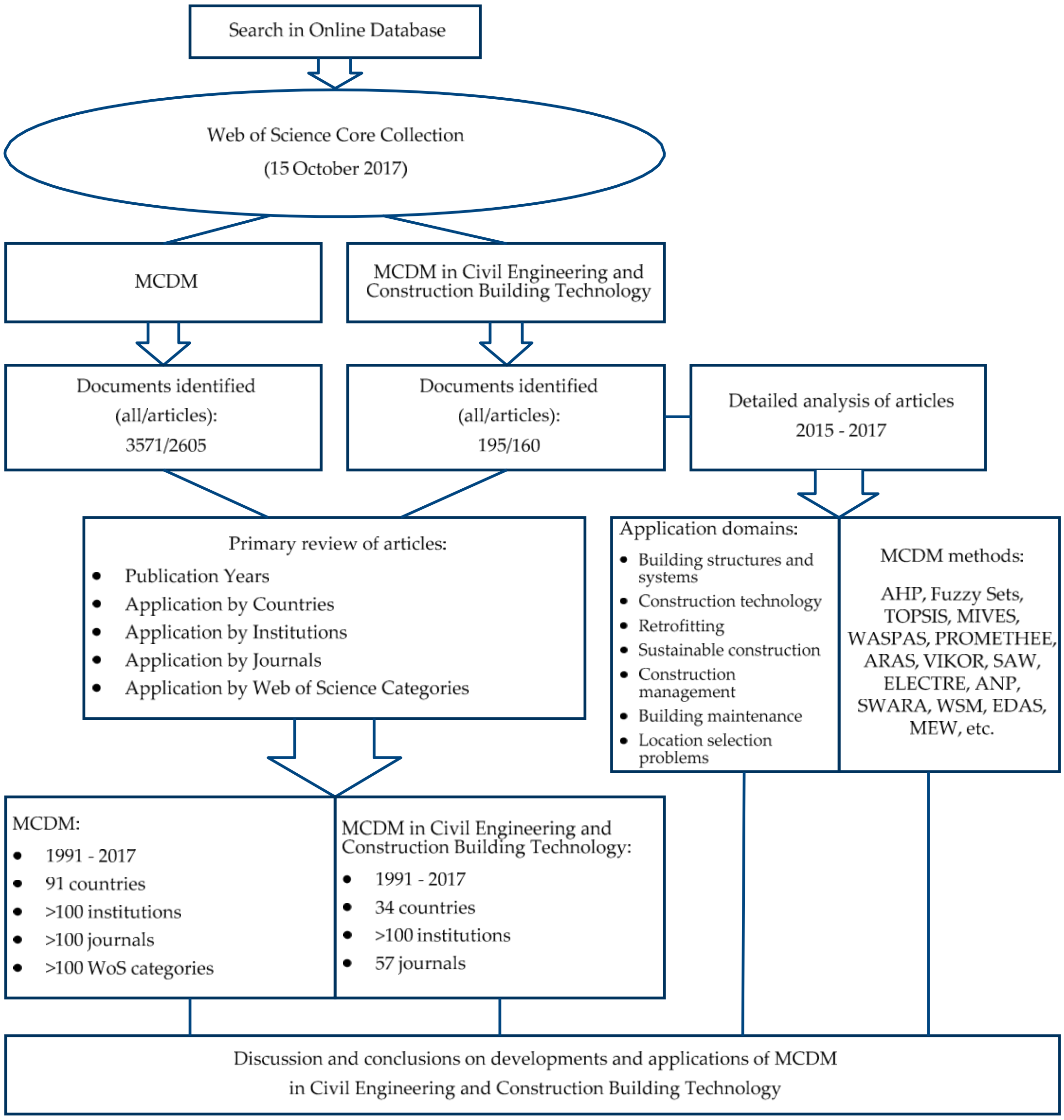

Figure 4. The research procedure and preliminary results.

The numerous papers on MCDM developments and applications were published in more than 100 different journals, often in operations research and computer science journals, while applications of MCDM for civil engineering, construction and building technology were published in 57 journals (Table 2), and mostly related to engineering. The leading journal was Journal of Civil Engineering and Management (24 articles).

As MCDM applications in civil engineering up to 2015 have been reviewed earlier [40,41], the current review focuses on detailed analysis of the papers published in 2015–2017. The changes during the period from 2014 until now are summarized in Table 3. It was found that the number of publications on MCDM methods increased by 56 percent in the three-year period. The geography of the authors expanded from 72 to 91 countries. A number of publications on the application of MCDM methods for civil engineering problems increased by 41 percent and the geography of the authors expanded from 28 to 34 countries in three year period. Researchers from the leading institution, Vilnius Gediminas Technical University, published 84 papers on the topic of MCDM in 2015–2017, including nine in the category of civil engineering and construction building technology.

Table 1. Publications by institutions on the topic "MCDM" civil engineering and construction building technology Web of Science categories (Web of Science core collection, 15 October 2017).

Institutions	Number of Articles
Vilnius Gediminas Technical University	30
University of Tehran	17
Amirkabir University of Technology	7
University of Naples Federico II	5
University of Arizona	5
Polytechnic University of Catalonia	5
Iran University Science Technology	5
Hong Kong Polytechnic University	5
University of British Columbia	4
Seoul National University of Science Technology	4
Istanbul Teknik University	4
Indian Institute of Technology IIT	4
Texas A&M University System	3
Royal Institute of Technology	3
Kaunas University of Technology	3
Islamic Azad University	3
Hohai University	3

Note: The names of institutions are presented as given in the Web of Science core collection database. The table does not represent the institutions that published less than three articles on the topic. Those are: two articles—Yonsei University; Yildiz Technical University; University of North Carolina; University of Nebraska System; University of Nebraska Lincoln; University of Illinois System; University of California System; Universiti Teknologi Malaysia; Universiti Malaya; Univ Mohaghegh Ardabili; Tsinghua University; Tennessee Technological University; Telecom Italia; Poznan University of Technology; Pontificia Universidad Catolica De Chile; Parthenope University Naples; Pacific Century Premium Dev Ltd.; National Central University; Nan Kai University Technology; Munzur Univ; Indian Institute of Technology IIT Roorkee; Engref; Engn Resinst Nat Disaster Shakhes Pajouh; Birla Institute of Technology Science. One article—Lublin University of Technology; Laval University;Lasbela Univ Agr; Kunsan Natl Univ; Korea University; Korea Environment Institute Kei; Korea Advanced Institute of Science Technology Kaist; Kocaeli University; Klaipeda University; Karlsruhe Inst Technol; Izmir Katip Celebi University; Istanbul Bilgi University; Isfahan University of Technology; Higher Institute of Applied Biological Sciences of Tunis; Inst Land Reclam Grass Farm; Indian Institute of Technology IIT Kharagpur; Indian Institute of Technology Iit Kanpur; Indian Institute of Science Iisc Bangalore; Indian Inst Remote Sensing; Imperial College London; Imam Khomeini Int Univ; Iett; Hyundai Inst Construct Technol; Hyundai Engn Construct Co., Ltd.; Huafan University; Hong Kong University of Science Technology; Heriot Watt University; Hellen Inst Transport;

Harp Akademileri Komutanligi; George Mason University; Gaziosmanpasa University; Firat University; Feng Chia University; Fed Univ Petr Resources; Fateh Res Grp; Eskisehir Osmangazi University; El Paso Metropolitan Planning Or; Ecole Natl Genie Rural; East Carolina University; Dogus University; Dalian University of Technology; Council of Scientific Industrial Research Csir India; Concordia University Canada; Chongqing Jiaotong University; Chia Nan Univ Pharm Sci; Centre National De La Recherche Scientifique Cnrs; Canik Basari University; Calif Dept Transp; Cairo University; Bursa Technical University; Bur Rech Geol Minieres; Brandon University; Bialystok Tech Univ; Beijing University of Technology; Beijing Normal University; Asian Institute of Technology; Aristotle University of Thessaloniki; Akdeniz University; Acad Sci Innovat Res Acsir.

Table 2. Publications by journal on the topic "MCDM" in civil engineering and construction building technology Web of Science categories (Web of Science core collection, 15 October 2017).

Title of Journal	Number of Articles
Journal of Civil Engineering and Management	24
Water Resources Management	23
Archives of Civil and Mechanical Engineering	7
Stochastic Environmental Research and Risk Assessment	6
Journal of Hydroinformatics	6
Energy and Buildings	6
Water Resources Bulletin	5
Journal of Construction Engineering and Management	5
Tunnelling and Underground Space Technology	4
Ocean Engineering	4
Journal of Advanced Transportation	4
Automation in Construction	4
Transportation	3
Sustainable Cities and Society	3
Structure and Infrastructure Engineering	3
Building and Environment	3

Note: The table does not represent the journals, which published less than 3 articles on the topic. Those are: two articles—Transportation Research Record; Transportation Research Part E Logistics and Transportation Review; Journal of Water Resources Planning and Management; Journal of Performance of Constructed Facilities; Journal of Irrigation and Drainage Engineering; Journal of Hydrology; Journal of Computing in Civil Engineering; Computer Aided Civil and Infrastructure Engineering; Civil Engineering and Environmental Systems; Baltic Journal of Road and Bridge Engineering; one article—Water International; Thin Walled Structures; Stochastic Hydrology and Hydraulics; Smart Structures and Systems; Proceedings of The Institution of Mechanical Engineers Part F Journal of Rail and Rapid Transit; Preservation of Roadway Structures and Pavements; Latin American Journal of Solids and Structures; KSCE Journal of Civil Engineering; Journal of Water Supply Research and Technology Aqua; Journal of Water Resources Planning and Management ASCE; Journal of Urban Planning and Development ASCE; Journal of Urban

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Planning and Development; Journal of Transportation Engineering ASCE; Journal of Structural Engineering ASCE; Journal of Management in Engineering; Journal of Information Technology in Construction; Journal of Hydrologic Engineering; Journal of Earthquake Engineering; Journal of Construction Engineering and Management ASCE; Journal of Building Engineering; Journal of Aerospace Engineering; Iranian Journal of Science and Technology, Transactions of Civil Engineering; International Journal of Geomate; International Journal of Concrete Structures and Materials; International Journal of Civil Engineering; Gradevinar; European Journal of Environmental and Civil Engineering; Earthquakes and Structures; Construction and Building Materials; Computers Structures; Advances in Structural Engineering.

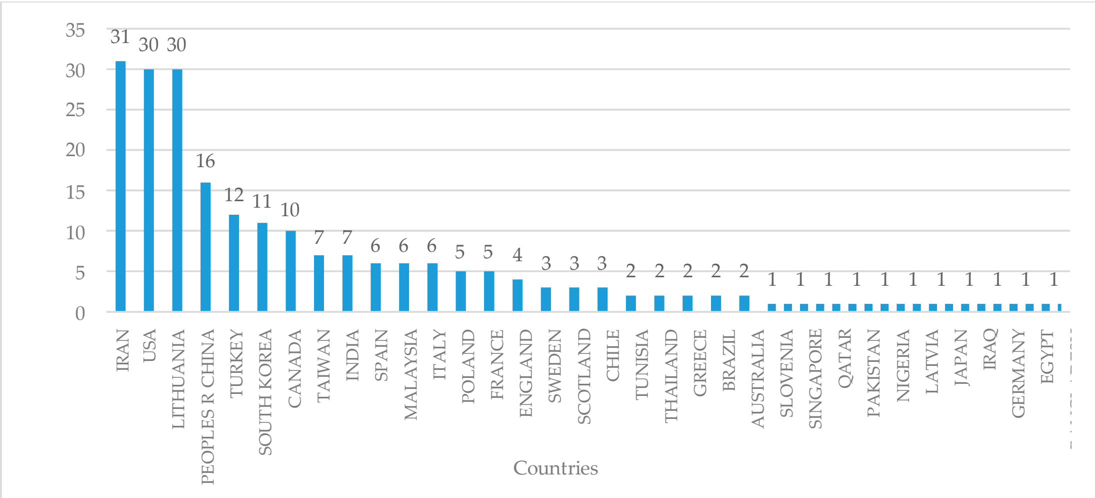

Figure 5. Publications by country on the topic of "MCDM" in civil engineering and construction building technology Web of Science categories (Web of Science core collection database, 15 October 2017).

Table 3. Changes in number of publications on the topic of "MCDM" in Web of Science core collection database.

Publications	Number of Publications	
	1991–2014	1991–2017 (15 October)
Publications on MCDM methods		
All	2290	3571
Articles:	1589	2605
• Countries	72	91
• Institutions	>100	>100
• Journals	>100	>100
Publications on MCDM in Civil Engineering and Construction Building Technology		
All	138	195
Articles:	113	160
• Countries	28	34
• Institutions	>100	>100
• Journals	38	57

Articles on the topic of "MCDM" in the Web of Science categories of civil engineering and construction building technology, published 1 January 2015–15 October 2017, are further

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analyzed in detail in Section 3.

3. Detailed Analysis of Articles Published in the Period of 2015–2017

The detailed review of the articles published in the research areas of civil engineering and construction building technology was made grouping journal articles by seven application domains (Figure 6) that cover separate aspects of the sustainable building life cycle. It was decided to analyze the most resent papers, specifically those published in the period 2015–2017. According to the research areas set out in the search, 61 papers formed the sample. After detailed review, papers published in the Web of Science categories "Water resources", "Environmental sciences", "Engineering mechanical", "Engineering marine", "Engineering aerospace" and "Engineering industrial" were removed from the sample, because their scope was not related to the object of this research. Research papers and review articles were only assigned to the analyzed research areas, in a total of 36 documents. This set was analyzed by scrutinizing the application areas (domains), problems solved and the MCDM methods applied.

The results of the detailed review presented in Table 4 revealed that the most important application domains in last three years were sustainable construction and construction technology. The number of articles in these domains was, respectively, 28% and 22%, of all set of sample articles. The next three important domains were building structures and systems, construction management and retrofitting, each comprising about 11% of the total number. Building maintenance and location selection problems as research domains were each about 8% in total.

Different problems related to sustainability in the construction sector were analyzed by the application of different MCDM approaches and methods. Naubi et al. [79] developed the watershed sustainability index (WSI) for the identification of the problematic areas within the watersheds. De la Fuente et al. [80] developed a method for analyzing the sustainability of different concrete and reinforcement configurations for segmental linings of tunnels. Arroyo et al. [81,82] compared different decision-making approaches applicable for design decisions involving sustainability factors in architecture, engineering and the construction industry. Ignatius et al. [83] proposed a novel integrated method for assessing green buildings realistically, based on stakeholders' fuzzy preferences. Hosseini et al. [84] presented a method for assessing the sustainability of post-disaster temporary housing. Chen & Pan [85] integrated Building Information Modeling (BIM) with MCDM and developed a BIM-aided variable fuzzy MCDM model for selecting low-carbon building (LCB) measures.

Jalaei et al. [86] proposed a methodology that integrates BIM with decision-making problem-solving approaches in order to optimize efficiently the selection of sustainable building components at the conceptual design stage of building projects. Medineckiene et al. [87] presented a new multi-criteria decision-making technique to select criteria for building sustainability assessment. Nakhaei et al. [88] presented the model to assess the vulnerability of buildings against explosion.

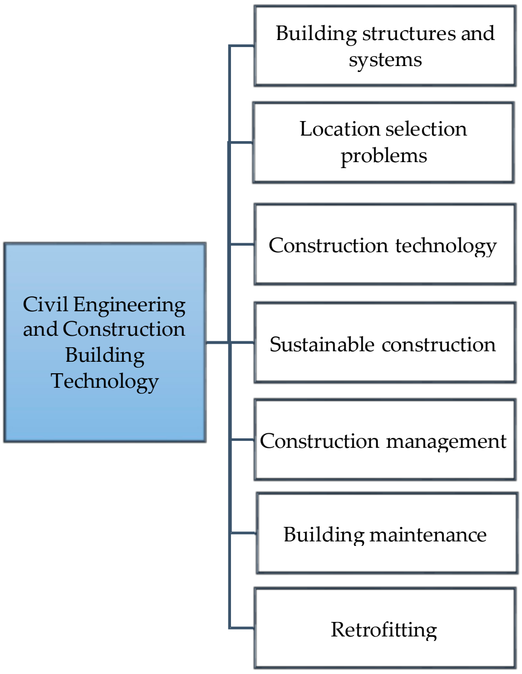

Figure 6. Application domains in research areas of civil engineering and construction building technology.

The MCDM approach was used very often for the solution of problems related to the construction technology area of research. Yousefi et al. [89] used the MCDM approach for the selection of combined building cooling, heating and power (CCHP) technologies. Kalibatas and Kovaitis [90] compared waterproofing alternatives for multifunctional inverted flat roofs by the use of multi-criteria decision-making techniques. Turskis et al. [91] presented a MCDM model for the evaluation and selection of building foundation alternatives. Leonavičiūtė et al. [92] analyzed personal protection devices for the prevention of falls from elevations using the new MCDM method. Turskis and Juodagalvienė [93] proposed a decision-making model to assess stairs for dwellings. Ebrahimian et al. [94] studied the selection of the most suitable construction method in urban storm water collection systems using a systematic and structured hybrid multi-criteria decision making approach. Nezarat et al. [95] performed a risk assessment of a mechanized tunneling project by the application of MCDM techniques. Shariati et al. [96] proposed a new multi-criteria decision-making model to evaluate the critical factors for the application of nanotechnology in the construction industry. A multi-criteria decision-making approach was used for the solution of building structures and systems-related problems, like the evaluation and selection of waste materials for recovery and reuse in concrete [97], the selection of a best practicable decommissioning method [98], the optimization of the fire protection of structures [99] and the selection of an appropriate fan for an underground coal mine [100]. Fewer applications were found in the construction management [101–104], retrofitting [57,105–107], building maintenance [108–110] and location selection [111–113] application domains.

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Table 4. Multiple-criteria decision-making (MCDM) applications in the domains of civil engineering and construction building technology research areas.

Application Domain and Problem Solved	MCDM Method(s) Applied *	Publication
	Sustainable construction (27.78%)	
Watershed sustainability	PROMETHEE	Naubi et al. (2017) [79]
Sustainability based-approach to determine the concrete type and reinforcement configuration	AHP, MIVES	de la Fuente et al. (2017) [80]
Sustainable building design	CBA, WRC approaches	Arroyo et al. (2016) [81]
Choosing problem in building detailed design	AHP, CBA	Arroyo et al. (2015) [82]
Approach for green building assessment	fuzzy ANP	Ignatius et al. (2016) [83]
Method for assessing the sustainability of post-disaster temporary housing	MIVES	Hosseini et al. (2016a) [84]
BIM-aided variable fuzzy MCDM model for selecting Low-carbon building (LCB) measures	fuzzy PROMETHEE	Chen & Pan (2016) [85]
Selection of Sustainable Building Components	TOPSIS	Jalaei et al. (2015) [86]
Sustainable building assessment/certification	AHP, ARAS	Medineckiene et al. (2015) [87]
Assessment of vulnerability of office buildings to blast	SMART, SWARA	Nakhaei et al. (2016) [88]
	Construction technology (22.22%)	
Integration of a hybrid CCHP system into a commercial building	AHP	Yousefi et al. (2017) [89]
Selecting the most effective alternative of waterproofing membranes for multifunctional inverted flat roofs	SAW, Hurwicz, Laplace and Bayes rules	Kalibatas & Kovaitis (2017) [90]
Multicriteria evaluation of building foundation alternatives	AHP, WASPAS-G	Turskis et al. (2016) [91]
Analysis and prevention of construction site accidents	WASPAS-G	Leonavičiūtė et al. (2016) [92]
Decision-making model to assess a stairs shape for dwelling houses	AHP, SAW, MEW, TOPSIS, EDAS, ARAS, Laplace Rule, Bayes Rule, FM	

Turskis & Juodagalviene˙ (2016) [93]

Selection of urban storm water construction method Fuzzy AHP and CP Ebrahimian et al. (2015) [94]
Ranking of geological risks in mechanized tunneling Fuzzy AHP Nezarat et al. (2015) [95]
The critical factors of the application of nanotechnology in construction IFS, ANP Shariati et al. (2017) [96]

Building structures and systems (11.11%)

Evaluation and selection of waste materials for recovery and reuse in concrete	Choquet integral based fuzzy approach	Onat & Celik (2017) [97]
Selection of a best practicable decommissioning method	AHP	Na et al. (2017) [98]
Optimization of fire protection of cultural heritage structures	AHP	Naziris et al. (2016) [99]
Selection of an appropriate fan for an underground coal mine	AHP	Kursunoglu & Onder (2015) [100]

Construction management
(11.11%)

Selecting the best bidder during a tendering procedure WRC, BVS, CBA approaches Schöttle & Arroyo (2017) [101]
Dispute resolution method for disputes in construction projects Laplace, Hurwicz, Hodges-Lehmann rules for games with grey numbers

Khanzadi et al. (2017) [102]

Introduction of private sectors into major projects. A hybrid model for evaluation and selection of the private sector for partnership projects

SWOT, Fuzzy VIKOR, PROMEEHTE Dadpour & Shakeri (2017) [103]

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Supply vendor selection model. Development of liquefied natural gas (LNG) plants as megaprojects Fuzzy TOPSIS Jang et al. (2016) [104]

Table 4. *Cont.*

Application Domain and Problem Solved	MCDM Method(s) Applied *	Publication
Retrofitting (11.11%)		
Optimal seismic upgrading of a reinforced concrete school building with metal-based devices	TOPSIS	
Assessment of building-integrated green technologies	AHP	
The optimal system for seismic retrofitting and vertical addition of existing buildings	TOPSIS, ELECTRE, VIKOR	
The analysis of vertical addition systems for energetic retrofitting of existing masonry buildings	TOPSIS	
Building maintenance (8.33%)		
Quantitative tool to support the definition of a maintenance-inspection policy	Multicriteria model based on the delay-time concept	
Assessment of existing telecommunication towers	Fuzzy TOPSIS	
Decision-making framework for procurement strategy selection in building maintenance work	AHP	
Location selection problems (8.33%)		
Location selection of distribution centers	ELECTRE I	
Garage location selection for residential house	AHP, WASPAS-SVNS	
Model to support decision makers in choosing site locations for temporary housing	AHP, MIVES	

* PROMETHEE—Preference Ranking Organization METHod for Enrichment of Evaluations; AHP—Analytic Hierarchy Process; MIVES—The Integrated Value Model for Sustainable Assessment; CBA—Choosing By Advantages; WRC—Weighting Rating and Calculating; ANP—Analytic Network Process; TOPSIS—Technique for Order of Preference by Similarity to Ideal Solution; ARAS—Additive Ratio ASsessment; SMART—Simple Multi Attribute Ranking Technique; SAW—Simple

Additive Weighting; WASPAS-G—Weighted Aggregated Sum Product ASsessment with grey numbers; MEW—Multiplicative Exponential Weighting; EDAS—The Method of Evaluation Based on Distance from Average Solution; CP—Compromise Programming; IFS—Intuitionistic Fuzzy Set; BVS—Best Value Selection; VIKOR—VIseKriterijumska Optimizacija I Kompromisno Resenje (that means Multicriteria Optimization and Compromise Solution); ELECTRE—ELimination Et Choix Traduisant la REalité (that means ELimination and Choice Expressing Reality); WASPAS-SVNS—Weighted Aggregated Sum Product ASsessment with Single-Valued Neutrosophic Set; FM—Full Multiplicative Utility function.

The question of how one method is better suited than another to address a specific problem is constantly scrutinized by researches and practitioners. This is also typical for the reports from the last three years. Schöttle and Arroyo [101] applied a value-based decision-making method conditionally named weighting rating and calculating (WRC), best value selection (BVS), and choosing by advantages (CBA) approaches to illustrate and compare the impact of these methods on the results of a tendering procedure. Khanzadi et al. [102] developed a hybrid MCDM model of discrete, zero-sum, two-person matrix games with grey numbers as a framework to solve dispute problems in the construction industry. The proposed approach was based on the application of several game theory methods—Laplace, Hurwicz, Bayes and Hodges-Lehmann rules. The integration of different methods in one model allows the minimization of the influence of shortcomings and the use of the advantages of separate methods, and at the same time to compare the obtained results. Dadpour and Shakeri [103] introduced a hybrid model that combines SWOT (Strengths, Weaknesses, Opportunities, and Threats) and fuzzy VIKOR methods for the evaluation and selection of the private sector for partnership projects. The case study compares the results obtained with the proposed approach and the PROMETHEE method.

Cases where the single method was applied are also common in the analyzed sample. Si et al. [57] employed AHP to derive the relative performance scores for technologies to be retrofitted in existing buildings to reduce carbon emissions and energy consumption. Lin et al. [110] presented the procedure based on AHP for the selection of the procurement method. Formisano et al. [105], with the TOPSIS method, assessed the five alternative upgrading techniques against cost, structural and environmental criteria. A final outcome of this study was the consideration that the applied TOPSIS method is a reliable technique to solve problems of different retrofitting solutions for existing buildings. The conclusion was complementary to the findings of earlier research, where Formisano and Mazzolani [106] used a combined application of TOPSIS, ELECTRE (ELimination Et Choix Traduisant la REalité (that means Elimination and Choice Expressing Reality)) and VIKOR methods for the analysis of retrofitting scenarios. Terracciano et al. [107] analyzed solutions for the vertical addition of existing masonry buildings and applied the TOPSIS method for the validation of the numerical results of the calculations. Through a sensitivity analysis, it was checked that the final results were not influenced by the decision-maker judgments. Agrebi [111] proposed a new approach for location selection based on the ELECTRE I method.

The combination of different approaches with the inclusion of MCDM methods is not a rare phenomenon. Cavalcante et al. [108] proposed a multi-criteria model based on the delay-time concept to provide the builder with a quantitative tool to support the decision-making process in building maintenance. The model proposed by Verma et al. [109] is a modified version of fuzzy TOPSIS applied in order to minimize the vagueness of visual inspection. This model ranks the alternative solutions based on similarity with fuzzy positive ideal solutions rather than the distance from fuzzy positive and negative ideal solutions. Baušys and Juodagalvienė [112], for the selection of garage locations, applied the AHP and an extension of the Weighted Aggregated Sum Product ASsessment (WASPAS) approach, namely Weighted Aggregated Sum Product ASsessment with Single-Valued Neutrosophic Set (WASPAS-SVNS), constructed based on the single-valued neutrosophic set. Hosseini et al. [113] assessed the sustainability of technologies using a newly designed sustainability model based on AHP and MIVES (Modelo Integrado de Valor para una Evaluación Sostenible (that means the Integrated Value Model for Sustainable Assessment), including a simplified life-cycle assessment (LCA).

Table 5 presents a summary of multi-criteria decision-making methods applied in articles published in the civil engineering and construction building technology application domains. The table show that the AHP [114], fuzzy approach [47] and TOPSIS method [115] were mostly used in the analyzed period. The most popular and commonly applied method in the analyzed sample was AHP, which was developed in 1980 [114]. AHP was used most commonly for the weighting of criteria as a single method or in integration with others for selection and decision-making [58,80,82,87,89,91,93–95,98–100,110,113]. Fuzzy sets were the second most popular approach in the analyzed sample. It was applied for different assessments as a single method and combined with others, i.e., ANP [83,96], PROMETHEE [85],

AHP [94,95], VIKOR [103], and TOPSIS [104,109]. The latter have been also intensively applied as a single method [86,105,107] or in integration with others [93,104,106,109].

Table 5. Methods applied in articles on civil engineering and construction building technology.

Methods	Articles
AHP, Saaty 1980 [114]	15
Fuzzy Sets, Zadeh 1965 [47]	12
TOPSIS, Hwang, Yoon 1981 [115]	7
MIVES, San-José, Cuadrado 2010 [116]	3
WASPAS-G, Zavadskas et al., 2015b [117]	2
PROMETHEE, Mareschal, Brans 1992 [118]	2
ARAS, Zavadskas, Turskis 2010 [119]	2
VIKOR, Opricovic 1998 [120]	2
SAW, MacCrimon 1968 [121]	2
Laplace Rule, Laplace 1814 [122]	2
Hurwicz Rule, Hurwicz 1951 [123]	2
Bayes Rule, Bayes 1763 [124]	2
WASPAS, Zavadskas et al., 2012 [125]	2
ELECTRE, Roy 1968 [126]	1
ANP, Saaty 1996 [127]	1
SWARA, Kersuliene et al., 2010 [128]	1
WSM, MacCrimon 1968 [121]	1
EDAS, Keshavarz Ghorabaee et al., 2015 [129]	1
MEW, Yoon, Hwang 1995 [130]	1

Hodges-Lehmann Rule, Hodges, Lehmann 1952 [131]	1
FM, Bridgman 1922 [132]	1

4. Discussion

A pressing task facing the world today is the sustainable development of cities and urban infrastructure addressed through the constructive interaction of environmental, economic and social factors. Sustainability priorities encompass integrated problems that address environmental protection, energy efficiency, optimized mobility, e-city technology and other fostering issues, including those appearing throughout all building life cycles, and deal with various levels of management and interest groups with different goals. From the mathematical point of view, these are multi-criteria group decision-making problems. In other words, the multi-criteria problems came from the multidimensionality paradigm conditioned by the ideology of sustainable development.

The most important advantage of the multi-criteria decision-making methods is their capability to address the problems that are characterized by conflicting goals. Therefore, the article was focused on the MCDM techniques and approaches that are being employed for decision-making in sustainability issues, particularly those related to the construction sector.

Usually, the selection of the most effective solution in construction-related problems is not such a simple task. The methods used in structural engineering do not allow for the assessment of the sustainability of alternative solutions. It has been noticed, that often alternative solutions and the results of numerical calculations have been validated by applying a MCDM method [91,105–107]. In particular, a sensitivity analysis was usually applied as a complementary approach to check that the results were not influenced by the judgments of decision-makers [83,86,99,101,105–107,109,111].

The results of the in-depth analysis revealed that AHP, fuzzy sets and TOPSIS methods are among the most well-known, not only during the last three decades, but also during last three years, and thus prevail in scientific articles. A rapid growth of AHP and TOPSIS applications was also recorded in Zyoud and Fuchs-Hanusch [133].

The TOPSIS approach is popular and employed for several main reasons most often referred to in analyzed articles [66,86,104–107,109]. First, the TOPSIS technique has a rational and understandable logic. Second, the computation process is straightforward; and the concept is depicted in a simple

athematical form. In several sources, TOPSIS is mentioned as one of the most popular MCDM techniques thanks to its easy application [105,106], as well as consistency and reliability [107]. Working with vast numbers of alternatives and attributes, TOPSIS is more efficient and faster compared with other MCDM methods, e.g., ELECTRE [86]. The technique creates two additional positive and negative ideal alternatives as a basis that guides the decision-maker to choose the optimal alternative among those considered. Subsequently, the solution of a problem is represented by the alternative with the minimum distance from positive ideal and the maximum distance from the negative ideal in a geometrical sense.

Generally, MCDM methods help the decision-maker to select objective solutions not influenced by the evaluation process. Real world problems are normally not defined exactly due to the uncertainty of human judgment; therefore, the extension of the classic methods enabling decision-making in uncertain environments has appeared, e.g., fuzzy TOPSIS. The popularity of fuzzy TOPSIS could be explained by one of the key advantages mentioned by Zavadskas et al. [66], i.e., the ability to deal with different types of values: crisp, interval, fuzzy or linguistic. Starting from the ideas presented in Zadeh's "Fuzzy Sets", published in 1965 [47], the fuzzy logic theory has proved to have numerous applications and developments until now [48,134]. Thus, the integration of fuzzy logic into classic methods provides a solution to handle subjective uncertain data and strengthens the comprehensiveness of the decision-making process.

The weights of the criteria in many papers in the analyzed sample were determined through the AHP method developed by Saaty (1980) [114]. Si et al. [57] emphasized that in the AHP method, the hierarchy between criteria influences weight value allocations. When more criteria are taken, the interrelations between the criteria can be changed, and alternative hierarchies may influence the difference in the allocation of weights. Consequently, different allocation of weight values will change the final ranking results. This leads to the necessity to set up an agreement regarding the development of a criteria hierarchy. Thus, sensitivity analysis is strongly recommended to identify the desirable weight values for decision makers. Despite the clear drawbacks, this method remains one of the most popular in technological and economic development, including multiple-criteria decision-making [49]. The superiority of AHP was proved by its predominance in the research and evidenced through the huge number of publications [133].

The analysis also revealed that research uses a combined approach instead of a single method. Particularly, [106] stated that the combined application of MCDM methods would allow decision-makers to find with the highest probability an objective optimal solution under different points of view. The diversity of the applied MCDM methods has also increased because of a growing trend to combine different MCDM methods and a need to integrate MCDM with other methods [62,72]. The use of MCDM methods reached various subareas of civil engineering and construction/building technology, proving that researchers in many fields are becoming increasingly aware of the importance of considering multiple aspects of reality when it comes to sustainable decision-making in civil engineering and construction/building technology. This review is also of political relevance because it shows that sustainability is a complex, manifold task, which urges political decision-makers to consider aspects that go beyond financials and implement solutions that make a balance between cost and benefits to all stakeholders.

This manuscript summarized carefully the papers that were available in the Web of Science core collection database, although a number of relevant works may have remained outside the scope of this study. However, the authors believe that this sample is representative, as the Web of Science core collection database is presented as the most accurate, objective, and complete resource available, and the articles included in it have passed a rigorous selection process inherent to high quality articles. Moreover, the authors limited the research on purpose; otherwise, the volume of the article would have increased significantly. On the other hand, the limitation specified above allows others in the future to get deeper into the subject, expand the sample and review those papers that are not mentioned in this article.

5. Conclusions

Sustainable decision-making in civil engineering, construction and building technology is based on fundamental scientific achievements and can be supported by multiple-criteria decision-making approaches. The current research justifies the need and usefulness of the application of MCDM methods for sustainable decision-making. It was identified that the number of publications on the topic of "sustainability" significantly increased in 2010. The number of publications on the topic "MCDM" began to grow starting from 2010. An analogous growth trend in publications applying MCDM methods has been observed in civil engineering and construction building technology Web of Science categories.

The main contribution of the current research is that it analyses in detail the newest publications for the last three year period. It was found that the number of publications on the application of MCDM methods for civil engineering and construction building technology problems increased by over 40 percent, the geography of the authors expanded from 28 to 34 countries in three years, 19 new journals were additionally added to the existing 38, and papers by researchers from over 100 institutions were published in 57 different journals by the current date.

The detailed analysis revealed that sustainable construction and construction technology were the most important application domains in last three years in the research areas of civil engineering and construction building technology. The number of articles in these two domains makes up to 50% of the sample. The next three important domains are building structures and systems, construction management and retrofitting, each comprising about 11% of total number. The analysis shows that the analytical hierarchy process (AHP), fuzzy approach and TOPSIS method were mostly used in the analyzed period. The results of the current research show that the MCDM approach is very useful for decision support in the construction industry in assessing design and technological alternatives with regard to sustainability, vulnerability and other important aspects.

The limitations of the current research are that only two Web of Science categories (engineering civil and construction building technology) were analyzed, while MCDM methods are applied in over 100 Web of Science categories, including some other categories also related to civil engineering. Accordingly, the research methodology is versatile and could be applied to analyzing publications including more Web of Science categories in a future.

The aim of the article was to introduce the thematic issue, to summarize the latest research in the field under study. As a result, the paper provides a better understanding of recent research directions in topics of sustainable development and construction engineering and can assist in conducting further research and seeking information. The study shows that decision-making methods have been developing in the last three years and their application has had a positive effect. The inclusion of multi-criteria decision-making methods as a robust and flexible tool for assessing possible alternatives provides the possibility to select a rational solution more precisely, taking into account the trade-offs that inevitably exist between the various candidate solutions. The obvious efforts to combine several methods show that the scientific community is still searching for the proper combination of decision-making methods for the solution of concrete problems. Thus, this analysis helps to anticipate future directions for the development of multi-criteria decision-making methods. Thus, the authors intend to make a comparative analysis and a more rigorous investigation of the existing methods, such as a comparison of previous approaches in terms of pros and cons, in the near future. In the light of the above, expectedly, this study can be employed by scholars as a basis for further research.

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References

1. Siddique, N.; Adeli, H. Nature-Inspired Chemical Reaction Optimisation Algorithms. *Cogn. Comput.* **2017**, *9*, 411–422.
2. Siddique, N.; Adeli, H. Physics-based search and optimization: Inspirations from nature. *Expert Syst.* **2016**, *33*, 607–623. [CrossRef]
3. Siddique, N.; Adeli, H. Brief History of Natural Sciences for Natural-Inspired Computing in Engineering. *J. Civ. Eng. Manag.* **2016**, *22*, 287–301. [CrossRef]
4. Siddique, N.; Adeli, H. Applications of Gravitational Search Algorithm in Engineering. *J. Civ. Eng. Manag.* **2016a**, *22*, 981–990. [CrossRef]
5. Siddique, N.; Adeli, H. Simulated annealing, its variants and engineering applications. *Int. J. Artif. Intell. Tools* **2016**, *25*, 1630001. [CrossRef]
6. Siddique, N.; Adeli, H. Central force metaheuristic optimisation. *Sci. Iran.* **2015**, *22*, 1941–1953.
7. Amezquita-Sanchez, J.P.; Adeli, H. Feature extraction and classification techniques for health monitoring of structures. *Sci. Iran.* **2015**, *22*, 1931–1940.
8. Qarib, H.; Adeli, H. Recent advances in health monitoring of civil structures. *Sci. Iran.* **2014**, *21*, 1733–1742.
9. Soto, M.G.; Adeli, H. Placement of control devices for passive, semi-active, and active vibration control of structures. *Sci. Iran.* **2013**, *20*, 1567–1578.
10. El-Khoury, O.; Adeli, H. Recent Advances on Vibration Control of Structures under Dynamic Loading. *Arch. Comput. Methods Eng.* **2013**, *20*, 353–360. [CrossRef]
11. Yeganeh-Fallah, A.; Taghikhany, T. A Modified Sliding Mode Fault Tolerant Control for Large Scale Civil Infrastructures. *Comput. Aided Civ. Infrastruct. Eng.* **2016**, *31*, 550–561. [CrossRef]
12. Ghaedi, K.; Ibrahim, Z.; Adeli, H.; Javanmardi, A. Invited Review: Recent developments in vibration control of building and bridge structures. *J. Vibroeng.* **2017**, *19*, 3564–3580.
13. Amezquita-Sanchez, J.P.; Adeli, H. Signal processing techniques for vibration-based health monitoring of smart structures. *Arch. Comput. Methods Eng.* **2016**, *23*, 1–15. [CrossRef]
14. Aldwaik, M.; Adeli, H. Advances in optimization of highrise building structures. *Struct. Multidiscip. Optim.* **2014**, *50*, 899–919. [CrossRef]
15. Soto, M.G.; Adeli, H. Tuned Mass Dampers. *Arch. Comput. Methods Eng.* **2013**, *20*, 419–

431. [CrossRef]
16. Bakule, L.; Rehák, B.; Papík, M. Decentralized Networked Control of Building Structures. *Comput. Aided Civ. Infrastruct. Eng.* **2016**, *31*, 871–886. [CrossRef]
17. Karami, K.; Akbarabadi, S. Developing a smart structure using integrated subspace-based damage detection and semi-active control. *Comput. Aided Civ. Infrastruct. Eng.* **2016**, *31*, 887–902. [CrossRef]
18. Chou, J.S.; Pham, A.D. Smart Artificial Firefly Colony-based Support Vector Regression for Enhanced Forecasting in Civil Engineering. *Comput. Aided Civ. Infrastruct. Eng.* **2015**, *30*, 715–732. [CrossRef]
19. Amezquita-Sanchez, J.P.; Valtierra-Rodriguez, M.; Aldwaik, M.; Adeli, H. Neurocomputing in civil infrastructure. *Sci. Iran.* **2016**, *23*, 2417–2428. [CrossRef]
20. Vaha, P.; Heikkila, T.; Kilpelainen, P.; Jarviluoma, M.; Gambao, E. Extending Automation of Building Construction—Survey on Potential Sensor Technologies and Robotic Applications. *Autom. Constr.* **2013**, *36*, 168–178. [CrossRef]
21. Streimikiene, D.; Balezentis, T.; Balezentiene, L. Comparative assessment of road transport technologies.
Renew. Sustain. Energy Rev. **2013**, *20*, 611–618. [CrossRef]
22. Pongiglione, M.; Calderini, C. Sustainable Structural Design: Comprehensive Literature Review. *J. Struct. Eng.*
2016, *142*, 04016139. [CrossRef]
23. Dai, H. A wavelet support vector machine-based neural network meta model for structural reliability assessment. *Comput. Aided Civ. Infrastruct. Eng.* **2017**, *32*, 344–357. [CrossRef]
24. Asadi, E.; Adeli, H. Diagrid: An innovative, sustainable, and efficient structural system. *Struct. Des. Tall*
Spec. Build. **2017**, *26*, e1358. [CrossRef]
25. Wang, N.M.; Adeli, H. Sustainable Building Design. *J. Civ. Eng. Manag.* **2014**, *20*, 1–10. [CrossRef]
26. Rafiei, M.H.; Adeli, H. Sustainability in highrise building design and construction. *Struct. Des. Tall Spec. Build.*
2016, *25*, 643–658. [CrossRef]
27. Mikaelsson, L.A.; Larsson, J. Integrated Planning for Sustainable Building—Production an Evolution Over Three ecades. *J. Civ. Eng. Manag.* **2017**, *23*, 319–326. [CrossRef]
28. Oh, B.K.; Kim, K.J.; Kim, Y.; Park, H.S.; Adeli, H. Evolutionary learning based sustainable strain sensing model for structural health monitoring of high-rise buildings. *Appl. Soft Comput.* **2017**, *58*, 576–585. [CrossRef]
29. Soto, M.G.; Adeli, H. Multi-agent replicator controller for sustainable vibration control of smart structures.
J. Vibroeng. **2017**, *19*, 4300–4322. [CrossRef]
30. Akbari, H.; Cartalis, C.; Kolokotsa, D.; Muscio, A.; Pisello, A.L.; Rossi, F.; Santamouris, M.; Synnefa, A.; Wong, N.H.; Zinzi, M. Local Climate Change and Urban Heat Island Mitigation Techniques—The State of the Art. *J. Civ. Eng. Manag.* **2016**, *22*, 1–16. [CrossRef]
31. Ceravolo, R.; Miraglia, G.; Surace, C.; Zanotti-Fragonara, L. A computational methodology for assessing the time-dependent structural performance of electric road infrastructures.

Comput. Aided Civ. Infrastruct. Eng. **2016**, *31*, 701–716. [CrossRef]
32. Katsigarakis, K.; Kontes, G.D.; Giannakis, G.I.; Rovas, D.V. Sense-think-act Methodology for Intelligent Building Energy Management. *Comput. Aided Civ. Infrastruct. Eng.* **2016**, *31*, 50–64. [CrossRef]
33. Wang, Y.; Szeto, W.Y. Multiobjective environmentally sustainable road network design using Pareto optimization. *Comput. Aided Civ. Infrastruct. Eng.* **2017**, *32*, 964–987. [CrossRef]
34. Wang, Z.; Wang, Q.; Zukerman, M.; Guo, J.; Wang, Y.; Wang, G.; Yang, J.; Moran, B. Multiobjective Path Optimization for Critical Infrastructure Links with Consideration to Seismic Resilience. *Comput. Aided Civ. Infrastruct. Eng.* **2017**, *32*, 836–855. [CrossRef]
35. Bozza, A.; Napolitano, R.; Asprone, D.; Parisi, F.; Manfredi, G. Alternative resilience indices for city ecosystems subjected to natural hazards. *Comput. Aided Civ. Infrastruct. Eng.* **2017**, *32*, 527–545. [CrossRef]
36. Cahill, P.; Jaksic, V.; John Keane, J.; O'Sullivan, A.; Mathewson, A.; Ali, S.F.; Pakrashi, V. Effect of Road Surface, Vehicle and Device Characteristics on Energy Harvesting from Bridge-Vehicle Interactions. *Comput. Aided Civ. Infrastruct. Eng.* **2016**, *31*, 921–935. [CrossRef]
37. Cinelli, M.; Coles, S.R.; Kirwan, K. Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecol. Indic.* **2014**, *46*, 138–148. [CrossRef]
38. Kabir, G.; Sadiq, R.; Tesfamariam, S. A review of multi-criteria decision-making methods for infrastructure management. *Struct. Infrastruct. Eng.* **2014**, *10*, 1176–1210. [CrossRef]
39. Jato-Espino, D.; Castillo-Lopez, E.; Rodriguez-Hernandez, J.; Canteras-Jordana, J.C. A review of application of multi-criteria decision making methods in construction. *Autom. Constr.* **2014**, *45*, 151–162. [CrossRef]
40. Zavadskas, E.K.; Antuchevic˘iene˙, J.; Kapliński, O. Multi-criteria decision making in civil engineering: Part I—A state-of-the-art survey. *Eng. Struct. Technol.* **2015**, *7*, 103–113. [CrossRef]
41. Zavadskas, E.K.; Antuchevic˘iene˙, J.; Kapliński, O. Multi-criteria decision making in civil engineering. Part II—Applications. *Eng. Struct. Technol.* **2015**, *7*, 151–167. [CrossRef]
42. Franklin, B. *Letter to Joseph Priesley, 1772*; Reprinted in the Benjamin Franklin Sampler; Fawcett: New York, NY, USA, 1956.
43. Pareto, V. *Cours E-Economic*; Universite de Lausanne: Lausanne, Switzerland, 1896/1897.
44. Simon, H.A. A behaviour model of rational choice. *Q. J. Econom.* **1955**, *69*, 99–118. [CrossRef]
45. Saaty, T.L. *Decision Making for Leaders: the Analytical Hierarchy Process for Decisions in a Complex World*; Lifetime Learning Publications: Belmont, CA, USA, 1982.
46. Zeleny, M. *Multiple Criteria Decision Making*; McGraw-Hill: New York, NY, USA, 1982.
47. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
48. Herrera-Viedma, E. Fuzzy Sets and Fuzzy Logic in Multi-Criteria Decision Making. The 50th Anniversary of Prof. Lotfi Zadeh's Theory: Introduction. *Technol. Econ. Dev. Econ.* **2015**, *21*, 677–683. [CrossRef]
49. Kou, G.; Ergu, D. AHP/ANP Theory and Its Application in Technological and

Economic Development: The 90th Anniversary of Thomas L. Saaty. *Technol. Econ. Dev. Econ.* **2016**, *22*, 649–650. [CrossRef]

50. Kou, G.; Ergu, D.; Lin, C.S.; Chen, Y. Pairwise Comparison Matrix in Multiple Criteria Decision Making. *Technol. Econ. Dev. Econ.* **2016**, *22*, 738–765. [CrossRef]
51. Zavadskas, E.K.; Antucheviciene, J.; Turskis, Z.; Adeli, H. Hybrid multiple-criteria decision-making methods: A review of applications in engineering. *Sci. Iran.* **2016**, *23*, 1–20.
52. Zavadskas, E.K.; Govindan, K.; Antucheviciene, J.; Turskis, Z. Hybrid multiple criteria decision-making methods: A review of applications for sustainability issues. *Econ. Res. Ekon. Istraz.* **2016**, *29*, 857–887. [CrossRef]
53. Yi, W.; Wang, S. Multi-objective mathematical programming approach to construction laborer assignment with equity consideration. *Comput. Aided Civ. Infrastruct. Eng.* **2016**, *31*, 954–965. [CrossRef]

