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A systematic review on MIVES: A sustainability-oriented multi-criteria decision-making method

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ABSTRACT

Sustainability has practically become a mandatory concept to be considered in every decision, and multiple decision-making methods have been adapted to take it into account. Among them, sustainability centred methods are also known as sustainability assessments, which provides sustainability indexes to select and prioritize alternatives. One of these most recent presented techniques is MIVES, a multi attribute utility theory multi-criteria decision-making value function-based method initially developed to introduce environmental and social indicators in civil engineering design decisions and later adapted for general evaluation and prioritization of homogenous and heterogeneous alternatives. Over the last decade, it has been widely studied and applied to specific situations, but a MIVES summary is currently lacking. Therefore, in this paper MIVES literature is reviewed with a deep bibliometric analysis carried out to provide on multiple data about MIVES state-of-the-art. Furthermore, a thematic clusters categorisation is done to reveal the usefulness of MIVES as design and decision-making tool, cataloguing the wide applications of MIVES as sustainability index. Finally, a MIVES characteristics discussion is carried out to help researchers deepen their knowledge towards the method and highlight potential future research pathways.

1. Introduction

Sustainability is a concept that rose to prominence in 1987 with the Brundtland Report, warning of the negative environmental consequences of economic growth and globalization, which tried to find possible solutions to the problems caused by industrialization and population growth. Many of these problems can only be solved by promoting sustainable development [1], a commitment to social progress, environmental balance and economic growth. This commitment requires the active involvement of individuals, businesses, administrations, and countries worldwide [2,3].

The current global scenario demands a radical change to align with the new government and global policies [4]. In addition, the sustainability moving up agendas and the enhanced awareness of the public is adding pressure to tackle the challenge of sustainability vs traditional financial goals [5].

This shift involves considering new inputs in their decision-making process, as the new set of indicators that European authorities are promoting to be considered in public investment [6], namely being able to make a sustainability assessment of the impacts and opportunities, and incorporating sustainability principles in the decision-making. Nevertheless, making sustainable decisions is often a complex and multifaceted problem [7] that requires balancing a broad range of considerations: environmental, economic and social aspects, technological and scientific data, ethical and political concerns, and stakeholder interests. All these considerations may make any decision process inherently multi-objective [8], limiting the individual or group capacity to decide. Consequently, decision-makers demand systematic frameworks to integrate all this heterogeneous information facilitating a structured, understandable and defensible decision [9].

Multi-criteria decision making (MCDM) is a systematic methodology capable of synthesizing these heterogeneous considerations to evaluate and prioritize different alternatives. This method is also known as Multiple-Criteria Decision Analysis (MCDA). MCDM or MCDA is defined as "a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups to explore decisions

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that matter" [10]. Several multi-criteria methodologies have been developed over time to provide a systematic framework that considers the multidimensional nature of the real-world problem [11] MCDM implies that each problem is broken down into its constituent parts to understand the evaluation process [12]. A complete review of the MCDA methodologies for ranking homogeneous alternatives developed over the last twenty years can be found in Kabirb et al. [13] and Cinelli et al. [14].

Among the different classic MCDM methods, those aiming to achieve sustainable decisions are known as sustainability assessments (SA) [15–17]. A good overview can be found in Refs. [14,18–21]. In general terms, Slowinski et al., [22] and Greco et al. [23] distinguished three underlying MCDA methodologies/theories groups: (i) utility function, (ii) outranking relation and (iii) sets of decision rules.

Utility-based such as multi-attribute utility theory (MAUT) and analytical hierarchy process (AHP), outranking approaches such as elimination and choice expressing the reality (ELECTRE) or preference ranking organization method for enrichment of evaluations (PROMETHEE) and decision rules technique such as dominance-based rough set approach (DRSA) have been the most widely MCDA tools in sustainability-related research [14,18,21,24,25].

Among the existing sustainability-related MCDM methods, it is noteworthy the methodology MIVES (Spanish acronym: Modelo Integrado de Valor para una Evaluación Sostenible, in English: Integrated Value Model for Sustainability Assessment), aimed at supporting decisions based on the MAUT theory [26]. It was initially developed to introduce environment and social indicators to construction decisions. Lately, it was adapted for general evaluation and prioritization of investments and alternatives, many of them focused on obtaining sustainable cities. MIVES has proved to be a coherent and straightforward methodology for evaluating, prioritizing, and selecting alternatives towards sustainable development, being applied in multiple scientific fields.

The aim of this paper is to review MIVES related literature to present a state-of-the-art in order to help researchers deepen their understanding and knowledge towards the potential and application of this MCDM technology. Furthermore, this literature review aims to identify trends and gaps in research and to propitiate further progress upon the foundation developed by others. Besides, a bibliometric analysis has been conducted to highlight the current state of MIVES.

2. MIVES multi-criteria analysis

MIVES is a MAUT MCDM methodology initially developed for the assessment of sustainability in construction and later adapted for general evaluation and prioritization of homogenous [27] and heterogeneous alternatives.

What makes MIVES different from other MAUT MCDM models is that it combines different features, among which: (i) multi-level requirement aggregation framework; (ii) the inclusion of a weighting process and (iii) indicator value utility functions. These elements endow MIVES with a high adaptation capacity, adjusted for every specific problem while providing rational sustainability-based reasoning for the decision criteria.

MIVES structures the problem within a multi-criteria analysis framework in which different alternatives may be evaluated according to a pre-stablished set of requirements to satisfy a pre-defined sustainable objective. These requirements, which are usually the economic, social and environmental sustainability pillars of the problem, contain sets of criteria. These, in addition, contain a set of indicators which in turn may have sub-indicators, thus creating a multi-level system known as decision tree (see Fig. 1A).

To evaluate the problem and reflect the relative importance of each component of the MIVES decision tree, different weights are assigned by decision-makers using techniques such as Analytic Hierarchy Process (AHP), the most widely used method in MIVES. AHP, initially devised by Saaty [29]; is a linear additive model that converts subjective assessments of relative importance into a set of overall scores or weights based on pairwise comparisons. Only the indicators are evaluated using either qualitative or quantitative variables, and different units and scales depending on the indicator. Then the evaluation is carried out by applying a value function to the indicators.

The value function is a single mathematical function that converts the qualitative and quantitative variables of the indicators, with their different units and scales, into a non-dimensional scale comprised between 0 and 1. These respective values represent the minimum and the maximum degree of satisfaction of the decision-maker.

Using the pre-defined value function equation [30] multiple shapes are obtained (see Fig. 1B): lineal, convex, concave or S-shape, according to the decision that are taken. Alternatively, functions with decreasing values may be used: i.e., they adopt the maximum value at X_{min}. The only difference in the value function is that the variable X_{min} is replaced by the variable X_{max}, adapting the corresponding mathematical expression.

Once the value functions have been used to obtain each indicator (or sub-indicator) index, these values are aggregated using the assigned weights by a weight sum model (WSM) process (see Fig. 1A) to obtain the final sustainability index.

3. Methodology

A systematic review involves a five-stage structure [31]: (i) formulation of the problem, (ii) determination of the data collection strategy, (iii) evaluating the retrieved data, (iv) analysis and interpretation of the literature and finally, (v) presents the resulting conclusions.

To address the paper objective the main question formulated in this

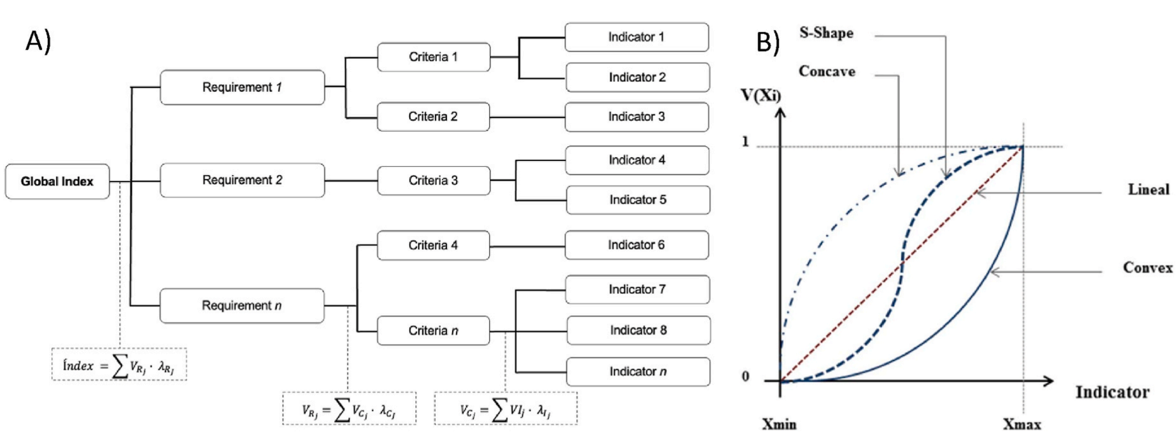

Fig. 1. A) MIVES decision tree. B) MIVES value function shapes. Source: [28].

study was: What specific types of decisional problems and applications have been addressed throughout MIVES Multi-Criteria Decision Analysis techniques. In order to answer this question data collection strategy was determined.

A preliminary search was conducted to collect any article related to the study object. Articles were identified by the internationally recognized bibliographic database Web of Science (WoS), which accesses articles from over 12000 journals worldwide [32]. One of the main reasons that justified the use of this database was the depth of its coverage, yielding more outputs than any other database collection.

Furthermore, WoS core collection (WoSCC) was used for the use of Bibliometrix [33]. Bibliometrix is a quantitative research analysis and mapping R programming tool for bibliography. It analyses data sources, authors and documents and conceptual, intellectual, and social structures with their relations using a WoSCC input.

Once the database was decided, the preliminary analysis was later filtered to obtain the final set of articles on which the qualitative and quantitative analysis would be performed. The filtering process was conducted as follows: (i) eliminate articles that, despite having close association with the study goal, were finally considered not at the core of the investigation (ii) discard duplicated articles.

As a result of this process, a final set of 67 references was selected for further analysis and interpretation. Among them, 59 are scientific papers. Other references encompass book chapters and proceeding papers. With the selected set of results, a double analysis was performed (see Fig. 2). The former focused on Bibliometrix usage to obtain quantitative external characteristics results about MIVES impact such as scientific production, expansion, internationalization and citations. The latter extended the bibliometric study with a deep manual reading to generate the final thematic division and analysed some MIVES outstanding characteristics. The characteristics, proposed by the authors, were selected by comparing the general methodology of MIVES with the latest advances in MCDM science, in order to find possible ways to improve the technique and are listed below:

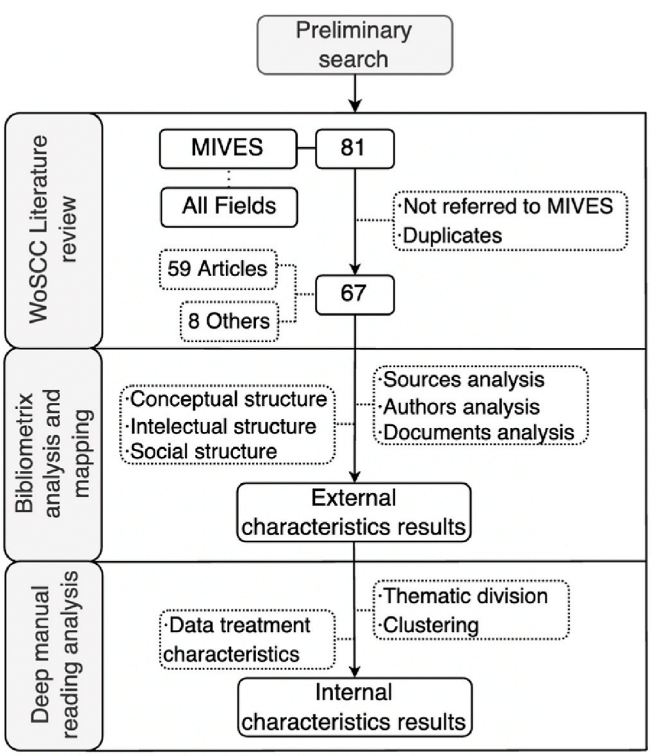

Fig. 2. Literature review and Bibliometrix use process.

- Multi-stakeholder consideration: Multi-stakeholder inclusion in MCDM methodologies is becoming appealing to public administrations and society, in general, to account for diverse and heterogeneous points of view and, thus, to distance themselves from unilateral decisions. Researchers have developed several methodologies for multi-stakeholder inclusion. For example, vectors projection [34] approaches and TOPSIS extensions [35] to consider multiple experts have been recently developed.
- Accounting for uncertainty: Uncertainty is a common characteristic in investment prioritization or selection methods. However, applying all alternatives is not possible due to high-cost implementation, so their effects must be theorized. Thus, multiple methods are used to deal with uncertainty, some applied in MCDM indicators (unknown data) and criteria weights (decision-makers hesitation).
- Adverse effects applied to indicators: Some alternatives can lead to negative consequences. For example, considerable adverse environmental and social impacts or future economic losses must be considered. Although these are considered in MCDM indicators, their contribution is usually positive. This fact means that even the indicator produces an adverse effect, the minimum calculation contribution is null.

4. Results and analysis

The present section exposes and studies the retrieved data and corresponds to the third and fourth Cooper stages (1989).

4.1. Evaluating the data

4.1.1. Global statistics

From the 67 documents collected from the database, 88.06% records were scientific journal articles (59), 4.48% were book chapters (3), and 7.46% were proceeding papers presented in conferences. Detailed information on the dataset is provided in Table 1. Documents were retrieved from 36 sources (scientific journals/repositories) with an average of 19.07 citations per document and contain 184 Keywords Plus and 234 Author keywords.

Fig. 3 pictures the MIVES annual scientific production (ASP) and Total citations (TC) regarding each year publications. The figure indicates that there has been moderate growth in the production of literature from 2008 to 2014 (9 documents). However, the number of articles has increased significantly since 2014, reaching 58 documents from 2015 to 2021. The presented annual scientific production growth rate is 20.82% throughout all periods.

Prior to 2014, MIVES was mainly used by a small group of authors (who had developed the methodology). Senior researchers as Professor A. Aguado and A. Josa (from Polytechnic University of Catalonia, UPC), A. del Caño and M.P. de la Cruz (from Coruña University, UDC) and J. Cuadrado, R. Losada, E. Rojí and J.T. San-José (from University of the Basque Country UPV/EHU) are among these initial authors.

However, from 2015 initiatives and research on MIVES methodology have become more intense, contributing and confirming the high interest in the subject in the last seven years. For example, the peak

Table 1
General information of the obtained dataset (2008–2021).

Description	Results
Journal articles	59
Book chapters	3
Proceeding papers	5
Sources	36
Average citations per documents	19.07
Keywords Plus	184
Author Keywords	234
Collaboration Index	1.95
Annual growth rate	20.82%

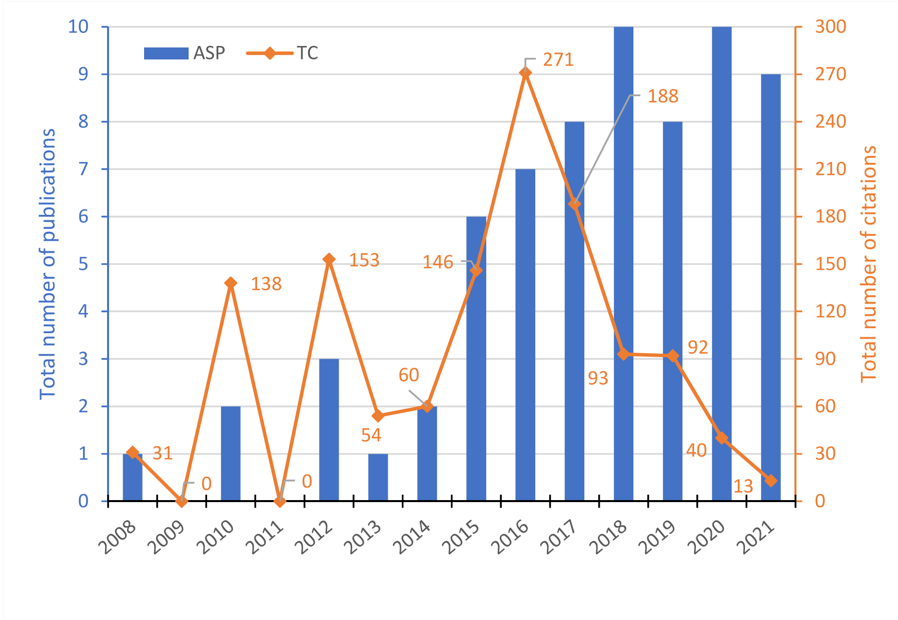

Fig. 3. Annual scientific production and total citation of each annual production of MIVES (2008–2021).

production period (2018–2020) encompasses 28 publications, mainly done by novel authors. These publications correspond to 22 different authors, among which 5 are current PhD students, 3 are PhD students who presented the doctoral thesis during the studied period, and 5 are PhD students who presented the doctoral thesis in a place of 2 years before the period (from 2015 to 2017). That means that 59.1% of second period authors are not experienced researchers and are considered part of MIVES expansion. Furthermore, the high collaboration index is shown in Table 1 (1.95) reveals the elevated relation between experienced and novel authors. Each document has an average of 3.61 co-authors, which indicates the knowledge transfer between researchers.

Regarding TC, the retrieved data shed light on scientific community response at MIVES presented publications. From 2008 to 2016 citations developed a direct increment with ASP. As MIVES production raises, citations were following a parallel growth. However, an outstanding point appears in the 2017–2021 period. Although MIVES presented the highest production, citations were constantly decreasing. This fact may be due to two reasons. The first one is related to MIVES novelty and expansion. Given the relative novelty of MIVES, most publications in this period are methodology introductions to diverse scientific fields to increase the MIVES applications range. With a scientific community unaccustomed to MIVES usage, it receives few citations.

The second one is regarding the annual citation (AC) between publications. Some MIVES publications have higher citation indexes than others (as shown in Fig. 3 for 2010, 2012, and 2016). For example, in 2010, papers with 6 AC [36] and 5.25 AC [37] were published. Similar

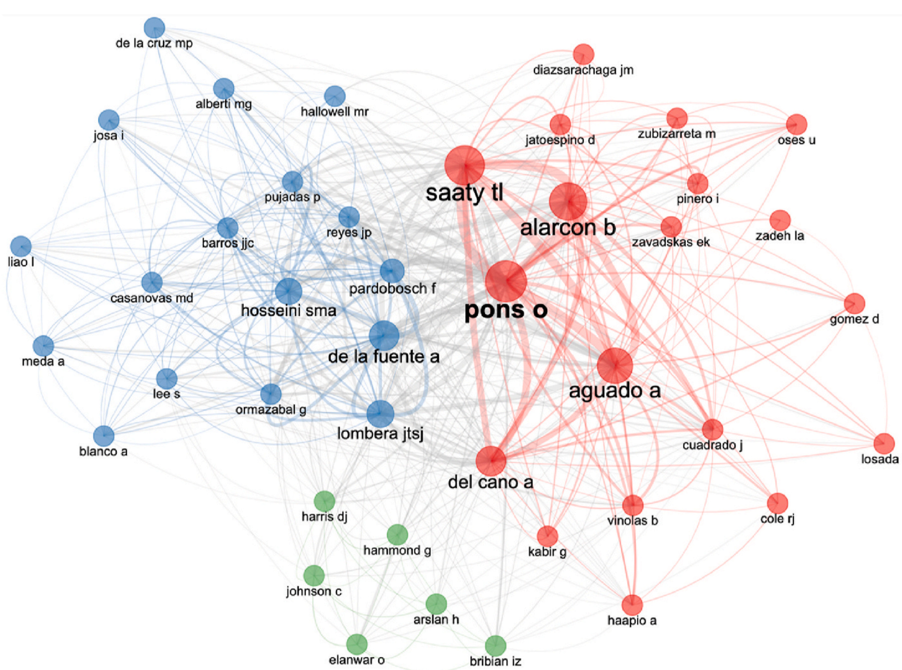

Fig. 4. Co-citation conceptual map. Own elaboration through Bibliometrix.

occurred in 2012 with 7.8 AC [38] or 6.4 AC [39] papers. Finally, 2016 encompasses the three most cited documents in this analysis. Exceptional values of 10.43 AC [40], 10 AC [41], and 8.33 AC [42] alter the ACA value.

4.1.2. Author statistics

This MIVES expansion through new authors methodology studied in Fig. 3 is further analysed by a co-citation map shown in Fig. 4. This figure depicts a clearer picture of the citation relation among different authors by tracking papers that have been cited together. Lines represent a citation between authors, while nodes sizes are related to frequency summation. Only first authors are considered in the co-citation conceptual map.

The conceptual map allows ratifying an extension of MIVES publications by means of different authors. The centred group of authors corresponds to experienced researchers, which have taken part of methodology development and multiple MIVES publications at different fields. These authors, strongly related by multiple connexions, reveal multiple work connexions. These work connexions refer to distant authors, mostly novel researchers developing new MIVES projects. The conceptual map allows identifying three great working groups or clusters by colour.

The first and red one contains the most significant node sizes. Their size is justified as these authors are MIVES developers (Aguado), MIVES aggregate methodology developers as value function (Alarcon) and Analytic Hierarchy Process (Saaty) or authors with early publication (Pons and del Caño). The node size difference between early publication authors is noticeable, given by the publication rate, 17 and 3, respectively. The second and blue one contains middle-sized nodes as de la Fuente, Pardo-Bosch or Lombera (San-José). These authors are considered a new cluster as they have expanded MIVES application over multiple scientific fields and trends to be cited together. The last and green cluster do not have any remarkable node size, as their connection with other groups is not notable. Nevertheless, a huge number of novel authors are detected in three clusters.

Even the node size difference highlights these authors disparity, Lotka's Law is applied to generate authors groups. Lotka's Law postulates the existence of a little group named core authors, which have the higher scientific production. Core authors are divided from occasional authors, which outnumber them but have less scientific production. In Fig. 5, authors are divided regarding their MIVES publications.

Nearly 70% of the authors only have one academic publication. Nevertheless, 0.80%, 1.50%, 0.80% and 2.30% of the authors have 4, 5, 6 and more than 16 publications, respectively. The analysis of all presented data indicates that the core is formed by only 4.60% of total authors, while 95.40% are occasional authors, which corresponds to a normal Lotka's law distribution.

This distribution ensures MIVES use expansion as core authors represent a small value. Even MIVES developers and pioneers have more publications, written mainly by occasional authors. These occasional authors are mainly new researchers who are applying MIVES in new fields.

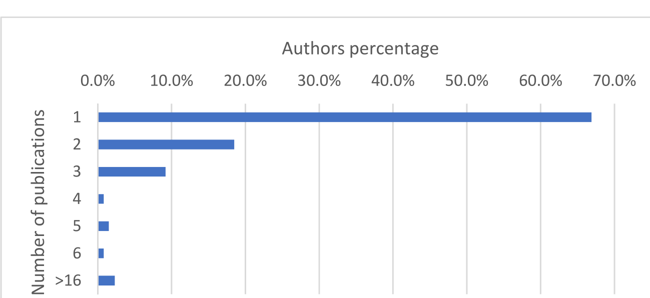

Fig. 5. Authors percentage and number of publications.

4.1.3. Country statistics

On the other hand, a mall cluster of core authors could negatively impact when their components are part of the same research groups. A centralized core author cluster can diminish international relations and global methodology development. Thus, MIVES internationalization must be studied. For this purpose, authors of the publication's location are used (Fig. 6A). This analysis differentiates between single country publications (SCP) and multiple country publications (MCP). SCP are written by a group of authors in the same country, whereas MCP are written by a group of authors located in different countries. These international collaborations involve mainly Spain research groups, as shown in Fig. 6B (the scientific production index in Fig. 6B was computed by Bibliometrix, international collaborations MCP have been manually added).

Approximately 90% of Spain's publications are SCP (53 of 59). This high SCP rate can affect the development and application of MIVES internationally as it means a few MCP rate. Among other publishing countries, only Iran and India have a 100% SCP. United States, Peru, Canada, and Brazil have a 100% MCP. Regarding the scientific production index, Spain stands by the highest value as most of the core authors are Spanish. International collaborations with Canada, Peru, the United Kingdom, United States, Norway, Cuba, Serbia, and Switzerland occur with this core at its origin.

However, some scientific productions must be pointed out. It is the case of India, Iran, Brazil, and Colombia, which have scientific production with no collaborative relations with MIVES core authors. Even Brazil and Colombia have international collaborations without connecting to the Spanish central node. This fact denotes MIVES internationalization.

Albeit internationalization allows to analyse methodology expansion and adoption outside developer country, a source analysis is needed to pick out MIVES influence level. It is not atypical that some new methodologies appear only in low impact journals without any repercussion in first quartile journals. This source analysis, shown in Table 2, is carried out concurrently Brandford's law. Brandford's law is used to determine the publication core, which exposes where MIVES has it's main contributions. The Table analyses the 59 journal papers as non-paper references (i.e., conference proceeding papers or book chapters) are not used in Brandford's law. It also contains information regarding total publications (TP), citations (TC), citation temporary rating (obtained through total citations per document since first publication in a journal), local h-indexes and quartiles. Sources have been ordered by TP and, secondly by TC.

The analysed MIVES publications have appeared in 30 different journals. That quantity is remarkable considering the number of analysed results. These journals are distributed among different knowledge areas such as sustainability sciences, building technologies, material, energy and chemical sciences. This implied that MIVES has widely attracted the researcher's attention in various fields as an appropriate multi-criteria method to select and prioritize alternatives. The journals present notable variances over TP and TC values. Due to these differences, TC/TP and TC/TP^D ratios gain significance. The first ratio allows analysing the impact in different thematic fields. For example, Energy journal with only 1 publication (12th in TP ranking) receives the first place in TC/TP ranking. Second and third place of these rankings belong to Construction and Building materials and Expert systems with applications, 6th and 13th in TP ranking. This means that these journals contain high impact publications in their respective fields.

According with 2021 Scimago data, 21 journals are first quartile (Q1), 4 are second quartile (Q2), 4 are third quartile (Q3) and 1 are fourth quartile (Q4). This means 70% of MIVES related journals are high impact sources. Furthermore, a similar percentage appears at a number of publications per quartile. 48 publications (81.36%) are placed over Q1 journals, 5 (8.47%) at Q2 journals, 5 (8.47%) at Q3 journals and 1 (1.69%) at Q4 journals. Publication core obtained by Bradford's law restates MIVES impact detected by publication sources. The core

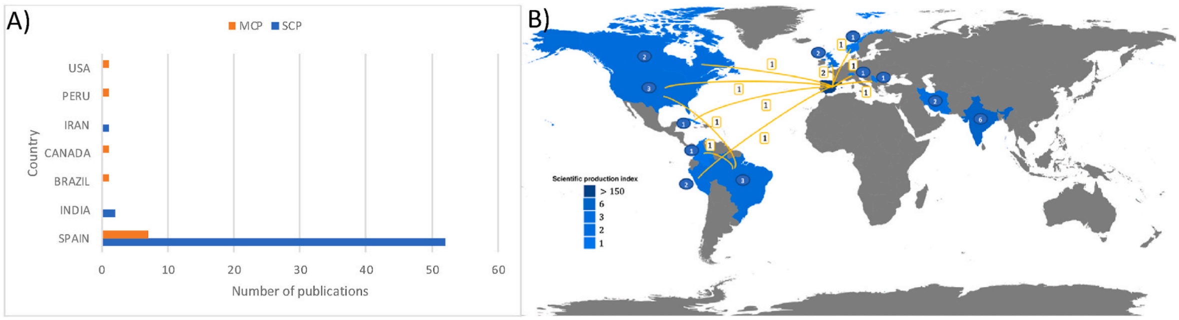

Fig. 6. A) Authors provenance. B) Countries scientific production (blue) index with international collaborations (orange). Own elaboration through Bibliometrix. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
MIVES source journals with publications, citations, and impact characteristics.

Sources	TP	TC	TC/TP	Local h-index	Quartile
Sustainability	10	75	7,5	4	Q1
Journal of cleaner production	5	102	20,4	5	Q1
Sustainable cities and society	5	115	23	5	Q1
Building and environment	4	165	41,25	3	Q1
Journal of construction Engineering and management	4	127	31,75	3	Q1
Construction and building materials	2	118	59	2	Q1
Journal of civil engineering and management	2	45	22,5	2	Q2
Environmental impact assessment review	2	42	21	2	Q1
Land use policy	2	42	21	1	Q1
Environmental science & policy	2	39	19,5	2	Q1
DYNA	2	3	1,5	1	Q3
Energy	1	75	75	1	Q1
Expert systems with applications	1	50	50	1	Q1
Tunnelling and underground space technology	1	38	38	1	Q1
Journal of management in engineering	1	31	38	1	Q1
Structure and infrastructure engineering	1	25	25	1	Q1
Journal of cultural heritage	1	24	24	1	Q1
Civil engineering and environmental systems	1	23	23	1	Q3
International journal of disaster risk reduction	1	16	16	1	Q1
Road materials and pavement design	1	14	14	1	Q1
Environmental geotechnics	1	11	11	1	Q2
chemosphere	1	11	11	1	Q1
Informes de la construccion	1	3	3	1	Q2
Environmental science and pollution research	1	2	2	1	Q1
Proceedings of the institution of civil engineers: engineering sustainability	1	1	1	1	Q3
Sustainable energy technologies and assessments	1	1	1	1	Q1
International journal of production management and engineering	1	0	0	-	Q4
Applied sciences	1	0	0	-	Q2
Detritus	1	0	0	-	Q3
Risk analysis	1	0	0	-	Q1

TP = Total number of publications, TC = Total number of citations, TC/TP = Total citations per document, Local h-index = h-index calculated from dataset, Quartile = Best journal quartile (2021 Scimago Journal and Country Rank®).

includes 4 Q1 journals ("Sustainability", "Journal of cleaner production", "Sustainable cities and society", and "Building and environment"). Main MIVES contributions can be found among these sources.

4.2. Analysis of the results and interpretation

4.2.1. Research hotspots and evolution

Once MIVES interest growth and usage expansion have been studied, methodology application fields are analysed. This section extends the bibliometric study with a manual analysis of the results. Even though the main objective of this section is to propose a final cluster division, the authors have identified several aspects related to data treatment that can be further studied. Thus, the data treatment analysis is exposed in this section.

A first step in analysing in which fields MIVES has been applied is with the study of authors' keywords, which consist in a list of terms that authors believe best represents the content of their papers (see Table 3). These therefore contain information on the specific field where MIVES has been applied. Through bibliometric analysis 200 most used words are obtained. A selection process is applied to them to filter the results: (i) Words with no contribution with the objective have been deleted. For example, "model", "Methodology", "Index" or "Assessment" were some of them. (ii) Commonly used words that do not aid the thematic division have been considered but deleted from the tree map. Typical words in these studies are "MIVES" with 41 repetitions, "Sustainability" with 37, "MCDM" with 32, and "AHP" with 22. Most studied results expose them as keywords but do not provide information about thematic. (iii) Similar pairing has been done as some words were nearly identical but with slight differences. For example, "Slab" and "Slabs" have been joined.

An outstanding point is the diverse range of fields where MIVES has been applied despite its short lifetime (first publication in 2008). Only 25.24% (26 of 103) shown words have more than one apparition. Most words have less than 1% ratio appearance (1 of 103). Due to this keyword spread, the clustering process is hardly applicable.

For example, "Concrete structures" or "Fiber reinforced concrete" could become a thematic. Similar clusters could be generated by "Floods", "Power plants", "Industrial Buildings", "roofs" or "reconstruction". Nevertheless, applying keywords directly to generate groups induce two difficulties. First, many clusters with low related papers would be obtained. Second, some keywords need to be associated with making sense (i.e., "Life cycle assessment" with "Roads" or "Knapsack" with "Concrete structures"). Consequently, a deep manual analysis is needed to support and improve thematic division.

Standard methodology structure in publications has been the first manual analysis revelation. It does not matter if they refer to comparisons, evaluations, or prioritization. Instead, all the results prepare a specific MIVES structure that provides rankings or alternatives ordering. For that reason, thematic division can be focused on the analysis instead of analysing different MIVES application forms.

Following the findings from Table 3, the deep manual analysis was performed to suggest a final thematic division in 10 clusters. These clusters are related to buildings, materials, elements, code and regulations, new technologies and strategies, public investment prioritization, energy, uncertainty, machinery, and risk analyses. Clusters have been

Table 3
Authors' keyword counting.

Keyword	Count	Keyword	Count	Keyword	Count
concrete structures	4	cities	1	low-cost housing	1
building	4	climate	1	management-public investment	1
fiber reinforced concrete	4	columns	1	mswi ashes	1
life cycle assessment	4	commercial bank branches	1	mswm scenarios	1
monte carlo	3	computer-aided design	1	pavement distress	1
post-disaster temporary housing	3	concrete pipe	1	pervious pavements	1
public assets	3	concrete technology & manufacture	1	power plants	1
standards and codes	3	construction materials	1	precast concrete	1
citygml	2	contaminated site	1	prefabricated buildings	1
concrete sustainable evaluations	2	d center	1	primary education	1
industrial	2	dbm	1	project management	1
polyolefin fibres	2	delphi	1	reconstruction	1
sustainable development	2	developing countries	1	reinforced concrete	1
urban agriculture	2	disaster recovery	1	reinforced soils	1
extreme events	2	disruptive innovation	1	residential	1
fuzzy arithmetic	2	eco-trench	1	retaining walls	1
knapsack	2	electrokinetic remediation	1	road	1
pavement condition index	2	elesdopa	1	robbery risk	1
pipeline	2	facade	1	rooftop greenhouses	1
recycled aggregate	2	floods	1	r&amp	1
risk analysis	2	flyover bridge	1	r&d centre	1
schools	2	food safety	1	sample buildings	1
site location	2	foundation piles	1	segmental linings	1
slabs	2	frc	1	sewer	1
social impact	2	general morphology analysis	1	shell and tube heat exchanger	1
steel fibers	2	genetic	1	single-family house	1
active learning	1	gis	1	sirsdec	1
air quality	1	green building	1	smart cities	1
architecture	1	green remediation	1	software	1
assessment urban street	1	historic buildings	1	solar control	1
bam	1	household waste	1	steel	1
bam earthquake	1	industrial buildings	1	steel-mesh	1
bloom taxonomy	1	infrastructure management	1	supply	1
brute force	1	intelligent facade layers	1		
building interior	1	lectures	1		

ordered by the first publication date and contains the publications shown in Fig. 7, in which cluster's dominance over years has been added. The dominance relates to the percentage of annual scientific production published. It allows analysing the methodology branching over time. Table 4 summarises the clusters encompassed publications by topic and reference inclusion.

The first cluster encompasses general building analysis. From 2008 to 2011, MIVES publications were only related to that cluster because MIVES research group developers are focused on civil engineering and construction proceedings. In tunnels topic, social values improvement decisions over Barcelona metro [43], Madrid and Rio tunnels sustainability evaluations [44], tunnel material selection [45] and tunnel concrete and reinforcement comparisons [46] are placed. These comparisons are similar to the flyover bridges topic with a fiber-reinforced concrete analysis [47]. Industrial buildings have comparisons [36,48] between alternatives; some focused on the design phase [37]. Temporary housing after a disaster has been recurrently studied. For example, there are post-disaster temporary housing location alternatives [28,49], their technology construction comparisons [41] and internal design optimization studies [50]. A comparison between bricks can be found in low-cost buildings [51]. Self-promoting housing has a study adapted to single-family homes [52]. Finally, the building's reconstruction considers adobe buildings in seismic zones [53]. Event nowadays is the most dominant cluster with a current value of 22.39%. This shows that mostly MIVES authors are still related to civil engineering and construction.

Once the method was presented, in 2012, second (code and regulations) and third (new technologies and strategies) clusters appeared and constituted 33.33% and 16.67% of results. The main objective was to improve the administrative proceedings (i.e., concrete design) with the inclusion of sustainability assessments and introduce MIVES on other scientific disciplines. In the second cluster, Spanish sustainability code assessment with MIVES inclusion proposal [39,54] and sustainability software code adaptations [55] are placed. The third cluster is generated by school construction technologies comparisons [38], R&D

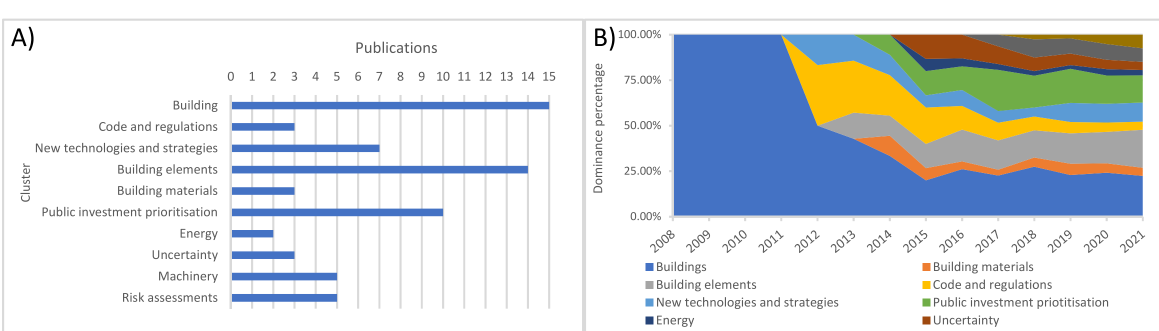

Fig. 7. A) Final thematic division and their number of outputs. B) Cluster's dominance by annual scientific production published (2008–2021).

Table 4
Cluster and publication summary.

Thematic	Topic	Reference
Buildings	Tunnels	[43–46]
	Flyover bridges	[47]
	Industrial buildings	[36,37,48]
	Temporary housing	[28,41,49,50]
	Low-cost building	[51]
	Self-promoting housing	[52]
	Building's reconstruction	[53]
Code and regulations	Code analysis	[39]
	MIVES code inclusion	[54,55]
New technologies and strategies	School construction	[38]
	R&D	[56,57]
	Electrokinetic remediation	[58]
	Active learning strategies	[59]
	MIVES applications	[17]
	Innovation evaluations	[60]
Building elements	Columns	[61]
	Beams	[26]
	Slabs	[62]
	Pipes	[42,63]
	Retention walls	[64]
	Trenches	[65]
	Concrete retaining tanks	[66]
	Piles	[67,68]
	Roofs	[69,70]
	Facades	[71,72]
Building materials	Wood structures	[73]
	Concrete structures	[74]
	Prefabricated structures	[75]
Public investment prioritization	New facilities and infrastructures	[76–82]
	Maintenance and rehabilitation	[83–85]
Energy	Power generation	[40]
	Biomass processing	[86]
Uncertainty	Fuzzy Arithmetic	[87,88]
	Monte Carlo	[89]
Machinery	Wind-turbines	[90,91]
	Heat exchangers	[92]
	Waste	[93,94]
Risk Assessments	Climate change	[95]
	Flooding	[96–98]
	Bank robbery	[99]

development technologies selection [56,57], electrokinetic remediation analysis models [58], active learning strategies and activities in large groups [59], MIVES applications in civil engineering and architecture studied [17], and project management innovation capability evaluations [60].

These new applications and sustainability assessment proposals opened the door to many specific publications. The fourth cluster involves articles based on sustainable building elements comparison, selection, or optimization. Remarkably, the dominance percentage of this cluster has been stable, with 14.29% in 2013 and 20.90% in 2021. This shows a sustained interest to apply sustainability in different building elements. Some of them are concrete columns [61], beams [26] and slabs [62] comparisons, as well as pipe systems [42] and pipe reinforcement [63] assessments. Other studies are focused on earth retaining walls [64], trenches [65], structural concrete retention tanks [66], flight auger piles [67] and fiber-reinforced concrete piles [68]. Finally, this group considers roofs and facades studies. Hence, sustainability roofs analysis [69], roofs selection to air pollution reduction [70], multiple stakeholder facades selections based on acceptance [71] and intelligent multi-layer facades comparisons [72] ends this group.

The fifth cluster contains general structures comparisons regarding their materials. Their dominance has been declining over the years as their generality complex multiple publications of the same thematic. Wood [73], concrete [74], and prefabricated [75] structures assessments have been considered in this cluster.

Sixth cluster publications are designer and decision-maker guides for construction and guidelines for public administration funds prioritization. Its present dominance is 14.93%, which indicates the high impact of these publications on the scientific community as is the third-highest current value. At the first topic, new facilities and infrastructures founding studies are placed. Sustainability inclusion in prioritization usefulness studies [76] gave way to public administration MIVES prioritization models. Some examples are found in MIVES application over Barcelona municipal investments [77], new urban infrastructure [78] assessments or public services buildings [79] prioritization models. Also, developing countries investment prioritization [80,81] and urban pavement selection models [82] were developed. Maintenance and rehabilitation are other considered topics in this cluster. Studies about hydraulic structures maintenance [83], rehabilitation investment prioritization in La Habana [84], and pavement status analyses [85] are close to this cluster.

The seventh cluster includes energy-related studies. It is generated by power generation alternatives [40] and biomass processing enterprises sustainability indexes [86]. Finally, eight clusters contain MIVES uncertainty inclusion studies. The included publications aim to analyse diverse uncertainty methods performance. Uncertainty has been applied by fuzzy arithmetic [87,88] or using the Monte Carlo technique [89]. This cluster dominance has been continuously decreasing as these studies are concentrated within a short period.

The ninth cluster is related to machinery comparison, selection, or optimization publications. Hence, wind-turbine support systems assessments [90], wind-turbine tower sustainability design analysis [91], shell and tube heat exchanger optimizations [92], and waste applications as solar waste devices use at schools [93] or civil engineering waste incineration applications [94] are considered. Its dominance has remained stable, from a 6.45%–7.48%, even with 5 years. This consistency is outstanding as it shows MIVES is gathering the interest of non-only civil engineering researchers, branching the assessment methodology across different fields.

Risk assessments form the tenth and final cluster. It includes climate change effects on sustainable cities development [95], extreme rainfalls effects on cities [96], cultural heritages [97] and roads [98] and bank robbery risk analysis to reduce the impact on personnel [99]. Finally, as the last cluster, is noticeable the dominance evolution, from 2.50% in 2018 to a current value of 7.46%, displaying MIVES expansion.

4.2.2. Data treatment discussion

With the thematic division exposed, the analysis of data aspects found by the authors is performed. A MIVES analysis framework must be delimited over the analysed characteristics: multi-stakeholder consideration, accounting for uncertainty and adverse effects applied to indicators. The first one is the common use of the Analytic Hierarchy Process (AHP) with MIVES to decide requirements, criteria, and indicators weights. This method is used to consider multi-stakeholder opinions. Thus, the analysis is going to expose a multi-stakeholder AHP or its modifications consideration. All other used methods will be described as every method used in second and third characteristics. This analysis results are shown in Fig. 8. The figure divides the 67 review publications between the ones which account or do not account with related characteristics.

As it can be seen, multiple stakeholders are considered in 19 of 67 publications, around 28% of them. Nevertheless, AHP is the most used methodology with an outstanding 84.21% application rate (16 of 19). Special mention must be done at some articles which expand the AHP with Shannon entropy [28] or use explicit Delphi techniques [68,72].

Even fewer publications have uncertainty characteristics. Only 6 of 67, around 9%, includes MIVES uncertainty considerations. Value functions included in MIVES methodology could explain this low uncertainty data concern. As these functions are used to convert qualitative and quantitative data to [0,1] values, some studies do not have the uncertainty treatment need. Besides uncertainty cluster presented publications, some others consider it by using Monte Carlo on data

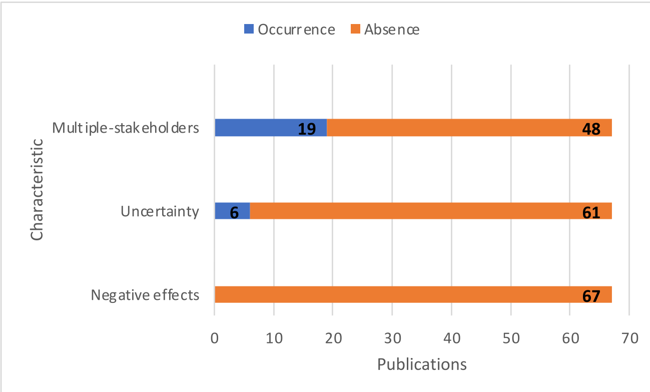

Fig. 8. Data treatment analysis. Characteristic occurrence (blue) and absence (orange). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

treatment [82,92,99].

Nevertheless, adverse effects characteristic presents an outstanding point. No publication presents a negative effects negative contribution, considering adverse indicators from a positive standpoint using an inverse (decreasing) value function. Hence, even a negative indicator containing parlous data is assessed with a minimum value of 0.

On the other hand, some authors consider that these adverse indicators must be assessed from a negative point of view [100], keeping the negative sign in the WSM. As MIVES uses this technique to aggregate the indexes obtained through value functions, the inclusion of negative values should be considered in order to provide MIVES with the ability to reduce its sustainability index. This feature could greatly improve the way in which not only adverse, but harmful indicators are assessed in MIVES.

5. Conclusions

The analysis conducted in this paper has revealed the growing national (i.e., Spain) and international interest in MIVES, as manifested by the number of scientific productions and the high impact journals publication core. That production mainly constitutes first MIVES applications on a wide range of topics to generate sustainability indexes to prioritize and select alternatives. The publications evaluated span a wide range of topics (from civil engineering structures and components to public investment prioritization models, among others), providing a better understanding of the use and impact of MIVES since its conception. This fact emphasizes the versatility of MIVES as a MCDM that can be applied to any problem.

However, the analysis also detected three areas where MIVES can improve. The first refers to multi-stakeholder considerations. Although some publications take it into account, AHP is mostly used while other techniques are rarely applied. Aside from their viability or efficiency, multiple new opinion aggregation methods have been developed in recent years. Therefore, new studies should be conducted to analyse the most suitable solution.

The second area to improve is associated with uncertainty. Until recently, only a few MIVES publications considered uncertainty in the data treatment. Generally, uncertainty was transformed into qualitative data and directly applied to value functions. Methods that include uncertainty would reduce the qualitative and subjective part of MIVES methodology. This could lead to a more objective, traceable, and quantifiable method.

The third and last improvement identified in the framework of this paper involves sustainability index reduction capacity. Providing MIVES with the SI reduction capability due to adverse alternative effects would have a substantial impact for sustainability. Furthermore, better and more accurate sustainability indicators would be provided in proposed alternatives if they could not only increase but reduce the prioritization alternative ranking index. Nevertheless, given the relative values obtained by the MIVES comparison system, a complete set of indicator values must be developed to compare with negative considerations.

Furthermore, future works should analyse the internal relationships between the decision trees used in each of the results. This would lead to a broader understanding of which requirements, criteria, indicators and value functions have been used in each case and could be related to the thematic clusters presented in this study. Other studies should consider the multi-period evaluations inclusion to shed light on uncertainty problem.

CRediT authorship contribution statement

David Boix-Cots: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Francesc Pardo-Bosch:** Validation, Supervision, Conceptualization. **Ana Blanco:** Writing – review & editing. **Antonio Aguado:** Supervision. **Pablo Pujadas:** Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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