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Material selection in the construction industry: a systematic literature review on multi-criteria decision making

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Abstract

Material choice is critical for ensuring sustainability in the construction industry. Higher carbon embodiment materials contribute towards greenhouse gas emissions and global warming. Decisions on sustainable material selection depend on multiple criteria and variables, thus creating a difficulty to determine the best choice. Multi-Criteria Decision Making (MCDM) techniques have the potential to address this challenge. However, there is limited data that reviews MCDM in choosing building and construction materials. This study aims to review the MCDM methods employed in the sustainable selection of building materials within the construction industry. This systematic literature review (SLR) incorporates meta-analysis and thematic mapping through applying "PRISMA framework" and "*Bibliometrix*", respectively. This study explored and analysed the records published from 2010 to 2023. This work identified the critical steps for addressing decision problems in building material selection: Establishing criteria, ranking the hierarchy, comparing the selection criteria, and enabling consistency indices. Moreover, one of the most used MCDM methods, i.e. Analytical Hierarchy Process (AHP) was particularly found particularly useful for the selection criteria and weight assignment of variables regarding the waste, recycled, and composite materials. The involvement of several criteria and alternatives raised the complexity of decision problems, leading to the use of Hybrid MCDM. Hybrid MCDM techniques possess the capacity guide informed decisions for the sustainable material selection in the construction industry.

Keywords Multi-criteria decision making · Building materials · Material selection · Sustainable construction · MCDM · Construction materials

Abbreviations

AHP	Analytical hierarchy process
ANP	Analytic network process
AR	Artificial reef
ARAS	Additive ratio assessment
CODAS	Combinative distance assessment
CRITIC	Criteria importance through inter-criteria correlation
DEMATEL	Decision-making trial and evaluation laboratory
DS	Dempster-shafer theory
EDAS	Evaluation distance from average solution
Fuzzy BWM	Fuzzy best–worst method
GRA	Grey relational analysis
IVIF	Interval-valued intuitionistic fuzzy sets
LOPCOW	Logarithmic percentage change-driven objective weighting
MACONT	Mixed aggregation by comprehensive normalisation technique
MCDM	Multi-criteria decision making
MCRAT	Multiple criteria ranking by alternative trace.
MEREC	Method based on the removal effects of criteria.
MTM	Modified toufar model
NGT	Nominal group technique
PSI	Preference selection index
TOPSIS	Technique for order of preference by similarity to ideal solution
WASPAS	Weighted aggregated sum product assessment
WPC	Wood plastic composite (WPC)

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1 Introduction

The pace of urbanisation to accommodate the growing population has sped up the expansion of construction industry. On top of that the resource intensiveness of construction sector accounts it for higher quantities of cement utilisation and increased human activities (Jie et al. 2023) exerting a toll on environment in the form of increasing levels of anthropogenic emissions, construction demolition and waste. Recent research has revealed that selecting sustainable materials can prove crucial for capacity building and laying and consolidating groundwork for decisions and actions to achieve net zero carbon goals.

Researchers have also highlighted the need for transitioning towards sustainable construction practises (Boobalan et al. 2022). Several studies have reiterated the need to select sustainable construction materials as a crucial step towards sustainable construction (Syed Naseer et al. 2023). The process of choosing a sustainable material for the construction field entails significant effort (Jahan et al. 2010). The struggle can become even more challenging while making informed decisions and guided actions for supporting sustainable construction. A stakeholder in the construction industry may succumb to a disadvantage owing to the unsuitable selection of materials (Jahan et al. 2011).

Traditionally, construction materials are selected based on technical and economic considerations hardly giving much importance to the environmental aspects (Alam Bhuiyan and Hammad, 2023). On top of that merely relying on the material datasheets or directories is not sufficient because of ever-growing construction industry. However, conventional material datasheets and directories are not sufficient for enabling such a sustainable design which do not adversely impact the environment and the habitats (Shaharuzaman et al. 2021a). The scope of using traditional methods and systems for choosing materials is relatively narrow compared with the newly emerging intelligent knowledge-based systems, and one of these is multi-criteria decision making (MCDM) for material selection (Oliveira et al. 2019). However, there have been few research publications that have methodically reviewed MCDM in the field of construction. One of the reasons is, the criteria for the selection of materials modestly differs industry-wise, for example, aerospace industry includes financial, safety, structural, manufacturing, and environmental impact, whereas the bicycle industry includes factors like weight and shape of the sections (Ul Haq et al. 2022, Syed Naseer et al. 2023). When it comes to construction industry, the focus of material selection is on strength properties, availability (of materials), sustainability, discoverability and design aesthetics and resourcefulness (Al-Radhi et al. 2023).

The other challenging aspect is the degree of flexibility MCDM applications as the material requirements also vary for a number of industries except for the point when it comes to selection of sustainable materials (Tajik et al. 2023). Oliveira et al. (2019) have presented barriers towards the adoption and implementation of MCDM. The MCDM approaches support the informed decisions in selecting the construction materials and to that end it is important to identify the materials used in the construction industry and also these methods take not only technoeconomic and environmental but also cultural and social factors into account (Mathiyazhagan et al. 2019).

Most commonly used construction materials are: (1) Timber, (2) Steel, (3) Concrete, and (4) Composite materials (Al-Radhi et al. 2023) and literature is available on benchmarking the performance of these materials through MCDM in the industries other than construction industry, however there is noticeable gap on seeking relevance of MCDM for new materials in construction industry.

MCDM approaches would help material scientists, architects, engineers, and construction manager to accelerate sustainability through material choice across a wide range of MCDM available. This study attempts to meet the requirements and hopes of the construction industry stakeholders particularly material engineers, quantity surveyors and sustainability scientists to be mindful, acknowledge and integrate MCDM for seamless material selection process. The study provides a thorough assessment of existing state of disruptive methods across various industries, their benefits, opportunities, and barriers. The study also focuses the foundational techniques for MCDM. This study is carefully crafted a systematic approach to offer a detailed review and actionable recommendations about the tested and successfully applied MCDM methods of key significance.

Thus, this paper directs its attention to the research objectives: To review the existing body of knowledge on multi-criteria decision-making methods and identify future research opportunities and limitations of MCDM.

2 Literature review

Sustainable construction is a mean to mitigate the negative impact of climate through creating low carbon building envelops (Chandrakumar et al. 2020). The definition of term *sustainable construction* is not that simple (Du Plessis, 2007), however Kiebert (1994) remarks sustainable construction means to create and responsibly manage healthy built environment on the basis of resource efficient and ecological principles. Sustainable construction in relation with material selection context means cutting down quantities of materials used in construction beginning from the extraction and processing to consumption as well as implying the

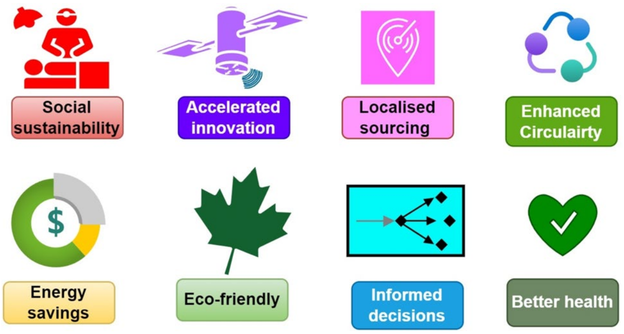


Fig. 1 Sustainable materials offer significant advantages (developed by authors)

less use of energy and producing less waste (Boyle, 2005). Moreover, Dutil et al. (2011) also argues on using the materials with low embodied energy as a crucial component for achieving sustainability. Main objectives of a sustainable design through materials selection approach are to ensure resource efficiency, support environmental conservation, and improve cost effectiveness (Samudrala et al. 2023; Oztemel and Gursev 2020; Monteiro et al. 2017), Fig. 1 illustrates a pictorial glimpse of the advantages that sustainable material practise offers. Material selection is one of the most crucial steps in achieving sustainable construction. Adopting sustainable material selection approaches can significantly lower the demand of virgin materials and produce less waste and carbon footprint (Cramer, 2023).

Sustainable material selection is an imperative in the building design as it influences important decisions regarding a construction project's environmental impact, cost, and quality (Shaharuzaman et al. 2021b). Studies have supported using multi-criteria decision-making techniques can lead to more effective material selection (Jahan et al. 2010). Another study has demonstrated the significance of multi-criteria decision methods in the ever-growing construction industry (Govindan et al. 2016). Multi-criteria Decision Making (MCDM) method implies a systematic approach to determine the best feasible solution according to an established criteria and problems that occur in real life (Jahan et al. 2016). The principals and applications of MCDM are represented as a mean to facilitate early conceptual design and product development process (Shaharuzaman et al. 2021a). The same study reveals that modern MCDM approach employs systematic and collective methods using advanced tools. MCDM approaches has been applied in different industries over the time to analyse, rank, and select the best materials tailored to their desired purpose and pursuit. MCDM approaches has been applied in different industries over the time to analyse, rank, and select the best materials tailored to their desired purpose and pursuit (Awate and Barve 2021). Furthermore, Yang et al. (2022) categorised sixteen (16) MCDM methods for material selection across a wide range of industries.

Initially, the application of multi-criteria decision analysis in the realm of environmental conservation was done by Kiker et al. (2005), who proposed a general analytical framework for complex environmental problems but so far the scarcity of research publications on MCDM for material selection in construction projects has been a challenge (Lazar and Chithra 2020). Material selection process has been categorised into two important steps (Fig. 2) (i) Screening (ii) Ranking; the former requires *screening techniques*, *knowledge-based systems* (KBS) and *expert systems* while *weight determination* and *hierarchical position* are the important components of the later method (Shaharuzaman et al. 2021a). The selection of the suitable materials is a complex issue as it requires multiple features of validation and precision (Alaaeddin et al. 2019).

However, despite gaining a ground in the research arenas the MCDM approaches face several challenges in terms of adoption. Extensive literature studies have shown management of larger datasets (Noryani et al. 2019), absence of realisation regarding advantages (Marttunen et al. 2017), level of methodical quality (Oliveira et al. 2019), effective utilisation of expert input (Estévez et al. 2021), and measuring the long-term consequences (Montibeller and Franco 2011) of MCDM to be the key barriers. The study has also identified the challenges and addressed the challenges by providing a roadmap for effective implementation of the highlighted MCDM approaches.

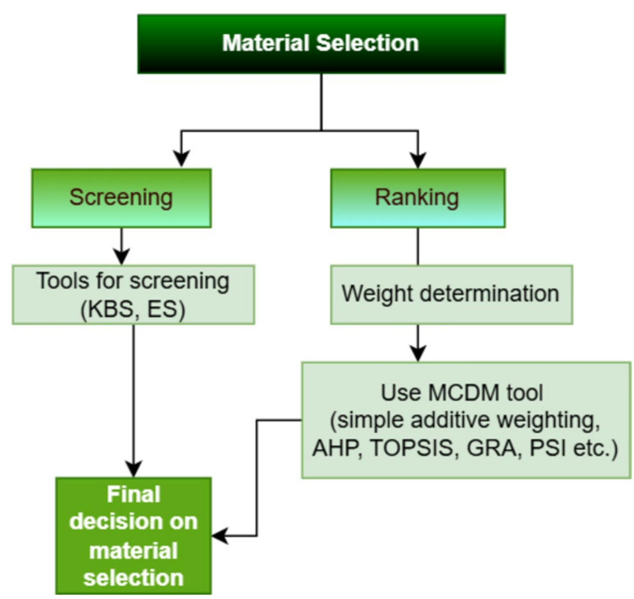
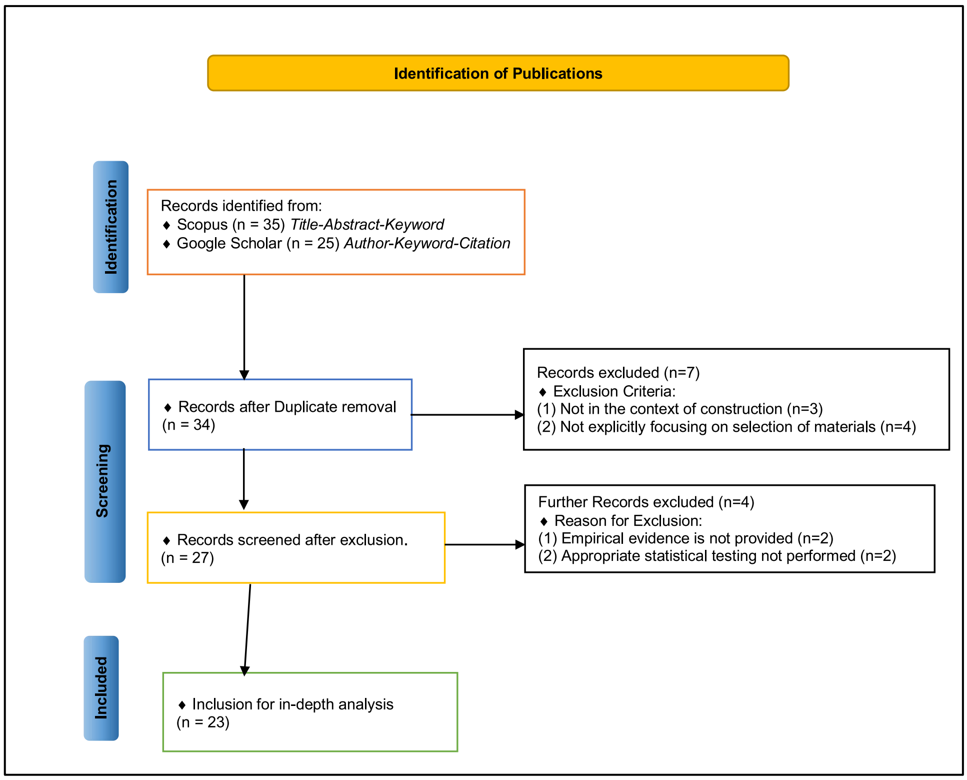


Fig. 2 Material Selection process for sustainable design, drawn by authors based on (Shaharuzaman et al. 2021b)

3 Research methodology

Motivated by the competencies and prospects of the MCDM, this research is concentrating on the standalone as well as hybrid MCDM approaches for material selection. This attempt strives to offer a holistic understanding about the formation and execution of MCDM oriented towards sustainability. A roadmap for implementing the appropriate techniques is one of the key outcomes of this effort. To achieve this goal, the research team conducted a systematic literature review (SLR) consisting of meta-analysis and thematic mapping through following the "PRISMA framework" and "*Bibliometric*", respectively (Figs. 3, 4). *Bibliometrix* is an R-package, to exhaustively examine the existing state of knowledge on MCDM inclusive

Fig. 3 PRISMA framework for inclusion and exclusion of records on MCDM in construction



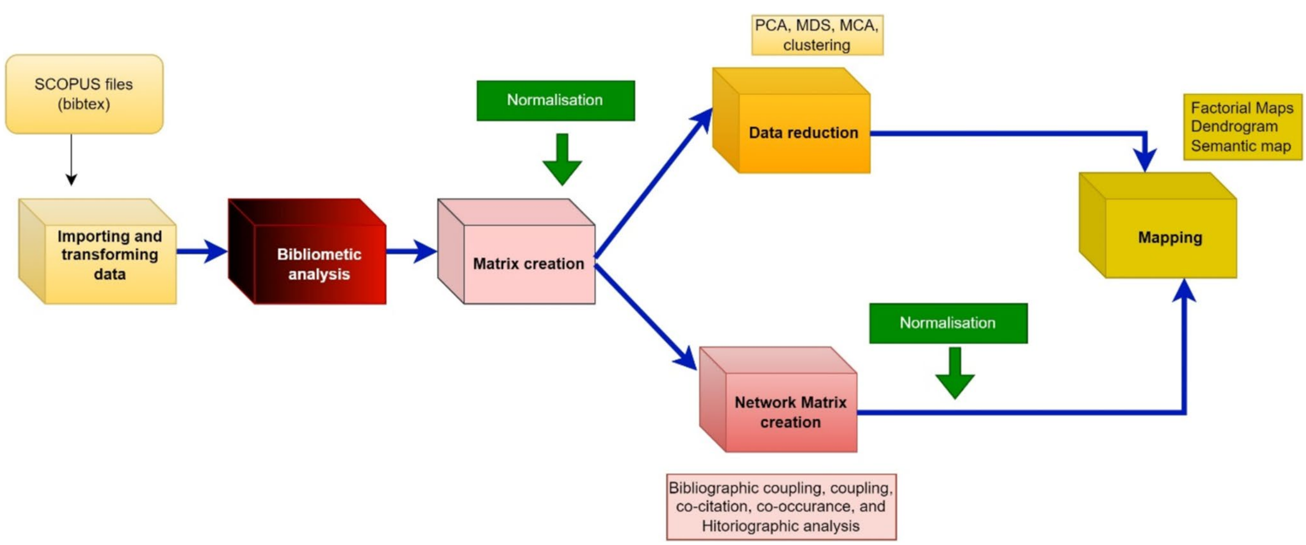


Fig. 4 Science Mapping Workflow and *Bibliometrix*, modified from (Aria and Cuccurullo 2017)

Fig. 5 Steps for conducting the Systematic Literature review (SLR)

of trends and thematic explorations Qualitative research approach is used to identify the essential components of each method contributing towards an effective and robust material selection processes.

3.1 Systematic literature review

This study employed systematic literature review of the published records through PRISMA framework. This approach (PRISMA) focuses on the general guidelines to conduct a review recommended by the studies (Pati and Lorusso 2018; Khan et al. 2003). Figure 5 provides the breakdown of the steps taken to conduct the SLR for this study.

3.1.1 Formulation of research problem

Ratan et al. (2019) expounded the important facets of the research questions, such as, (a) Detailing the problem statement, (b) Refining the issue under study, (c) Adding focus to the stated problem, (d) Guiding collection of data and analysis, and (e) Developing the scope of research. Furthermore, description and classification-format based research questions are, (1) What are the different categories of MCDM methods available in published literature on construction? (2) How MCDM approach is applied to tackle the decision problems of material selection?

3.1.2 Identification of relevant work

The closely relevant publication records were explored by choosing the SCOPUS database. Peer-reviewed literature database, excellent navigation, and reliable, rapid, and relevant availability are the reasons behind choosing SCOPUS (Burnham, 2006). Combining the keywords after going through extensive literature study on MCDM for material selection, this research attempt began. The combination of keyword string was placed in the "Search within" option of SCOPUS. At first the field code (All "material selection" AND "multi-criteria decision making" OR mcdm AND "construction") is applied to assess the frequency of the records.

The second stage begins by applying the field code (Title-Abstract-Keyword "material selection" AND "multi-criteria decision making" OR mcdm AND "construction") is total of 35 SCOPUS records are selected through the predefined exclusion criteria set by this study, whereas an additional 25 number of publications are added through Google Scholar's author citation network. This whole scheme for including and excluding the relevant records is available in the form of PRISMA mapping following the guidelines Sarkis-Onofre et al. (2021) has charted out.

3.1.3 Quality assessment of the studies

The quality evaluation of the publication records yielded through PRISMA framework is the 3rd step of this SLR. Kelly et al. (2001) suggested that the SLRs need to pay attention to explicate the exclusion and inclusion criteria with utmost clarity. Focusing on the recommendations of (Kelly et al. 2001; Oxman and Guyatt 1988), the study included records from Scopus database which is a peer reviewed search engine. Moreover, Mallen et al. (2006) clarify in their study on "Quality assessment of observational studies…" that there is no consensus in the method for quality evaluation, however, they provide 30 different criteria for the quality checks to examine the records. It is necessary to avoid any misleading and inaccurate information in the research practise, (it can be seen in Fig. 6, where this work judged the published records based on the four quality checks, reducing the selected research records to 23).

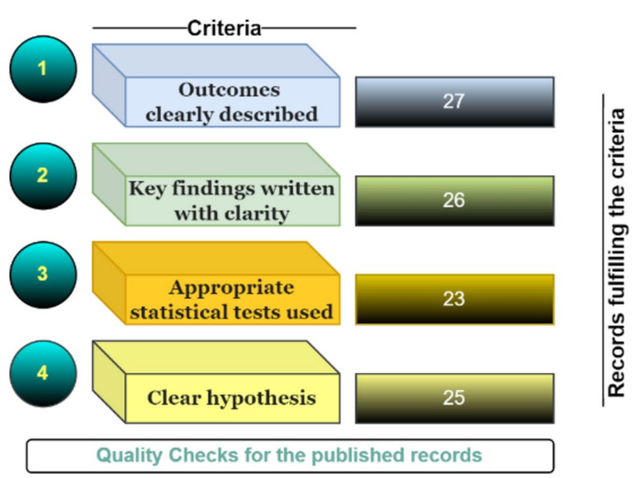


Fig. 6 Assessment framework for the quality of selected records

3.1.4 Summarising the evidence

The study conducted a detailed analysis of the included records and interpreted the findings to recognise different MCDM approaches. Study has identified following broader trends after the in-depth analysis of the publication records.

The initial analysis of the records revealed that the MCDM approaches are divided into two distinct branches from application point of view in construction: (1) Standalone MCDM and (2) Hybrid or Integrated MCDM (The details and applications of both approaches are briefly discussed in the "Findings" section).

3.2 Method for bibliometric analysis

The current investigation adopted bibliometric analysis to understand the intellectual structure and grasp the boundary of accumulated knowledge on Multi-criteria decision-making (MCDM) approaches. The significant advantage of performing the bibliometric analysis is its potential to introduce a "…systematic, transparent, and reproducible review process…" as Aria and Cuccurullo (2017) reported based on scrutiny of multiple research records. "*Bibliometrix*" is the specific, user-friendly, and open source "*R package*" for synthesising a comprehensive scientific mapping of published records. This tool also offers an interactive workflow with multiple mapping options. Figure 4 displays a pictorial scheme of the tool starting from importing a "*Bibtex*" from a chosen database (SCOPUS) into the workflow of *Bibliometrix*.

The dataset (in *Bibtex*) contains essential information about citations, bibliography, abstract and keywords, and miscellaneous data. The next step is loading and conversion of the data under consideration. The third and fourth stages capitalising one of the options available on *Bibliometrix*: (1) Clusters and conceptual maps, (2) Network mapping, (3) Keyword co-occurrence map, and (4) Wordcloud based on the guidelines (Aria and Cuccurullo 2017).

4 Findings

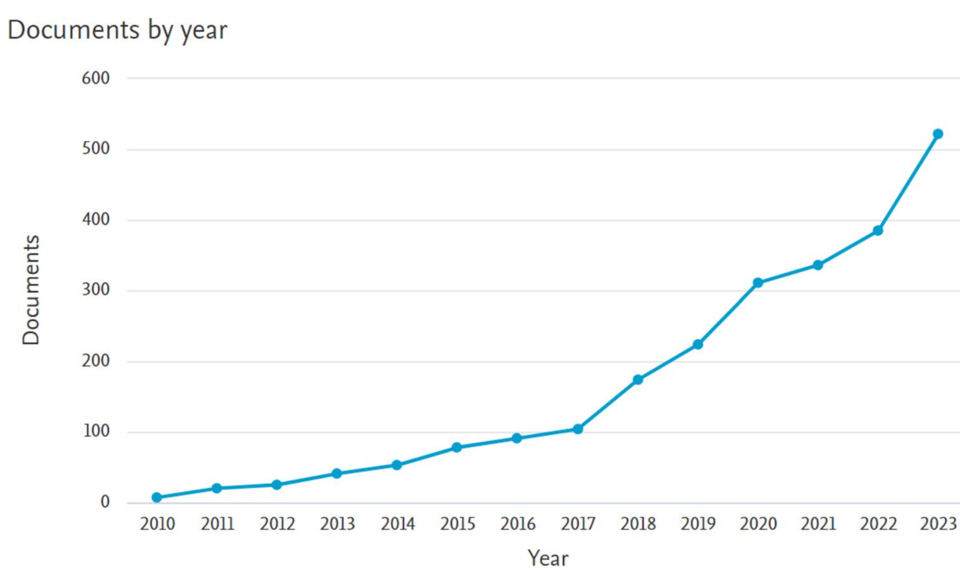
The structure of this section is such that we briefly express the outcomes of bibliometric analysis followed by the systematic literature review. One of the study's objectives was to discuss the current state of knowledge on MCDM for selecting materials in the construction industry. The findings section of this work represents the evidence-based analysis of the published records. The bibliometric analysis helped paint the visual canvass of the research; on the other hand, systematic analysis of the literature particularly stood out in delineating the trends, relationships, applications, and advancements in the MCDM, specifically in the material selection process.

4.1 Bibliometric analysis—results

This section depicts the visual picture of critical themes and prominent concepts within the chosen research literature. There has been an increasing trend of published research records on the application of MCDM in the construction industry (Fig. 7). Moreover, the top four countries publishing more articles on MCDM are India, Malaysia, Iran, and Turkey (Fig. 8).

Figure 9 represents the countries receiving the most citations ranking Denmark, Malaysia, and Serbia among the top 3 countries. There rankings of the countries change slightly

Fig. 7 Trend of publications on MCDM in construction



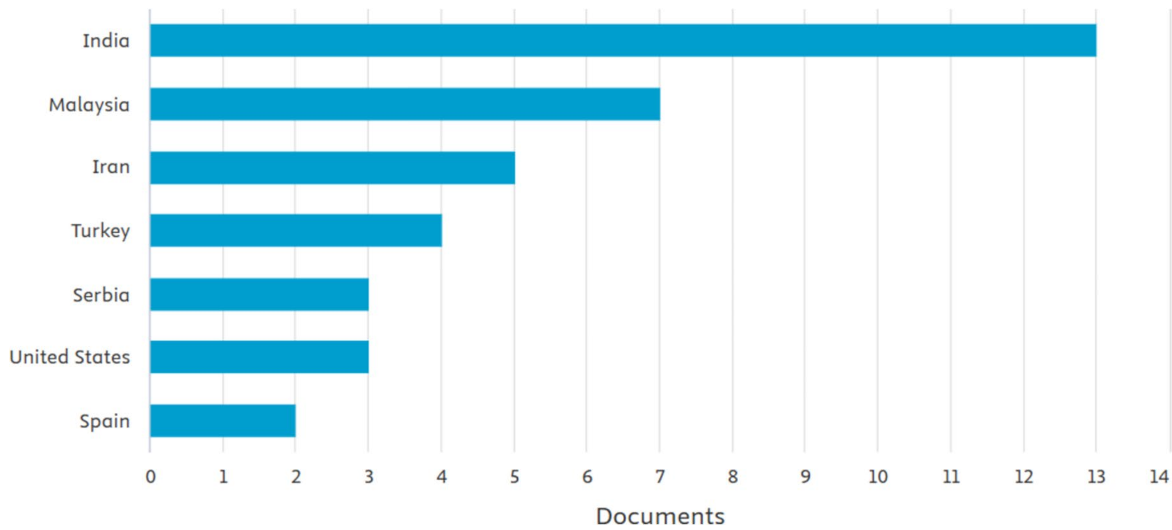
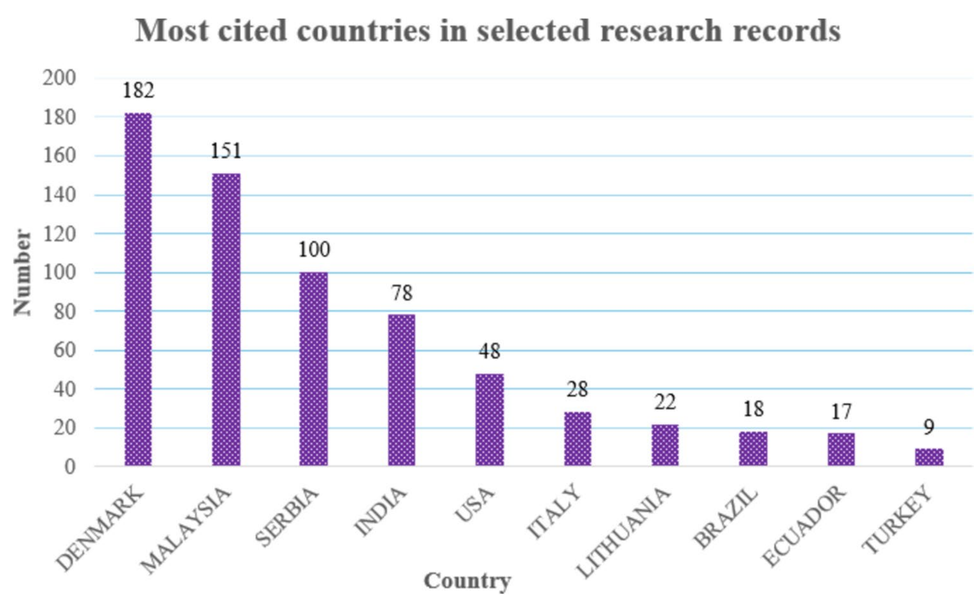


Fig. 8 Publications on MCDM in terms of territory

Fig. 9 Most cited countries in the literature



while comparing the number of publications per country (Fig. 8) and the number of most cited countries (Fig. 9).

Word frequency analysis displayed the most/least common keywords. “Decision making" ranks as the most frequently used keyword, followed by construction and industry, which are the second and third most frequently occurring words, respectively (Fig. 10). The first four most used keywords also form a pattern: “*decision making…*” in “*construction industry…*” through “material selection” for “*sustainable development*”. It signifies the cruciality of material selection as a potential decision-making problem that can support actions and guidelines towards sustainable development. Multi-criteria decision-making is also one of the most prominent keywords; it could have Top of the chart keyword. The difference happened because different authors preferred to use distinct syntax for the keywords with, for example, hyphenated ‘-’ symbols in different placements of keywords, e.g. (“multi-criteria decision-making”), (“multi-criteria decision-making”), and (“multi criterion decision making”).

Finally, the research team provided the keyword analysis of the research documents across three domains: abstract, author keywords, and titles. *Bibliometrix* has a Keyword Plus feature which provides most frequent keywords. Most frequent words using keyword plus feature are Decision making, construction industry, material selection, and sustainable development (Fig. 11a). This study also capitalised on unigram, bigram, and trigram keyword analysis, a derivative feature of Keyword Plus that only classifies the keywords across the abstract of the

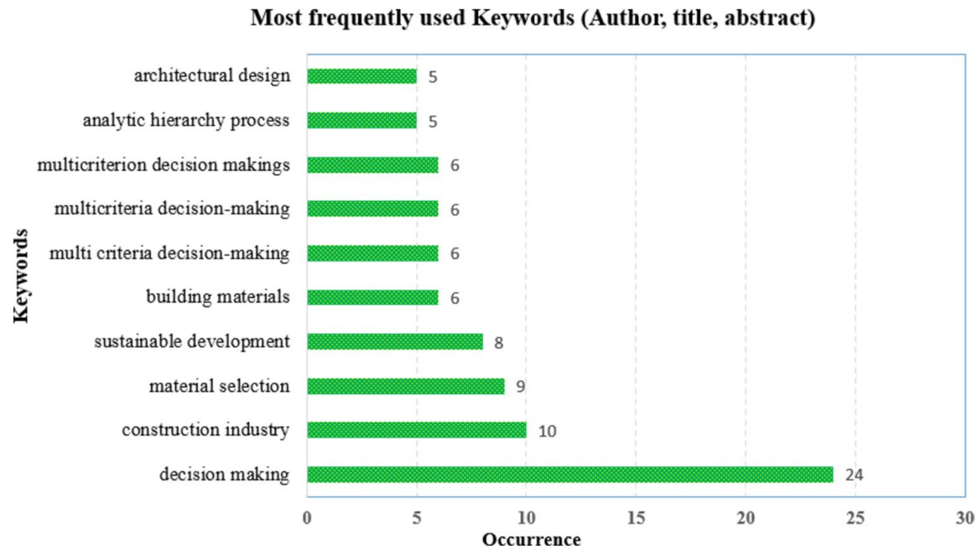


Fig. 10 Most prominent title, abstract, and author keywords

Fig. 11 Keyword Plus (Title, keywords, abstract) and Keywords (unigram, bigram, trigram in abstract)

records under consideration. Unigrams (Fig. 11b), bigrams (Fig. 11c), and trigrams (Fig. 11d) are the one, two, and three word-units of a keyword phrase across the abstract, respectively.

The co-occurrence network is a semantic map constructed using *Bibliometrix*. This network provided keywords extracted from selected studies. The network consists of nodes, the individual words (in the title, abstract, and indexed keyword), and knots between these nodes express the frequency with which the words co-occur (Fig. 12).

The "Co-occurrence degree plot" feature of *Bibliometrix* exhibits a graphical distribution of connection strength (Fig. 13). "Decision making" with a degree value of "1" represents the reference value of this topic to be maximum at rate 1. The degree distribution of all other nodes (i.e. Construction industry degree value with 0.475) is calculated as a fraction of the reference value. Thus, the lower value cumulative degree represents weaker connectivity of a topic with other co-occurring topics. The top nodes exhibited the higher cumulative degree in the network because topics like

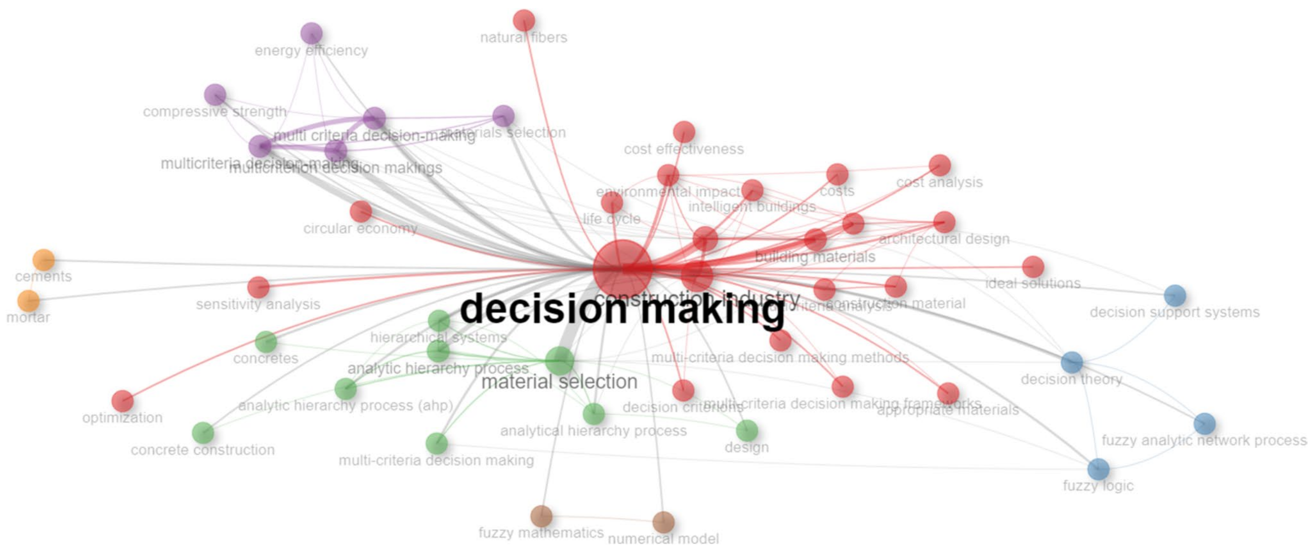


Fig. 12 Co-occurrence network

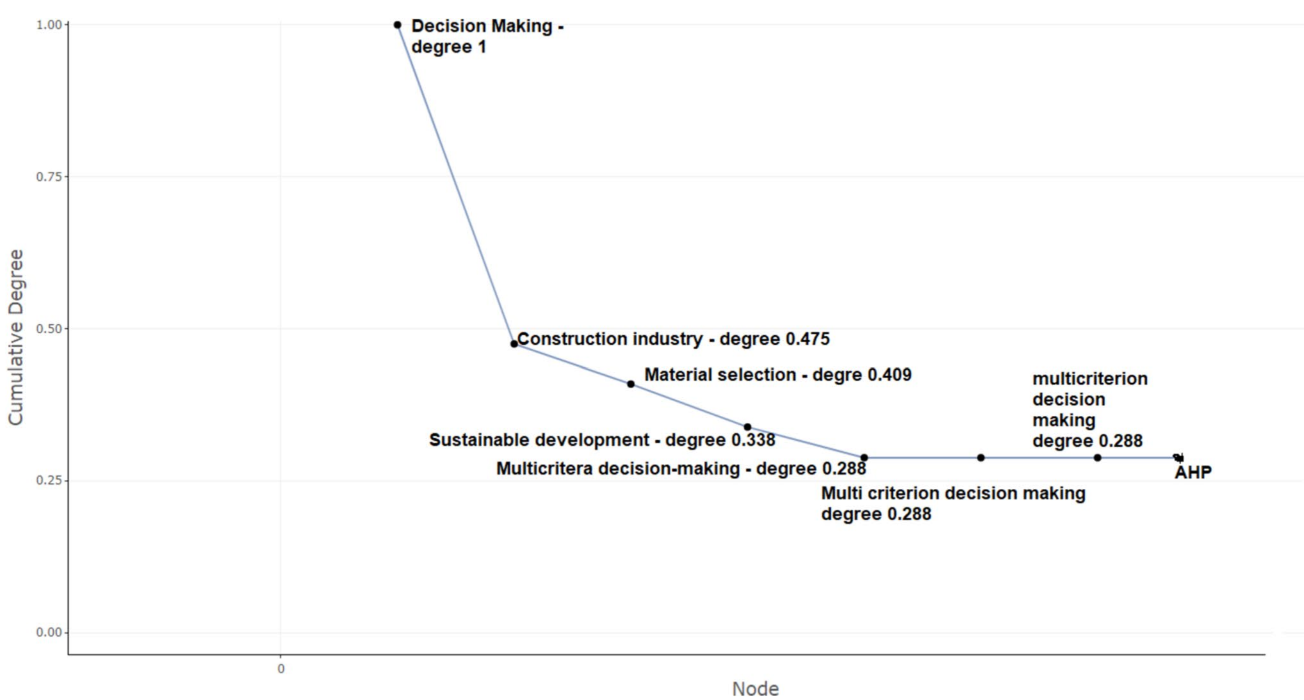


Fig. 13 Co-occurrence degree plot

"*Decision making*", "construction industry", "material selection", and "sustainable development" hold key considerations while tackling decision problems of material selection. The analytical hierarchy process (AHP) is also one of the most connected nodes in this field; it is one of the MCDM methods (Fig. 13).

Figure 14 provides the visual map of the major research themes found in selected studies. Niche themes hold minor relevance to the research area but have connections to other low-relevance topics. Motor themes signal (Analytical hierarchy process, multi-criteria decision making, construction materials) highly significant and well researched decision methods explored in studies. Emerging or declining themes express that the topics are in earlier development and their relevance has not been tested significantly in research (Table 1).

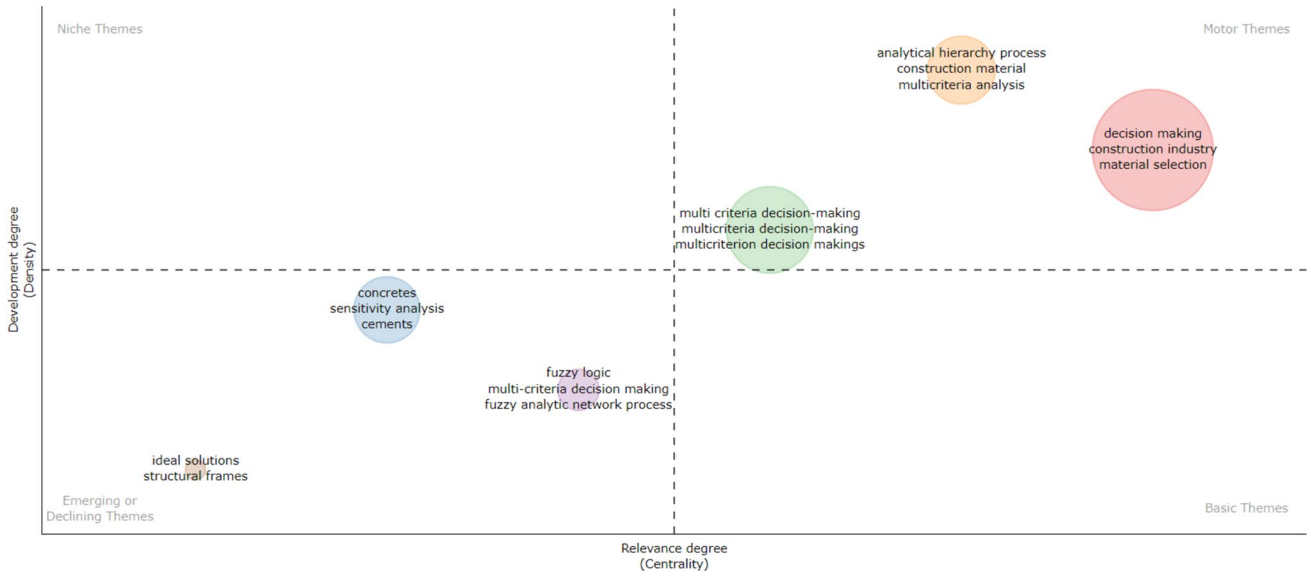


Fig. 14 Thematic overview of the multi-criteria decision methods

Table 1 Use of different MCDM in material selection

No	MCDM method	Key strength of the used method	Citation
1	Hybrid/Integrated Multi-Criteria Decision Making	Combines various MCDM techniques to evaluate and select among multiple alternative materials under complex scenarios	(Aksakal et al. 2022; Khoshnava et al. 2018)
2	Analytical Hierarchy Process (AHP)	A method delving to explore grouting material selection problems and to determine the best grouting material	(Lehtonen, 2019)
3	Analytical Network Process (ANP)	An effective method for building engineers to choose high performing green building materials thereby addressing three key aspects of sustainability	(Khoshnava et al. 2018)
4	Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	A method that identifies solutions from a finite set of alternatives based upon simultaneous minimisation of distance from an ideal point	(Reddy et al. 2022)
5	Best–Worst Method (BWM)	Combines Bayesian inference with BWM and Simple additive weighting (SAW) for decision-making under uncertainty	(Aksakal et al. 2022)
6	Dempster-Shafer Evidence Theory and Additive Ratio Assessment (ARAS)	Integrates Dempster-Shafer theory with ARAS for decision-making under uncertainty	(Hatefi et al. 2021)
7	VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)	MCDM that focuses on ranking and finding compromise solutions among alternatives such as optimal repair materials	(Kiani et al. 2018)

4.2 Interpretation of the in-depth analysis

This review attempted to explore the role of MCDM methods. The study detailed the information about the most critical steps in solving the materials-related decision problems through MCDM, most used MCDM approaches, a descriptive analysis of the existing problems, influence factors and limitations and future of MCDM approaches. A summary of the relevant evidence with respect to sources, year of publication, MCDM method (hybrid or standalone), construction material type, and research findings have been tabled. The extracted findings focused on the identified methodological approach, criteria evaluation, and research gaps in a succinct tabular form (Table 2).

4.2.1 Deconstructing the multi-criteria decision problem

A growing body of research agrees that the critical aspects of any MCDM method across the disciplines have

Table 2 Applications of MCDM for material selection in construction (Publications 2010–2023)

No	Specific applications for material selection	Method/Approach	Interpretation of the finding(s)	Author
1	Phase change material (PCM) for roofs and walls of the buildings	Integrated (COPRAS, VIKOR, and TOPSIS)	MCDM helped to explore the appropriate environmental assessment variable. The study focused on energy efficiency applications	(Beltrán and Martínez-Gómez 2019)
2	Green decoration materials for interior design	Integrating AHP and GRA followed by GC-TOPSIS	GC-TOPSIS ranked the best material benchmarked against the variables of comfort (physiological, psychological, and environmental)	(Tian et al. 2018)
3	Best suited Bricks for any kind of building	Fuzzy TOPSIS	This attempt applies to evaluating environmental, social, and economic sustainability. However, the limitation of the study is that criteria would be prone to update upon the arrival of a new class of materials	(Mathiyazhagan et al. 2019)
4	Wood plastic composite (WPC) cladding products for facades	AHP	The study underpins WPC optimisation criteria compared to standard compliance, and thus, it is applicable in the process of strategic innovation planning for small and medium enterprises	(Friedrich and Luible 2016)
5	Mortar materials for 3D printing of the artificial reefs (ARs)	EDAS	EDAS method supports the selection of Cement geopolymer and crushed glass materials for the buildability of ARs. Preferences ranking is evaluated based on distance from the average solution, and a good correlation is observed between the EDAS and other MCDM methods	(Yoris-Nobile et al. 2023)
6	Insulation materials for healthy buildings	Integrated Fuzzy BWM, CRITIC, MACONT	Fuzzy BWM and CRITIC stepwise evaluated the subjected and objective weights. MACONT helped in ranking the ten (10) best insulation materials. The limitation of the study is its reliance on a few experts, which leaves this study untested for practical implications	(Aksakal et al. 2022)
7	Green materials for an eco-friendly project	Hybrid (DEMATEL and FANP)	Developing Green Building Materials (GBM) criteria and DEMATEL explores the efficiency and interconnectedness between the criteria. FANP ranks GBM criteria based on three pillars of sustainability, as mentioned above. The study is open to expansion in the direction of green actions in construction	(Khoshnava et al. 2018)
8	Selection of materials for general construction	AHP, VIKOR, TOPSIS	This research study represents the flexibility and effectiveness of the standalone methods and future research for evaluating the new and hybrid methods	(Lam et al. 2023)

Table 2 (continued)

No	Specific applications for material selection	Method/Approach	Interpretation of the finding(s)	Author
9	Binder material alternatives (OPC, GP, PPC-F, and Flyash)	TOPSIS	Integrating objective and subjective criteria weights is crucial in evaluating the most suitable material for application preference. This study addresses sustainability by presenting Global warming potential (GWP) and resource consumption as two of the most influential criteria. This study is adoptable in the presence of several decision-makers and criteria	(Reddy et al. 2022)
10	Sustainable indicators leading sustainable materials	DANP (DEMATEL and ANP) and TOPSIS	The research in the context of the United Arab Emirates reveals Recycling potential and wool brick as the indicator and material for sustainability, respectively. However, the study's sample is small because of the specific geographic location	(Govindan et al. 2016)
11	Repair materials for concrete structures	VIKOR	The proposed method addressed the cost and performance of repaired concrete structures under normal and severe conditions (loads and corrosion). A sensitivity analysis was performed to determine the reliability of the VIKOR process and its adoption in future fatigue applications	(Kiani et al. 2018)
12	Insulation materials (Cotton vis-à-vis Fibreglass)	Standalone (AHP and CBA)	Methodological differences matter, and CBA has shown superiority over AHP during a seven-factor analysis comparison. The challenges arise when there is uncertainty about the attributes of the available options. Moreover, the study expresses the limitations of both methods when dealing with the factors' interdependence	(Arroyo et al. 2015)
13	Geomembranes in the construction	AHP	AHP, assisted by several other MCDM methods, ranked the best alternatives through standardised templates of models for future research work	(Chingo et al. 2020)
14	Insulation materials (Steel Slag crumb rubber blocks)	TOPSIS, EDAS, and WPM	The study focused on finding the best mix for crumb rubber (waste material) as filler for optimum thermos-mechanical properties of steel slag. Thus, MCDM, in combination with energy analysis and heat transfer modelling, provides a tailored alternative. This study also emphasised the significance of applying MCDM for carefully selecting optimal mixtures	(Kumar Chilukuri et al. 2023)

Table 2 (continued)

No	Specific applications for material selection	Method/Approach	Interpretation of the finding(s)	Author
15	Construction materials (Uncertain conditions)	Integrated IVIF and CODAS	The study modified the classical CODAS method and proposed addressing suitable material selection considering uncertainty and sustainability constraints. This method can help solve complex problems like project and supplier selection in the future	(Roy et al. 2019)
16	Façade materials (Conflicting conditions)	ARAS	The researchers developed the ARAS method combined with the DS theory against four main criteria (environmental, technical, social, and economic) alongside 25 sub-criteria to choose one of the best façade materials (Aluminium siding) among a lot of five alternatives. The limitation of the study is defining its feasibility for a more significant number of materials	(Hatefi et al. 2021)
17	Exterior wall systems (Traditional building)	EDAS+	Leveraging the strengths of NGT and Delphi, the study established (Eight income and two expenditure) criteria and determined the weights, respectively. The classical MCDM method (EDAS) extension ranked polystyrene concrete combination as the best among the alternative seven groups under study. The study is significantly supportive of MCDM methods for future projects	(Štilić and Štilić, 2022)
18	Grouting materials	AHP	They have ranked the grouting materials for the rock construction project works for decomposition, composition, and synthesis stages. The main criteria of the study were the extent of the grouting operation, the cost and schedule, the environmental impact assessment, and finally, the numerical standing of materials like polyurethane, colloidal solution of silica, and acrylics. The investigation sheds light on the transparency of the MCDM method	(Lehtonen, 2019)

Table 2 (continued)

No	Specific applications for material selection	Method/Approach	Interpretation of the finding(s)	Author
19	Materials with circularity potential (Deconstruction designs)	Standalone (AHP, TOPSIS, and Kano)	Identified and computed the relevance of nine influential criteria significant for deconstruction, focusing on potential recyclability. AHP weighted and prioritised the chosen criteria. Conclusively, the TOPSIS method ranked five wall configurations with precast gypsum board. The work is vital during crucial stages of material selection. Future research can observe combining MCDM with BIM through experts expressing their experience with automated material selection	(Zoghi et al. 2022)
20	Waste-plastics and Agro-waste based composites	Integrated (AHP-WASPAS)	The critical criteria (abrasive wear, water absorption and strength) and rankings of the alternatives were recognised by AHP-WASPAS, and the results were compared with several MCDM methods. This study performed the experimentation guided through MCDM for material selection. The research effort has limitations in the procedure for defining criteria. Future efforts could create support mechanisms for material scientists	(Soni et al. 2023)
21	Plaster materials	AHP	Cost, durability, curing, raw material availability, and environmental impact were the criteria for deciding the best alternatives (Lime, gypsum, and sand-based plasters). AHP evaluated the weighted scores. The availability of raw materials influenced the ranks. The study foresaw the use of computer based AHP to be quicker and more informed in the future	(Churi and Biswas 2019)
22	Aggregate material	MTM	This paper addressed selecting a proper source of an aggregate of tailored size and proportion for optimal packing density	(Shah et al. 2020)
23	Natural fibre based commercial insulation	Integrated (PSI, MEREC, LOPCOW, and MCRAT)	This research developed an integrated MCDM model to handle the complexity of several criteria and alternatives. The study contributed towards creating a new model to choose the most tailored insulation material that is energy efficient and sustainable	(Ulutaş et al. 2023)

following key steps (Govindan et al. 2016, Alam Bhuiyan and Hammad, 2023, Tajik et al. 2023, Tian et al. 2018).

(1) Define the scope and goal,
(2) Establish the criteria,
(3) Mark its sub-criteria,
(4) Calculate the weight of the criteria, and.
(5) Examine the alternatives.

MCDM methods have been applied to choose diverse range of materials, i.e. composites (agri-waste, recycling, rubber, and fibre based). Moreover, a wider scope of the applicability of the MCDM is discovered by this study as the multi-criteria decision making is useful for the customised, reliable, and optimum selection of external walls, roofs, insulations, and aesthetic amelioration. Figure 15 displays the list of four most used MCDM methods AHP, TOPSIS, COPRAS-G, and VIKOR and the critical stages to address decision problems.

For example, Alam Bhuiyan and Hammad (2023) indicated the goal of their study as to selecting most sustainable structural material, followed by the classification of technical, economic, social, and environmental criteria. Durability (life expectancy) and maintainability, material cost and end of life cost, compatibility and skilled labour availability, and greenhouse gas emissions and recycling potential were among the 16 technical, economic, social, and environmental sub-criteria, respectively. They formulated the decision problem by comparing the alternatives such as reinforced concrete, structural steel, timber, and reinforced masonry (Table 2).

4.2.2 Material selection in construction through MCDM

4.2.2.1 Rationale for choosing the MCDM The results of the selected articles reported that multifaceted nature of material selection problems draw the need for using an MCDM (Kumar Chilukuri et al. 2023). For the identification of the most optimal alternative TOPSIS, EDAS, WPM are the preferred MCDM methods. TOPSIS is particularly effective in addressing physical, mechanical, and mix composition properties of the composite construction materials (Soni et al. 2023). However, some studies reported the utilisation of AHP for similar case scenario, where exploring alternative grouting materials was the problem under study (Lehtonen 2019). Table 1 displays the key strength of the methods used for material selection applications.

4.2.2.2 Standalone MCDM This study has highlighted several material selection problems addressed by standalone or a single MCDM method. Analytical hierarchy process (AHP) stands out as the mostly utilised standalone MCDM approach. Waris et al. (2019) argues the wider and successful applicability of AHP in multiple disciplines. However, a study has described the limitation of AHP in contrast with Choosing by Advantage (CBA) method, reasoning that AHP does incorporate the conflicting verdicts (Arroyo et al. 2015). Figure 16 reveals the materials selected for different construction applications based by using MCDM. Analysis of the articles, this study has found that most studies have used one the three so-called pillars of sustainability, namely eco-

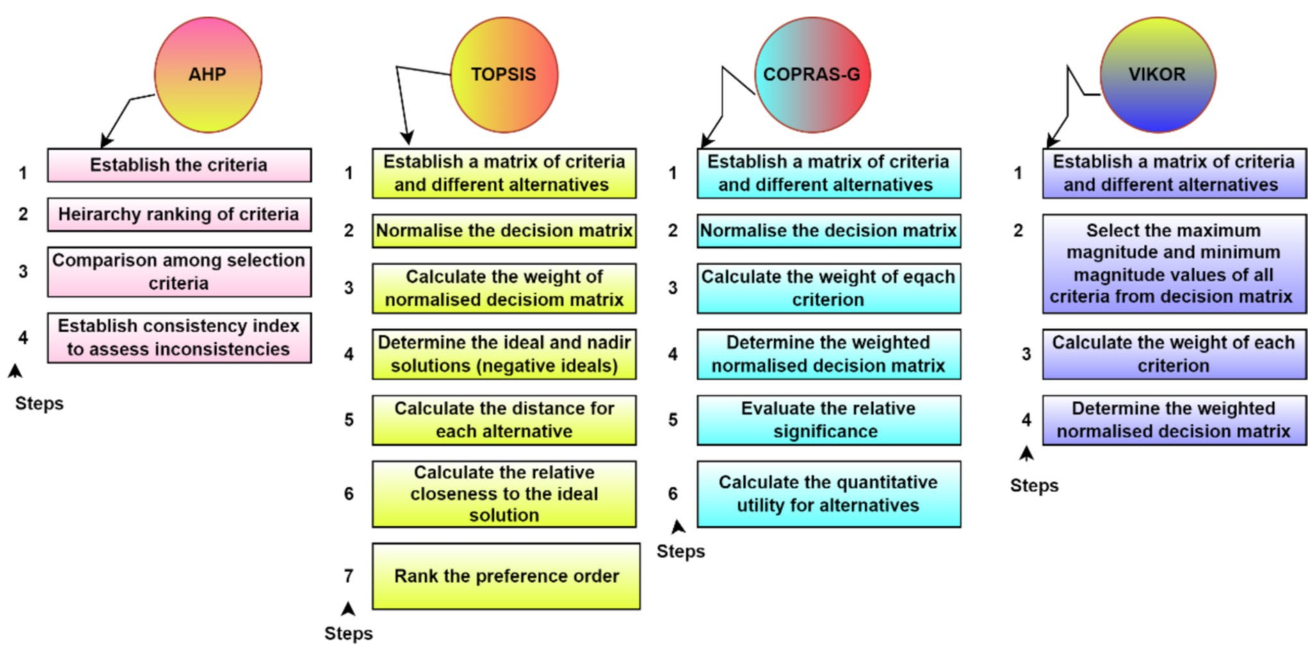
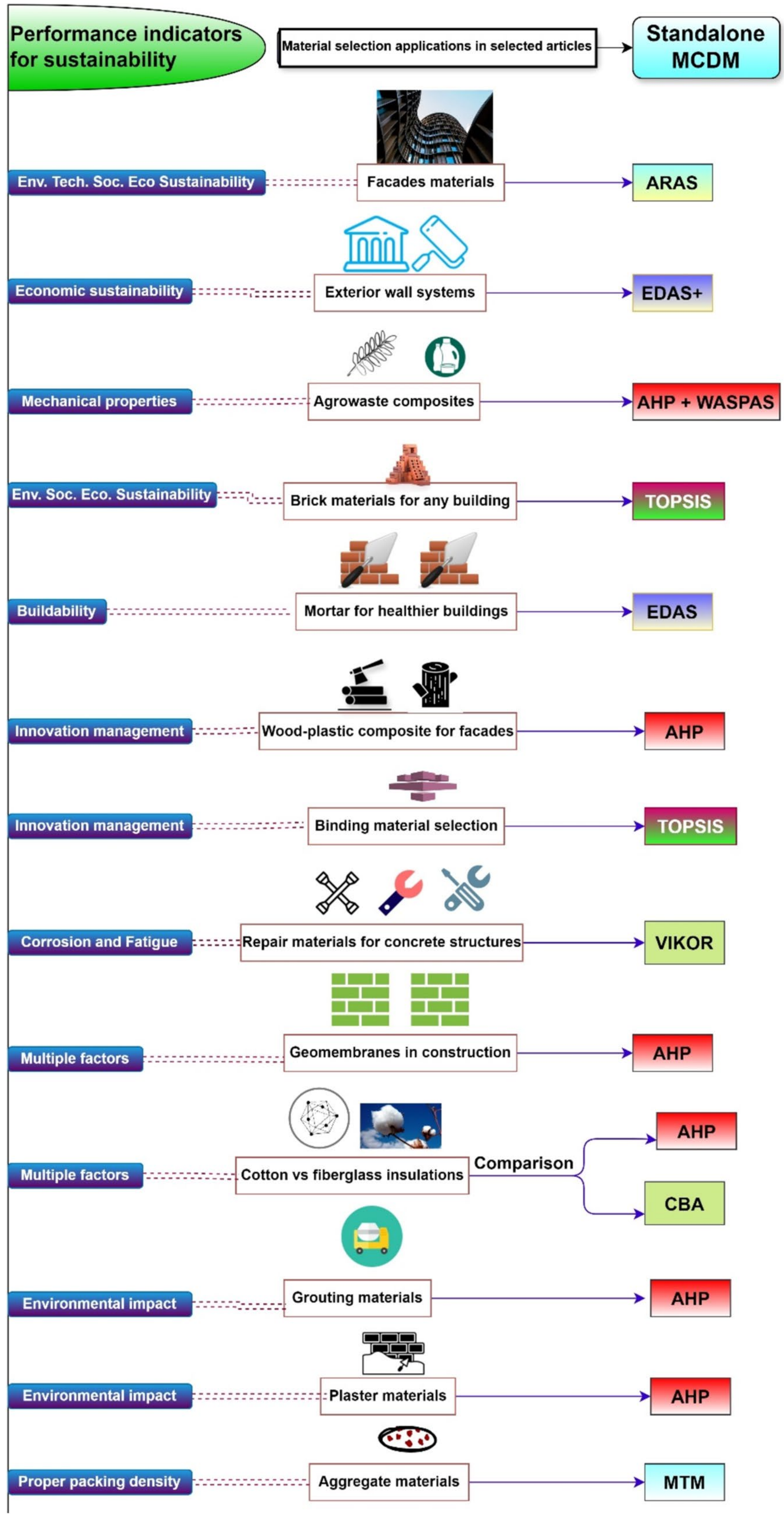


Fig. 15 Algorithm of the most common MCDM methods used in construction, adapted from (Beltrán and Martínez-Gómez 2019)

Fig. 16 Overview of standalone MCDM in multiple material applications



nomic, environmental, and social sustainability. These sustainability indicators have been further subdivided into subcategories shown in Fig. 16. Studies have not expressed the rationale behind using a particular standalone MCDM method, however, AHP was one of the most used standalone methods with applications in the selection of composite and insulation materials.

4.2.2.3 Hybrid or integrated MCDM An MCDM approach is hybrid or integrated when a decision problem is addressed by combination of two or more than two methods. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) with its comprehensiveness and robustness is the most connected method (Iqbal et al. 2021; Awate and Barve 2021; Reddy et al. 2022; Phong et al. 2017). The key applications of hybrid or integrated MCDM approaches are shown in Fig. 17**.** The hybrid approaches are useful for addressing broad indicators of sustainability.

4.2.3 Factors of influence

Most studies have addressed the three pillars of sustainability as factors of common interest while applying MCDM methods in the sustainable selection of materials (Fig. 18). Studies by Tian et al. (2018), (Mathiyazhagan et al. 2019; Beltrán and Martínez-Gómez 2019) indicate that sustainability (environmental, economic, and social) is a crucial factor in selecting the materials. However, the analysis of the included records revealed that technical factors also influence the decision problems of material selection (Yoris-Nobile et al. 2023; Kiani et al. 2018; Kumar Chilukuri et al. 2023). A decision support system (DSS) combining three methods AHP, VIKOR, and TOPSIS helped out select the timber materials (Alam Bhuiyan and Hammad, 2023). The same study notably defined the three pillars of sustainability as economic, social, and environmental sustainability. Kiani et al. (2018) sought the usefulness of the VIKOR method for best suited repair materials, however they also mentioned the significance of assigned weights to affect the reliability of results.

The future efforts can address the conflicting parameters and assigned weights through comparing more than one MCDM methods for reliable results. Packing density of concrete materials affected the performance of the concrete materials and Modified Toufar Model (MTM) supported the decision mechanism for choosing the appropriate source for optimal aggregate size and packing density in required proportions (Shah et al. 2020). It is interesting to note that most of the research work analysed in this study capitalised on multi-criteria decision systems to ensure the sustainability as a major goal in all the material selection decision problems (Di Ruocco et al. 2022, Zavadskas et al. 2018, Alam Bhuiyan and Hammad, 2023, Estévez et al. 2021, Mathiyazhagan et al. 2019, Khoshnava et al. 2018, Markatos and Pantelakis 2022, Hatefi et al. 2021, Taylor et al. 2023).

4.3 Limitations of MCDM

Lam et al. (2023) recognised that the effectiveness and flexibility of MCDM for material selection problems are crucial. Uncertainties arise when the factors are interdependent, and judgment about selection becomes complex (Arroyo et al. 2015). There are limited number of research records on the validation of the MCDM has not been performed and the MCDM applications has been more reliant on the opinions of a few experts (Aksakal et al. 2022). The feasibility studies are also limited on the decision making methods, its role is vital ensuring the effectiveness of these methods (Hatefi et al. 2021).

4.4 Future of MCDM

Studies have hinted at the inclusion of automation of MCDM methods. For example, an AI-based AHP will likely be fast-paced and informed for sustainable selecting material. A study has hinted connecting MCDM with Life Cycle Assessment (LCA) parameters to address the challenge of sustainability during material selection decisions (Churi and Biswas 2019). However, majority of the research articles using MCDM did not consider life cycle assessment (LCA) tools. This is a noticeable research gap explored in the chosen studies and require further research efforts in future. The consensus on the interpretation of sustainable construction may vary from one organisation to another, primarily when the opinions are based on individual respondents' expertise, so statistical tools are suggested to validate the results (Govindan et al. 2016). It is possible to create a support mechanism for helping the material selection scientists through integrated MCDM (Soni et al. 2023). There is abundant room to expand the applications of MCDM for green actions in construction (Khoshnava et al. 2018). Further research with more focus on the transparency of the MCDM could also be a focus of interest in future. Moreover, solutions devised through MCDM can be adapted at a broader scale for similar decision problems arising in other parts of the world, thus creating and consolidating the effectiveness of these methods in fragmented domains of the construction industry (Beltrán and Martínez-Gómez 2019).

4.4.1 MCDM and LCA integration for sustainable material selection

Life Cycle Assessment (LCA) and Multi-Criteria Decision Making (MCDM) integration is a powerful way of evaluating complex sustainability issues. The structured

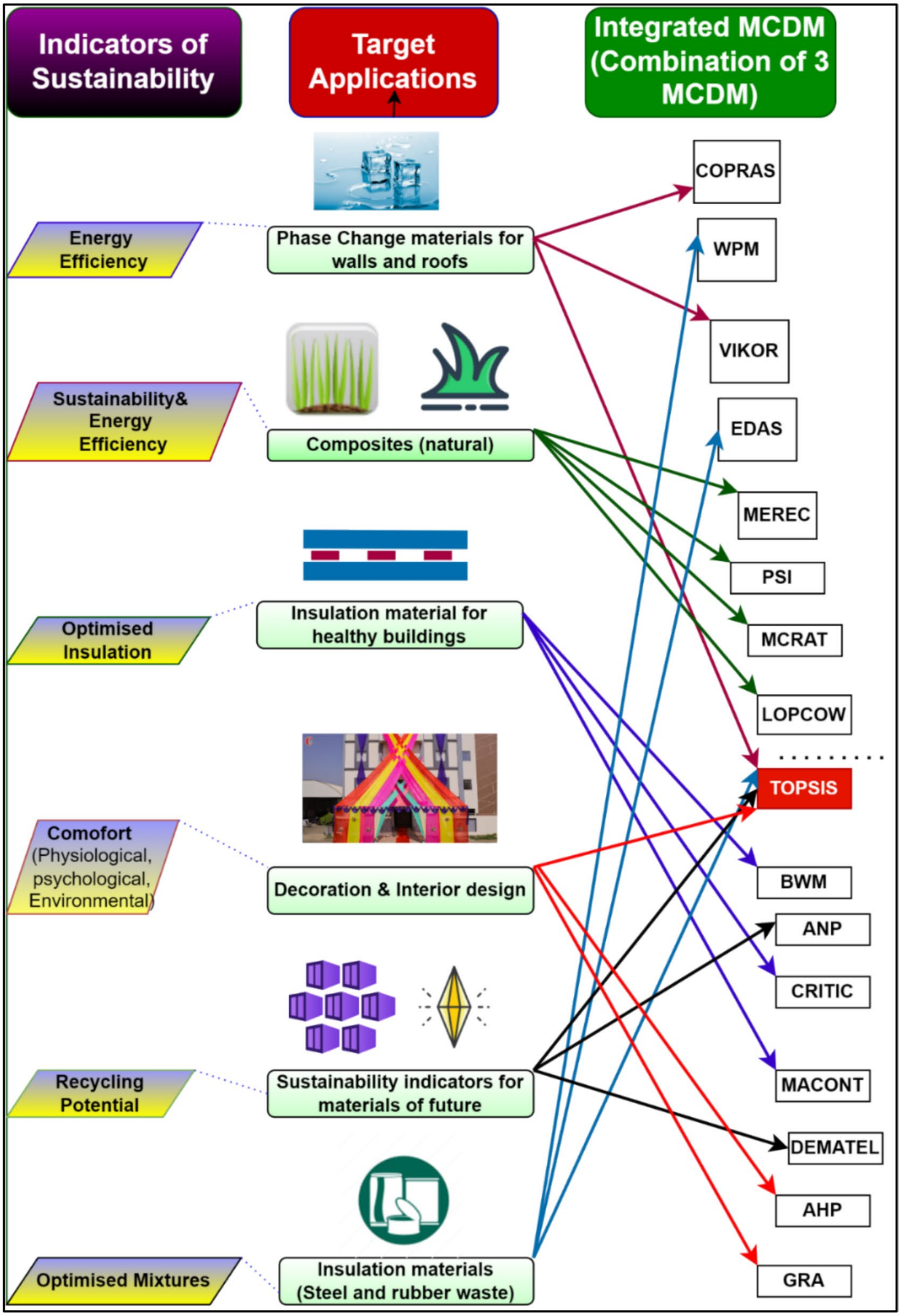


Fig. 17 Applications of Hybrid/Integrated MCDM for sustainable material selection

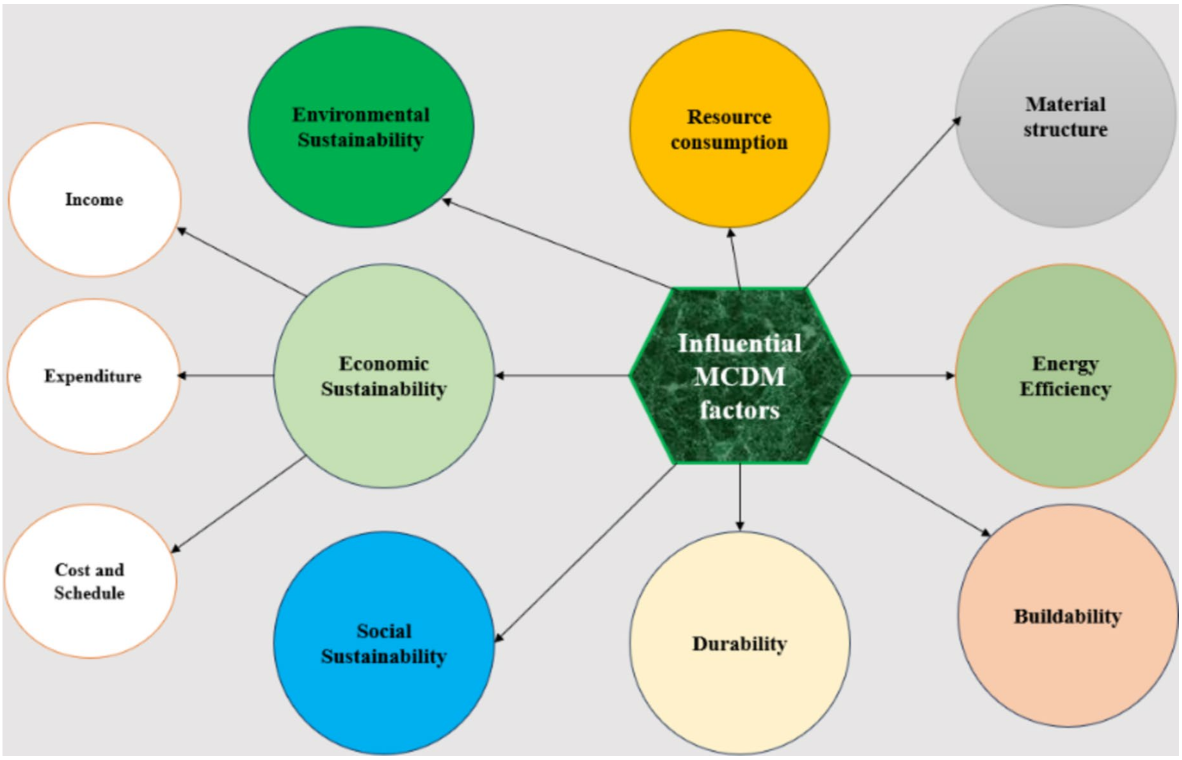


Fig. 18 Factors influencing the decision problems of material selection

framework offered by MCDM is essential to handle both quantitative and qualitative criteria at the same time needed for interpreting LCA results (Fig. 19). The combination provides decision-making processes that take into account an integrated manner environmental, economic, and social dimensions.

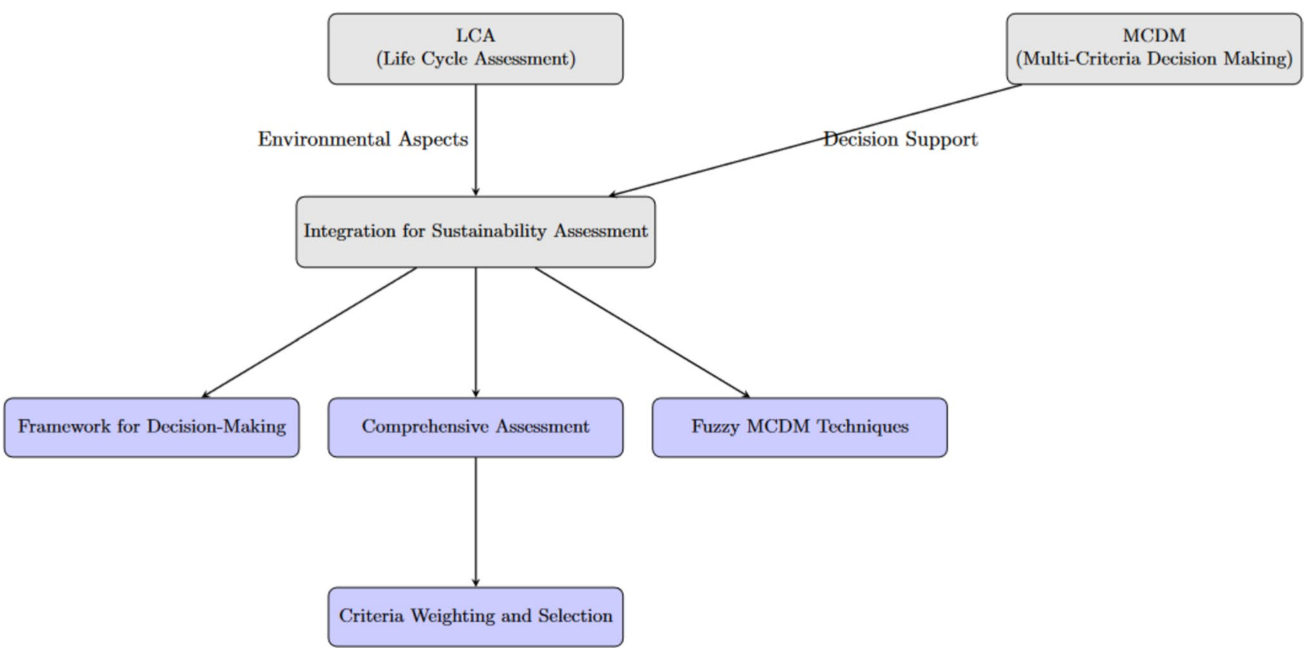


Fig. 19 Framework for potential integration of MCDM and LCA

By integrating MCDM with LCA, the holistic evaluation of building designs is possible, as applied to residential projects with ecological performance as a priority (Vollmer et al. 2024). Interpreting LCA results requires a consistent structure for decision making, which is possible through the application of MCDM. It supports environmental and sustainability assessments by helping to evaluate alternatives considering different criteria (Angelo, 2021).

The combination of LCA and MCDM produces a comprehensive evaluation of products and services at the same time considering environmental, economic, and social aspects. This is important in life cycle sustainability assessment (LCSA) as it helps to fit for a more comprehensive environmental sustainability evaluation (Dias et al. 2019). Fuzzy MCDM methods including fuzzy TOPSIS are used to provide better reliability for the assessments by incorporating time-based satisfaction and risk factors. This is especially appropriate to high-investment, long life cycle projects (Shao et al. 2024). The selection and assessment of criteria are one of the major challenges in coupling MCDM with LCA and can influence significantly the assessments (Dias et al. 2019).

5 Conclusion

This study presents a methodology for addressing the decision problem of material selection through MCDM. This approach utilised the PRISMA framework and *Bibliometrix* for Meta-analysis and thematic analysis. We showcased a combination of MCDM methods, relative specifications, frequency of utilisation, applications to multiple categories of materials, limitations, and direction for future work. The core objective of the MCDM problems appeared to be sustainability in several research studies. Our literature review approach uniquely considers evaluating MCDM methods like AHP, VIKOR, TOPSIS, COPRAS-G, MTM, BWM, and CBA as standalone and integrated to rank the alternatives. This review defined multi-criteria approaches to solve the conflicts among thresholds provided by different prediction models and certain constraints described by different regulations in different and diverse settings.

The limitation of this study is that it does not cover the specific segments of the construction industry for meta-analysis; for example, it views MCDM approaches for general construction industry applications towards decision problems on material selection but does not focus on meta-analysis of other categories like 3D printing, modular construction, and prefab construction. Another limitation of this study is that it needs to include the feedback of the industry stakeholders to draw a holistic picture of MCDM.

In summary, the systematic literature review probed into the competencies and potentials of Multi-criteria Decision-Making (MCDM) for sustainable material selection across diverse construction categories. The findings from 23 meticulously chosen studies and their corresponding MCDM methods reveal a cause-and-effect relationship between methodological choices and material selection outcomes. From exploring environmental assessment variables to ranking materials against comfort parameters, the research showcases the versatility of MCDM. Methodological nuances, including the integration of objective and subjective weights, the development of innovative approaches, and the emphasis on regional specificity, underscore the intricate role of MCDM in shaping decisions, and delivered in a simple manner to address the concerns of multiple construction industry stakeholders. This review will equip the building scientists, material engineers, sustainability experts, and policy makers with the essential knowledge of the standalone and hybrid MCDM methods.

Author contributions AURB contributed towards the research design, literature analysis, infographics, and main writing of the main manuscript text. CS and WS proofread, edited, and refined the review. MAN worked towards defining exclusion and inclusion criteria in the PRISMA framework.

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Declarations

Competing interest The authors declare no competing interests.

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