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Advancing Sustainable Material Selection in Construction: A Systematic Review of Multi-Criteria Decision-Making Applications

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ABSTRACT

Choosing sustainable materials for construction projects is essential to achieving global sustainability goals, as environmental challenges and economic and social issues continue to escalate. The research applies PRISMA methodology to identify and select of MCDM applications in sustainable material selection studies through a systematic review. The research analyzed 120 peer-reviewed papers to identify four main categories which included Site Selection, Infrastructure Planning, Sustainability Assessment, Performance Indicators and Supplier and Material Selection Decision Support Systems, Sustainable Materials and Construction Methods. The research shows that hybrid MCDM methods like AHP-WASPAS, MLCAQ and fuzzy TOPSIS are being used increasingly due to their stronger performance and ability to handle complex evaluation scenarios. Bibliometric analysis of co-authorship shows that there is close collaboration among researchers. New research directions are moving toward combining Internet of Things technologies with Artificial Intelligence systems. Future research agendas for sustainable construction should focus on the development of coherent sustainability assessment frameworks using practical tools that help professionals deliver sustainable construction projects with positive environmental effects.

1. Introduction

Selecting appropriate building materials for sustainable construction projects is a major obstacle. This is a complex process that has to depend on many criteria, including the environmental impact, the cost, the durability of the material and construction specifics of the project [3]. Because worldwide trends are increasingly concerned with sustainability and construction uses a large quantity of resources, energy and generates pollution [31], the choice of materials must consider social, environmental and economic consequences, in addition to the construction requirements [10].

To manage these complexities, Multi-criteria Decision-making (MCDM) methods can be utilized. These methods allow users to create systematic evaluation systems and analyze trade-offs, leading to better material selection [43]. Buildings produce large amounts of greenhouse gases and consume

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high amounts of resources, thus sustainable construction practices must be developed and used [45].

Recently, MCDM methods have been applied to material selection problems. In one study, a hybrid method employing the Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was used for material selection [6]. In addition, the MCDM method has been used for green building material selection based on life cycle assessment data, taking into account environmental, social, and economic dimensions. Likewise, the entropy-weighted TOPSIS model was formulated for the optimal selection of sustainable material suppliers [11]. This underlines the potential of employing MCDM to promote sustainable supply chains, and the applicability of MCDM to aid in material selection across various applications and constraints.

Besides these, there are contributions in the modes of digitalization and use of new technologies in MCDM models pointing to the prevalence of the trend towards data-driven decision-making. For example, Reddy et al. [38] proposed an entropy-based fuzzy TOPSIS approach for construction material selection under uncertainty. Furthermore, Nofal and Hammad [34] have applied MCDM methods to high-tech projects through fuzzy TOPSIS to select sustainable wall materials for smart buildings, focusing on energy efficiency and the use of IoT technologies. This applications show how MCDM methods can be employed to reflect current circumstances such as the use of technology and the characteristics of the region and project [3].

Decision making in sustainable construction can be represented through frameworks such as the Life-Cycle Sustainability Assessment (LCSA) which uses environmental, economic and social indicators to assess the sustainability performance of building products [26]. MCDM methods are used in decision analysis to help conflicting criteria converge to achieve a sustainable building outcome [12]. These theories can also be applied to the complex decision-making process of selecting materials in construction.

Despite this progress, research on these frameworks has often been restricted to specific applications. In addition, it has not considered emerging technological advancements such as artificial intelligence (AI) and the Internet of Things (IoT). Furthermore, many studies do not consider the scalability of MCDM frameworks to larger projects or their adaptability in different regions. Although a recent foundational review provided some perception into the development of the field, it covered only studies published until 2019; recent progress remains understudied [44]. Since then, many MCDM applications have emerged to address the challenges and developments in sustainable construction research and practice.

The significance for this research is founded through the pressing sustainability demands of material selection processes within the construction industry, which is a critical factor in global sustainability targets. The current practice of material selection processes within the construction industry is often poorly integrated in terms of environmental, economic and social aspects. This work not only shows the need for structured decision-making tools but also highlights the applicability of MCDM to sustainable development decision-making.

This review systematically synthesizes recent MCDM applications in sustainable material selection (2019 to 2023). The review addresses existing literature gaps and identifies trends in literature. It provides perceptions into recent developments in novel MCDM applications, regional customization of MCDM methods. In addition, it highlights the recent trend in the use of MCDM methods in large construction projects and their contribution to the progress of these methods in the construction materials sector. The importance of standardized sustainability metrics, adaptive decision-making processes, and advanced tools such as IoT and artificial intelligence is stressed for improving the material selection process. The results are relevant to engineers and architects that need formal decision support, policymakers responsible for devising measures of sustainability, and academic researchers studying new technologies for sustainable building and global sustainability.

This review informs engineers, architects, policymakers, and sustainability practitioners about recent MCDM advances and their role in advancing sustainable materials and methods in construction. Moreover, the study provides recommendations for future research related to the digitalization of the construction sector, the development of standardized sustainability assessment metrics, and the implementation of adaptive measures to address emergent issues.

The paper is structured as follows. The second section focuses on the methodology, including the PRISMA procedure followed in the systematic review and the bibliometric methods used in the study. The third section identifies themes outlined in the literature. Section 4 describes the findings and the gaps throughout the research field, as well as outlining the future directions. The report is concluded in Section 5 by a summary of the findings and implications for sustainable construction.

2. Methodology

The research design involves gathering and analyzing literature from previous studies to examine the application of MCDM in the sustainable building material selection process. The sequence of this process comprises four stages, which are defined as follows.

2.1 Literature retrieval

The Scopus database was used as the literature search engine for the current study, as it is widely recognized as one of the largest abstract and citation databases covering a range of peer-reviewed research, including journals, conference proceedings, and books records [9]. The literature search identified a wide variety of academic literature: journal articles, review articles, e-books, book chapters, conference papers and other previously conducted literature reviews. The search was performed in the Scopus database using the following keywords: ("MCDM" OR "material" OR "resource" OR "selection" OR "green" OR "sustainable" OR "construction" OR "multi" OR "criteria" OR "decision" OR "making"). The title, abstract and keywords sections of the publication were screened and filtered to return specific and related publications' results.

2.2 Literature screening

The PRISMA guideline, shown in Figure 1, was selected for the literature screening. It offers a transparent systematic approach for reviews or meta-analyzes. After duplicates were removed, a total of 147 publications remained like shown in Figure 1.

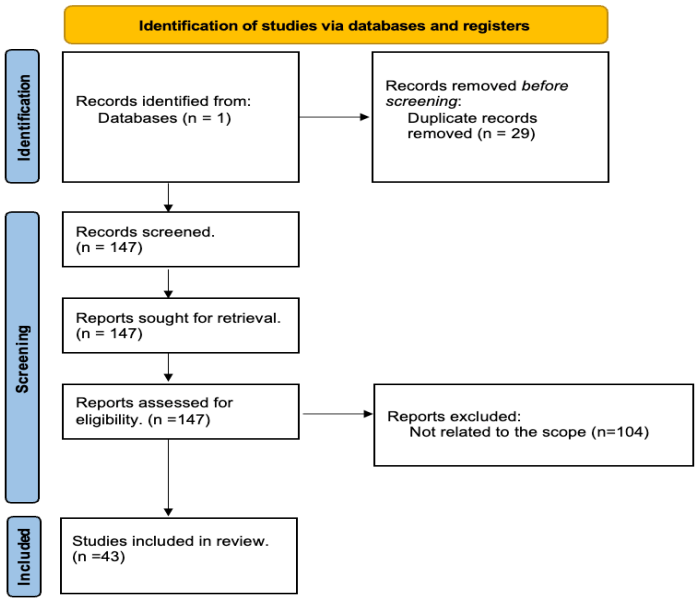

Fig.1: Methodology for Literature Screening

The final step excluded non-relevant articles, all books and conference papers. Thus, the final number of studies under review totaled 43. Details of the literature screening method and selected publication years are shown in Figures 1 and 2.

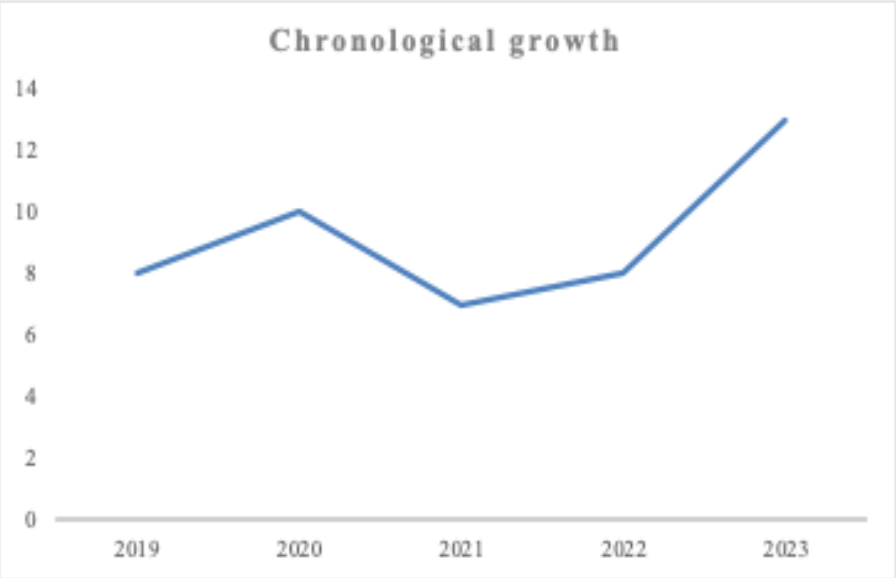

Fig.2: Chronological growth of research publications

2.3 Content Analysis

A systematic analysis of the publications was conducted, and the data were classified into categories to identify key topics. The methodology involved classifying studies into distinct themes, enabling a clearer understanding and more robust conclusions regarding the insights derived from the literature.

2.4 Bibliometric Analysis

The bibliometric analysis considered a total of 43 studies that analyzed MCDM methods for selecting sustainable materials and provided mapping applications using the visualization tool VOSViewer. The evaluation at this stage consisted of six parts: author identification, distribution of research among countries, keywords, document types, interpretation of the area, and research methods. The bibliometric analysis provided valuable insights into the trends, patterns, and collaborative networks within the selected body of literature.

3. Content Analysis

The importance of sustainable construction practices has gained significant attention, addressing the environmental, economic, and social impacts of modern infrastructure projects. Research studies employed decision analysis models such as MCDM techniques to optimize material selection and operational planning. The following section evaluates sustainable construction practices through different key themes.

3.1 Site Selection and Infrastructure Planning

This section explores the different multi-decision analysis models that have been utilized to make site selection or infrastructure planning decisions. The papers in Table 1 receive classification based on their primary research emphasis.

Table 1
Site selection and infrastructure planning

Authors	Year	Focus
[18]	2022	Systematically selected suitable sites for temporary housing post-earthquake in Isfahan, Iran, identifying 60% of the area as exposed and proposing vacant lots, stadiums, and public green spaces for temporary settlements.
[16]	2020	Proposed a method for selecting sustainable packaging materials, utilizing an integrated DELPHI and fuzzy-PROMETHEE approach, validated by sensitivity analysis.
[28]	2019	Evaluated and selected short-span sustainable bridge designs in Brazil, identifying mixed concrete/steel bridges as the most sustainable option, considering environmental impact, cost, and lifespan. AHP and VIKOR were implemented.
[4]	2023	Applied systemic circularity principles to select optimal partition systems for modular buildings with a focus on the circular economy. The systems chosen were notable for their high recyclability and low CO2 emissions, although the prototype for systemic circularity was identified as needing further improvement. The VIKOR method was employed in this study to support the evaluation process.
[46]	2023	Enhanced ELECTRE II for multi-criteria group decision-making by incorporating Z-numbers and group consensus models. The novel HFLT-Z-h-ELECTRE II approach effectively managed group divergences and vague information, improving decision-making in sustainable construction material selection.
[19]	2020	Selected the most suitable phase change materials (PCMs) to enhance indoor comfort in buildings by using a hybrid target-based MADM method that considered both technical and managerial factors. This approach revealed how these different criteria are interconnected throughout the decision-making process.
[32]	2023	Used multi-criteria analysis combined with the VIKOR ranking method to evaluate geopolymer bricks produced via solar drying, and compared their performance with other types such as clay, cement, bio, and eco-friendly bricks. The findings, based on both experimental and analytical data, showed that the geopolymer solar-dried bricks outperformed the alternatives.
[35]	2022	Located and evaluated potential sites for a PV solar power plant in Khuzestan province, incorporating fuzzy logic and decision analysis.
[8]	2020	Modeled fleet planning in aviation, incorporating risk management and resource dependency perspectives to achieve sustainable organizational performance using AHP.
[39]	2023	Addressed the challenge of selecting suitable sites for subsurface dam construction, emphasizing GIS techniques and decision-making processes for sustainable water resource management.
[20]	2022	Developed a decision-making system for selecting urban railway routes using AHP, considering socio-economic and technical criteria for sustainable urban transportation.
[7]	2023	Investigated desalination plant locations in the Caspian region, emphasizing multi-criteria decision-making for sustainable construction.
[36]	2023	Selected pilot cities for "zero-waste city" construction in China, using a multi-attribute decision-making model for sustainable development.
[21]	2020	Created a theoretical model for selecting resettlement sites in reservoir structure, utilizing the Pythagorean fuzzy MULTIMOORA method for decision-making.
[22]	2021	Addressed a solar site selection problem in eastern Iran by proposing a hybrid MCDM approach that uses BWM for criteria weighting, GRA and VIKOR for ranking, and a Monte Carlo-based sensitivity analysis, identifying Birjand, Sarbisheh, and Khezri as optimal locations with VIKOR showing higher robustness.

The papers in this section discuss decision support systems for site-selection and infrastructure planning that consider multi-evaluation criteria. Sustainable infrastructure can be developed only through the application of efficient decision-making systems. The identified papers highlighted decision analysis models applied to the problems of site selection, solar power plant siting, subterranean dams' construction, and urban railway networks design indicating how these models can help support creating sustainable infrastructure projects. The models provide decision-making frameworks for practitioners in selecting temporary shelter locations, sustainable bridge locations, solar power plants, and modular building circular economy strategies. The models outperformed similar studies by integrating geographic information systems (GIS) and decision-making processes. The models also offer operational solutions for numerous infrastructure creation problems.

Furthermore, these studies identified focus areas for further investigation in the environmental,

economic and social aspects of sustainability, with the absence of an integrated framework for sustainability performance indicator creation for different types of infrastructure construction and development projects noted as an important gap in the existing body of literature. Further research is needed for developing common sustainability assessment criteria for infrastructure projects, so that these projects can be assessed on a similar basis.

Moreover, many studies focus on static models in which criteria are assessed using fixed information and parameters. Future research might explore the prospects for dynamic decision support systems that adapt to new information and changing conditions. Such adaptive decision support systems may be able to take environmental, economic and social changes into account in planning infrastructure projects.

Finally, although some studies include socioeconomic criteria, social and cultural factors. such as community attitudes, local practices, and social dynamics. remain underexamined. Future research should look more closely at how these factors shape project acceptance and long-term success, especially for sustainable infrastructure in community settings.

3.2 Sustainability assessment and performance indicators

The review revealed that a variety of sustainability assessments and performance indicators have been employed in sustainable material selection, utilizing MCD methods, as shown in Table 2. Therefore, it is crucial to evaluate these indicators and the importance they hold in choosing sustainable materials.

Table 2
Sustainability assessment and performance indicators

Author	Year	Focus
[30]	2023	Outlined how "smart" design and technology enhanced building user-friendliness, security, and energy efficiency while proposing a model to assess public buildings' "smartness" through six categories with consistent ranking methods.
[33]	2020	Selected optimal interior wall materials using a sustainable decision-making framework that included environmental, financial, social, and technical criteria.
[15]	2019	Developed a quantitative framework to evaluate pavement design for robustness and reliability.
[47]	2023	Discussed eco-friendly materials and insulation, proposing a hybrid model to assess their energy use and environmental impact.
[5]	2019	Applied a four-bottom-line approach to sustainable construction in India to create a tool for material selection in developing countries.
[48]	2020	Established a decision framework for assessing the sustainability of load-bearing structures during early design phases.
[50]	2021	Highlighted a robust and adaptable methodology for evaluating the integration of construction and destruction waste within sustainable waste management.

The papers reviewed reveal many critical gaps. Many of them highlight the importance of bioclimatic design, the use of ecological resources, smart metering technologies, and renewable energy systems for building sustainable and intelligent buildings. Several frameworks have been used, including the consideration of sustainability in decision making for high-rise residential buildings and frameworks for the selection of pavement designs and construction methods for roads and other pavements combining resilience with sustainability. Furthermore, MCDM methods improved material selection by enabling sustainability assessments of alternative structural solutions in the initial design stage.

On sustainability assessment and performance indicators, the paper identified that a key area for development is exploring the automated selection tools' ability to make decisions about structure elements in alternative load-bearing systems. Another suggestion is to improve data interoperability

between the various software tools used for completing sustainability assessments of these materials, allowing for better integration and collaboration.

To provide a broader view, Figure 3 presents publications based on different sustainability criteria in the field of sustainable construction. Most papers are published on the environmental aspect, as environmental aspects are the most prominent ones within the subject of climate change and conservation. The economic factor includes questions about cost efficiency and the lifetime of the construction project. The small number of publications on social and technical factors such as social benefits indicate that this subject is considered, although not as relevant to the environmental and economic factors.

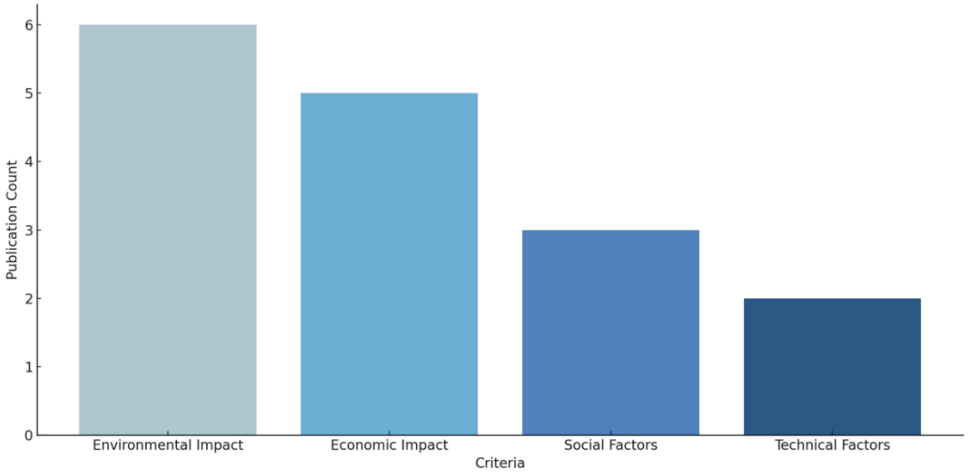

Fig.3: Sustainability Assessment Indicators

3.3 Supplier and Material Selection Decision Support Systems (DSS)

Within the analysis of Decision Support Systems (DSS) in sustainable material selection, it was found that supplier and material selection using MCD methods is a key theme, as illustrated in Table 3.

Table 3
Supplier and material selection decision support systems

Author	Year	Focus
[29]	2019	Developed a hybrid MCDM model for choosing sustainable providers in a construction company's supply chain.
[49]	2021	Created a CoCoSo/FAHP-based model for biomass furnace supplier selection in Vietnam.
[26]	2021	Focused on a decision support concept integrating AHP and PROMETHEE for sustainable contractor selection in construction.
[3]	2023	Developed a DSS for selecting sustainable structural materials for multistory buildings, validated through an eight-story case study using AHP-TOPSIS-VIKOR.
[25]	2020	Proposed a multi-criteria model for sustainable provider selection in construction, with the use of SWARA and DNMA with hesitant fuzzy linguistic terms and validated via sensitivity analysis.
[24]	2023	Presented a hybrid fuzzy MCDM method for sustainable circular supplier selection, applying the circular economy model to enhance industry practices.

The review of these papers highlighted several key points and insights. The implementation of the rough Dombi aggregator and sensitivity analysis has confirmed the ability of the new model to assess suppliers based on 21 sustainability criteria. The proposed model integrates qualitative and quantitative components. This was the first successful application of hybrid decision-making in the context of supplier selection. Thanks to innovative technologies, an organization can choose the suppliers who are most appropriate for it, easing smart ordering, better performance, and a reduced ecological footprint. The use of DSS for the selection of contractors makes it possible to consider the

different inputs of the stakeholders, increasing the transparency, repeatability and quality of the process. Another study showed that DSS can improve the objectivity and consistency of decision making in sustainable construction. The proposed hybrid fuzzy MCDM framework provides a systematic approach for the selection of sustainable and circular contractors to save resources.

Many opportunities exist within supplier selection and supplier material selection decision support systems for future research, such as the impact of new technologies on supplier selection and smart ordering, the most effective stakeholder participation and the way and means to maximize the decision outcome. The hybrid fuzzy MCDM methodology has the potential to provide a structured decision-making framework for construction projects, and further research is required to test its effectiveness and applicability in practice. Addressing these gaps will further develop MCDM methods and decision support systems in a broader range of contexts in sustainable construction.

3.4 Construction Methods and Sustainable Materials

The review of sustainable materials and construction methods reveals that MCD methods are widely utilized in sustainable construction, as summarized in Table 4.

Table 4
Sustainable materials and construction methods

Author	Year	Focus
[27]	2019	Proposed a three-phase sustainable assessment model for Indian construction, evaluating 23 triple-bottom-line sub-criteria and ranking materials using Best Worst and Fuzzy TOPSIS methods.
[37]	2020	Employed MCDM techniques for selecting recycled aggregate concrete (RAC), finding RAC offers cost savings, lower CO2, and improved conservation despite reduced compressive strength.
[42]	2023	Developed an AHP-WASPAS model for ranking waste-plastic composites, identifying a rice husk ash and PEEK composite as optimal, aligning with circular economy principles.
[1]	2019	Introduced a decision-support framework for selecting sustainable SCMs, prioritizing technical characteristics using OSM, AHP, and TOPSIS, with siliceous and agricultural waste rated highly.
[2]	2021	Identified criteria for selecting green building materials for sustainable building projects in Malaysia.
[40]	2020	Presented a decision-making framework for optimizing cement replacement materials in concrete.
[29]	2022	Selected low-carbon materials for Indian construction using generalized fuzzy information (GFI).
[14]	2019	Focused on obtaining optimal unconventional wall-building material, this paper used multi-criteria decision-making methods to identify a paper pulp brick as the best solution, leading to a conceptual design for a residential building based on this material choice.
[13]	2019	Created a hybrid decision-making model for material selection under uncertainty using basic uncertain linguistic information.
[41]	2023	Developed MLCAQ for comparing material alternatives on environmental and economic impacts, validated on construction materials.
[17]	2022	Designed five concrete mixes with standard and alternative binders to assess environmental and cost performance for sustainable material choices.

Most of the papers reviewed focus on the assessment, selection, and optimization of GBMs and RAC as building materials, highlighting them as one of the major building materials used in green construction. The sustainable materials presented included aluminum composite panels, solar roof tiles, and new composites made from waste plastics and agro-industrial residues. Furthermore, these studies show the potential of these materials to reduce environmental emissions, natural resource consumption, and environmental impacts. The reviewed studies mainly contribute by including decision support frameworks and MCDM approaches, such as the AHP-WASPAS and the MLCAQ methodology. They play an important role in enabling the selection of green materials based on technical, environmental, social and economic criteria to lead the construction sector to a more sustainable and cost-effective practice.

Nonetheless, several gaps remain. The lifecycle assessment, long-term performance assessment,

and the durability and sustainability of green building materials need additional experimentation. The practicality and feasibility of building materials, approaches and designs for the construction of green buildings in different regions and climatic conditions also need additional research and assessment. As such, further efforts are needed to assess these decision-support tools in practice. Another potential research avenue is evaluating alternative low-carbon cementitious materials and testing their usage in large-sized construction projects. Bridging these gaps will be critical for developing inclusive, cross-sector sustainable construction solutions and knowledge systems that are fairer and smarter.

Through this review, different kinds of decision-aid models are presented, and the ways they can enable a more sustainable outcome of site selection and infrastructure development in a variety of construction projects are shown. Figure 4 outlines the various themes of sustainable construction decision making explained below. The obtained keywords are categorized into four thematic areas: Site Selection and Infrastructure Planning, Sustainability Assessment and Performance Indicators, Supplier and Material Selection Decision Support Systems, and Sustainable Materials and Construction Methods. The circles representing the research areas depict the degree of research interest on these topics, thus providing a visual representation of the content analysis.

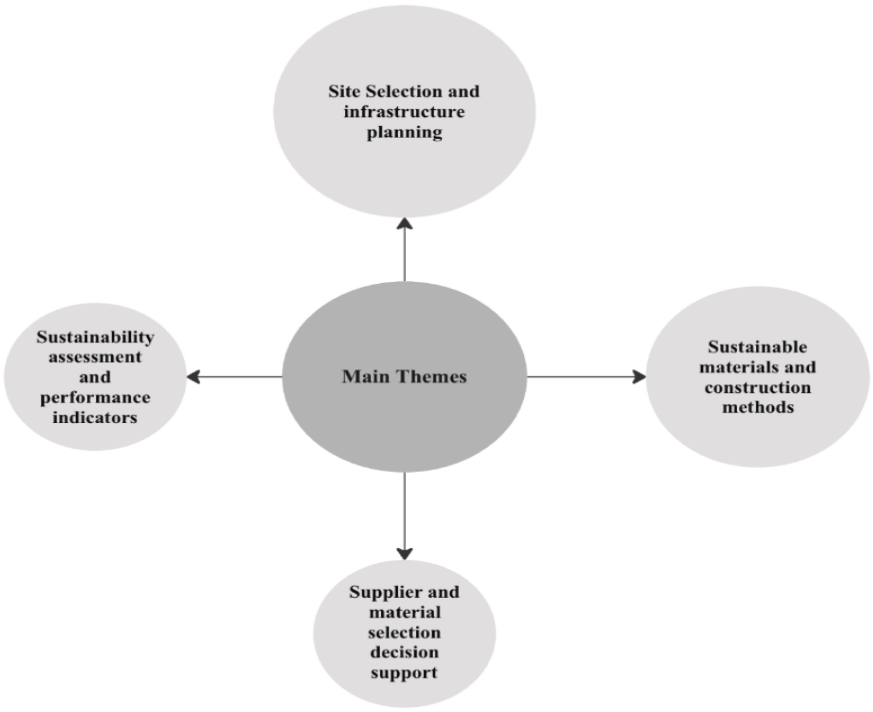

Fig.4: Summary of identified research themes

These approaches, particularly MCDM models, incorporate environmental, economic, and social criteria in alignment with global sustainability agendas in their design. Furthermore, the use of geographic information system (GIS) and other methodologies can further enhance models with data-driven and flexible solutions. However, there is still a need for standardization sustainability metrics and improving data interoperability. Cultural and social aspects should be better considered to provide a more holistic approach to assessing sustainable construction practices. Furthermore, as presented in Figure 4, further research could be carried out on the integrative frameworks uniting these constructions and how it could be applied within sustainable construction projects. Additionally, the themes represented in Figure 4 indicate opportunities for further exploration, especially in developing integrative frameworks for practical applications in sustainable construction projects.

4. Bibliometric Analysis

This section provides a bibliometric analysis to collect and highlight the most important and relevant studies analyzing the application of MCDM methods in the material selection process in the construction field. To have a general view of the recent studies on the selection of materials with MCDM methods, VOSviewer software was used to extract five different types of maps. In these maps, the size of circles for authors, countries, keywords, etc. shows researchers' activity in a specific field of study (larger circles reflect more activity while smaller ones reflect less activity) [23]. The closer the two circles are, the stronger the relationships between the two entities, whereas if the circles are farther away, the relationship is weaker.

4.1 Map of Co-occurrence based on text data

Text data from 43 publications was analyzed to extract key material construction terms from titles and abstracts. A co-occurrence network identified 50 out of 1,861 terms with at least two occurrences, shown in Figure 5.

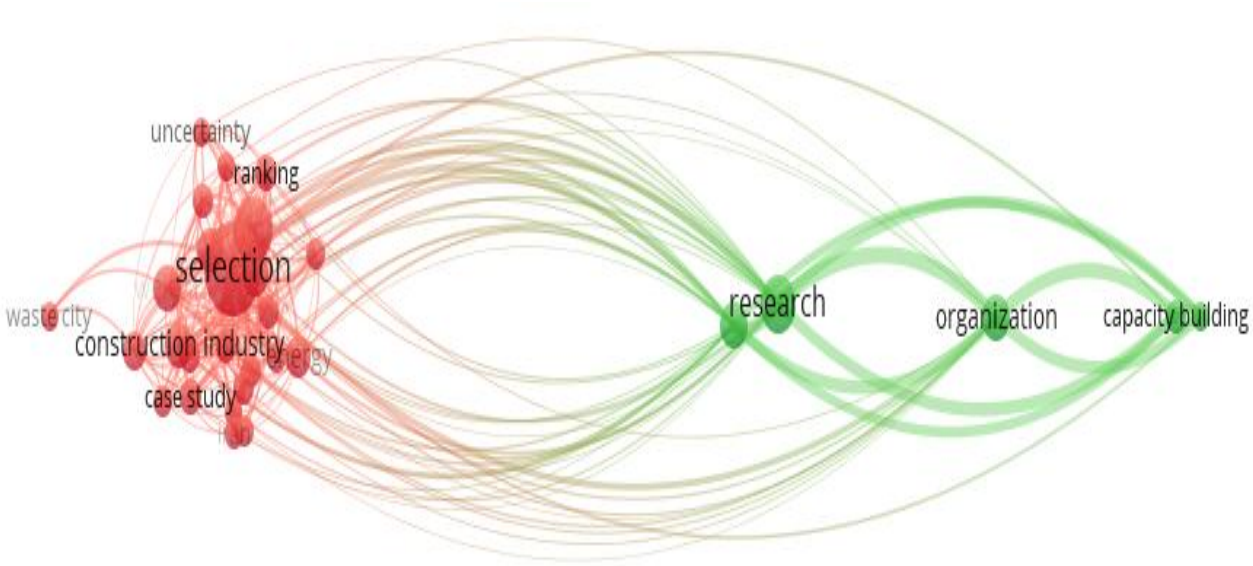

Fig.5: Co-occurrence map derived from text data

Figure 5 presents the network map of the keyword for the research study on material selection in the construction sector. The terms are illustrated in two different clusters in the network map (the red nodes and the green nodes). The red cluster with the keywords "selection", "construction industry", and "criteria" refers to the methods and standards implemented for material selection in construction. In contrast, the terms from the green cluster (e.g., 'research', 'organization' and 'capacity building') suggest a wider organizational and research background supporting the material selection practices. The proximity of the two clusters suggests an interplay between the selection criteria in use and the broader organizational and research implications of material selection practices.

Further analysis involved uploading a thesaurus file to VOSviewer to remove duplicate terms. This process yielded 1,855 terms, with 32 meeting the minimum of eight occurrences. VOSviewer calculated relevance scores, and the top 60% were selected, resulting in a network comprising 19 terms, as displayed in Figure 6.

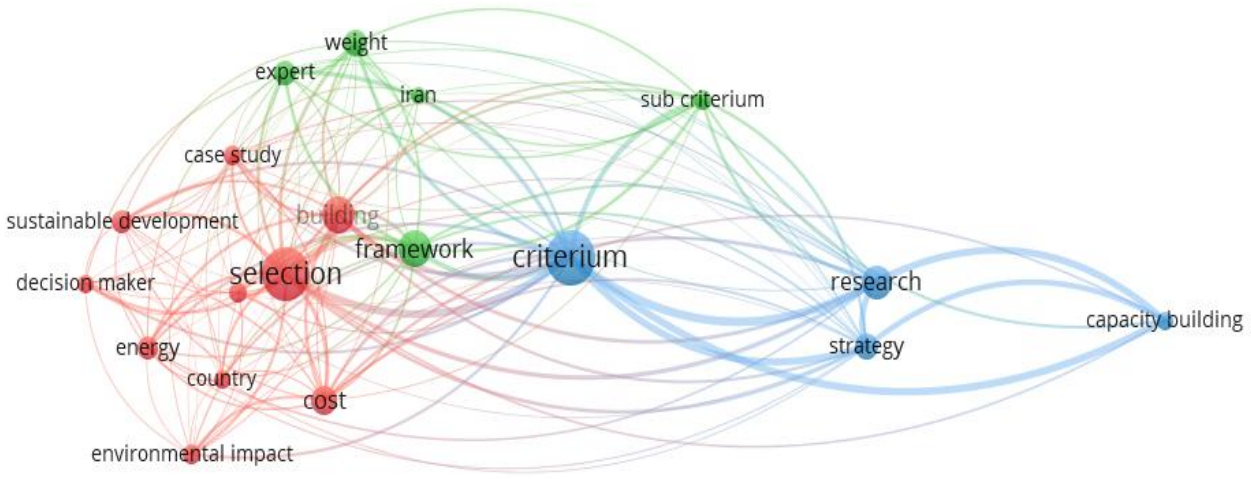

Fig.6: Co-occurrence map based on refined text data

In figure 6, the co-occurrence network map of the main search terms for material selection in construction, shows that the red cluster concentrates mainly on practical issues regarding material selection, such as the terms "selection", "cost", and "environmental impact". Clear economic and sustainability orientation can be identified with the choice of material. The green cluster including "framework", "weight" and "sub-criterion", on the other hand indicates methodological and criteria-related decision making. The general terms within the blue cluster like "research", "strategy" and "capacity building" refer to the planned and organizational aspects of the material selection process. The connection of the clusters again shows the interplay of the practical, methodological and planned aspects and therefore highlights that multidisciplinary research is important in selecting sustainable construction materials. Some larger nodes such as "selection" and "criterium" are indicative of the topic's importance.

Table 5 shows the ten most frequent terms, the number of times the terms were used, and the terms' weight in the VOSviewer.

Table 5
Top 10 terms by occurrences

Rank	Keyword	Occurrences	Total link Strength
1	capacity building	9	2.5771
2	decision maker	9	1.6737
3	sustainable development	13	1.3945
4	research	28	1.3509
5	mcdm	10	1.2797
6	environmental impact	10	1.2714
7	strategy	17	1.1302
8	country	9	1.0973
9	energy	14	1.0648
10	case study	11	0.8121

This table shows that the term with the highest frequency, "capacity building", is also the term with the highest relevance score, 2.577, indicating that capacity building is the most prominent topic in terms of relevance in the studied domain. The second highest term is "decision maker". This indicates its relevance to sustainable material selection. The term "research" points at the importance of academic investigations for the domain under study, while the inclusion of terms like "decision

making" and "strategy" specifies the methodological aspect of the sustainable material selection process.

4.2 Co-occurrence map based on keywords

Examining the bibliographic data of the selected papers revealed commonly used keywords. Out of 495 unique keywords identified, only 60 met the main threshold of at least two occurrences. The keyword map is shown in Figure 7. This analysis includes author and index keywords.

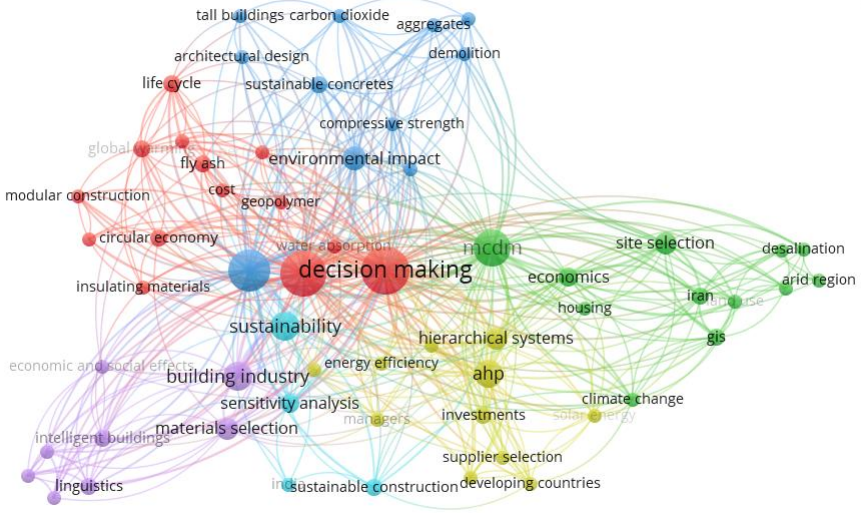

Fig.7: Map of all keyword co-occurrences

A keyword co-occurrence network map of the most frequently used keywords in material selection for sustainability literature is presented in Figure 7. The central keyword in the red cluster is "decision making". The cluster includes sustainability, environmental impact, and building industry, suggesting a decision-based approach for sustainable construction. Economics also is a theme in the green cluster, with words like "economics" and "site selection". Methodological approaches include hierarchical systems, AHP, fuzzy sets theory, and multi-criteria analysis. The interlink between the clusters illustrates different interdisciplinary aspects of sustainable material selection, including environmental, economic, practical, and methodological aspects.

The keyword frequency analysis revealed that the most used keywords were "Decision Making", "Sustainable Development", "Building Industry" and "Sustainability", among others (see Table 6, for the 10 most used keywords). In addition to the number of occurrences of keywords, the overall link strength (total link strength) is used. The total link strength represents the amount of linkage that a keyword has to other keywords via co-occurrence of keywords.

Table 6
Top 10 keywords by occurrences

Rank	Keyword	Occurrences	Total link Strength
1	decision making	24	157
2	sustainable development	22	142
3	construction	18	115
4	mcdm	14	98
5	building industry	9	37
6	sustainability	9	32
7	ahp	8	54
8	environmental impact	6	40
9	hierarchical systems	5	39
10	materials selection	5	26

To expand the scope of the investigation, two additional keyword maps were developed. The initial map displays the most common author keywords, each of which appeared at least twice. This criterion led to 22 author keywords displayed in the network illustrated in Figure 8.

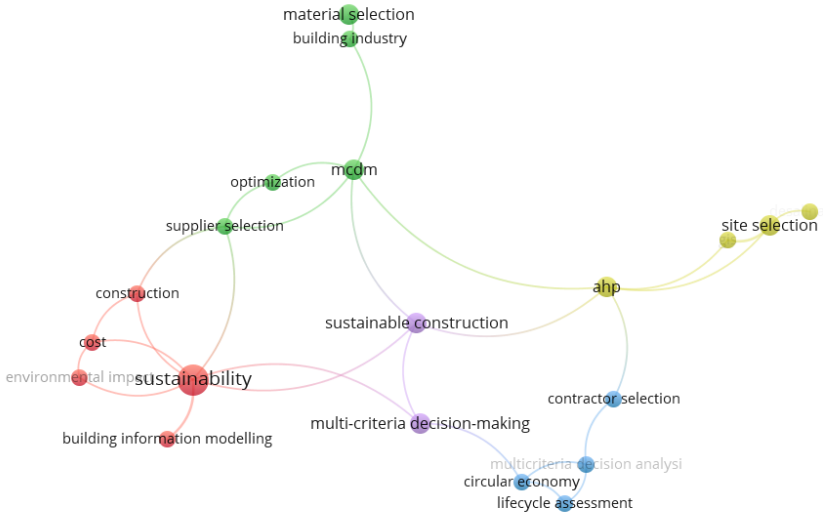

Fig.8: Co-occurrence map of authors' keywords

Figure 8 maps the different research topics related to sustainable material selection. Three central research topics are identified: "sustainability", "material selection", and "multi-criteria decision-making". Red cluster focuses on sustainability aspects to balance the environmental and economic issues, including topics like "environmental impact", cost, and "building information modeling". For the green cluster, material selection and optimization have been the focus, particularly the sustainable supply chain efficiency in the construction sector. The yellow cluster deals with AHP, aiding in making decisions on site location and material selection. The blue and purple clusters are related to circular economy and MCDM techniques in selecting contractors. A similar map was created to describe the most frequently cited index keywords based on two or more occurrences. Out of the 386 index keywords, only 59 are included in the map (shown in Figure 9).

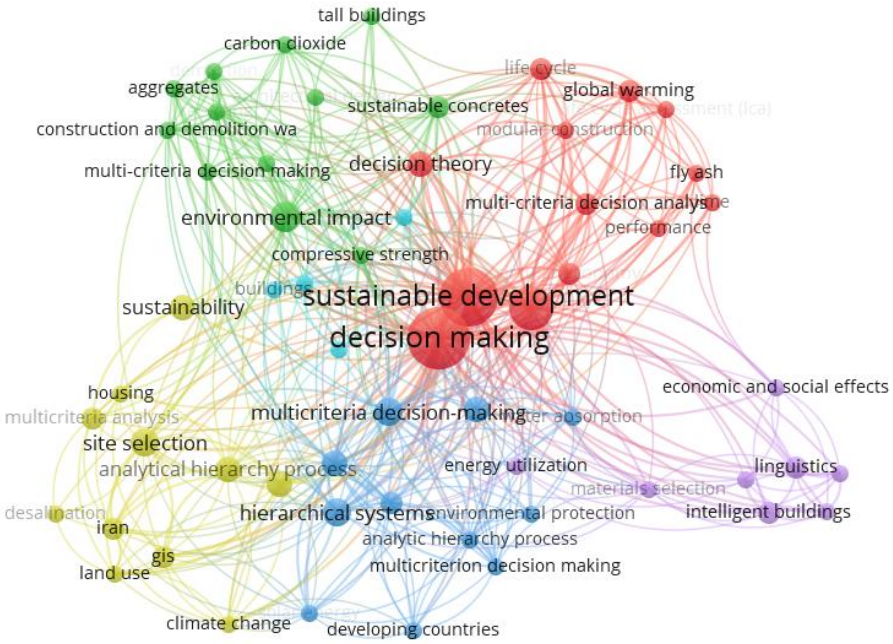

Fig.9: Co-occurrence map of index keywords

Figure 9 outlines how the terms discussed in this paper are related to each other. Sustainable development and decision making are the center of the image. Clusters are characterized by lines of colors indicating their thematic similarity. The red cluster includes global aspects such as "global warming", "economic and social effects" and the green cluster include environmental aspects such as "environmental impact" and "carbon footprint". Blue cluster includes terms associated with decision-making, such as "multi-criteria decision-making" and "hierarchical systems". Yellow cluster includes terms associated with urban planning such as "climate change" and "land use". The technology-related purple cluster includes "artificial intelligence" and "intelligent buildings". The dense network of connections underscores the interdisciplinary nature of sustainable development, where economic, environmental, social, and technological considerations are all interconnected, reflecting the need for integrated approaches in sustainability-related decision-making.

4.3 Co-Occurrences Map Based by Country of Co-Authorship

This section examines co-authorship distribution by geography. The map was created by identifying countries that have at least two publications and among 31 countries, 17 of them are connected to others. The network is illustrated in Figure 10.

Fig.10: Country of co-authorship

Figure 10 presents the co-authorship network generated by countries in the topic of sustainable construction. Iran has the highest number of ties with countries such as Saudi Arabia, Serbia, and Turkey in this network. This also shows regional cooperation. China is a key player, especially with Saudi Arabia and Iran. For example, Serbia and Turkey have a strong two-sided connection, indicating a focus on the intersection of Europe and Asia. In contrast, Indonesia and Spain have weak two-sided connections, indicating selective partnerships. These links of global awareness about sustainable materials and collaboration based mostly in Asia and the Middle East create a worldwide networked community of shared knowledge.

Countries with the most connections are also shown in Table 7. The 10 countries listed below have the most impact on research related to the selection of sustainable materials. As evidenced, selection of sustainable materials is an international topic and research has worldwide impact. Spain was the second most productive with 6 papers published in these subcategories and 198 citations. The country with the highest total link strength was China with 7 papers and 11 link strength. Other countries with a similar relatively high degree of relatedness are for example Lithuania and Hong Kong. While the United States and Canada maintain moderate collaboration levels, their influence is notable through substantial citation counts. Taiwan, Poland, Bosnia and South Africa contribute a relatively small number of publications, but these countries still represent emerging contributors to the global network of research on sustainable construction practices. This reflects the growing geographic expansion of the field of sustainable development research in both developed and developing countries.

Table 7
Top 10 countries ranked by link strength

Rank	Country	Documents	Citations	Total link Strength
1	China	7	181	11
2	Spain	6	198	10
3	Lithuania	6	163	9
4	Hong Kong	4	162	8
5	Canada	3	89	8
6	united states	3	63	7
7	Taiwan	2	56	7
8	Poland	2	56	6
9	Bosnia	2	90	5
10	South Africa	2	90	5

4.4 Article Sources and Data Analysis

To identify the sources of the 43 publications, a summary list of each unique source was created. The articles were then mined from 11 different sources in decreasing order of frequency. The Sustainability (Switzerland) and the Journal of Cleaner Production were the most common with 9 and 7 publications, respectively. Figure 11 shows a bar graph of the number of publications per each top source.

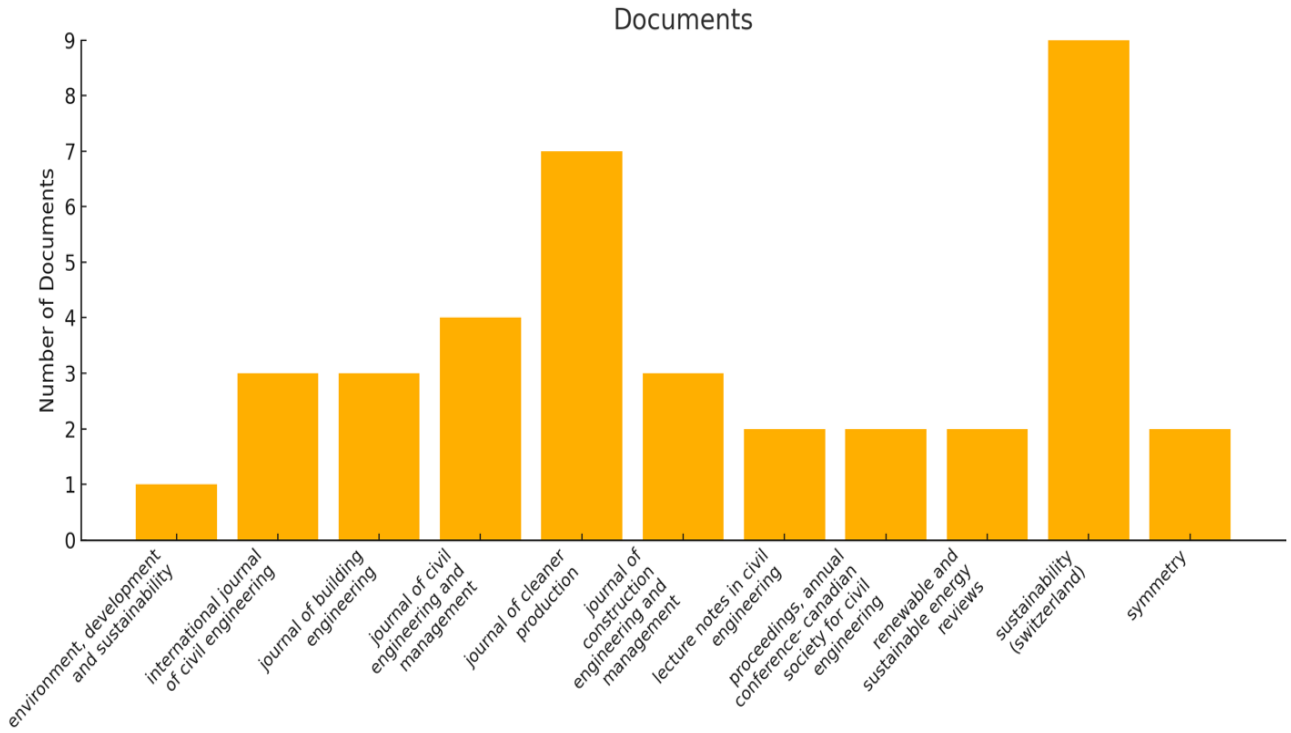

Fig.11: Chart displaying the leading sources ranked by publication count.

4.5 Data Analysis on the Type of MAUT Used

Further analysis reveals a diverse application of Multi-Attribute Utility Theory (MAUT) methods in sustainable building material selection, as shown in Figure 12, with the MCDM method being the most frequent use technique with 22 publications. The AHP appraoch is also widely applied, appearing in 5 publications. Fuzzy AHP, TOPSIS and VIKOR are used in three publications each which indicate the importance of uncertainty management and hybridization in selecting sustainable materials. The complex nature of sustainable material selection necessitates a range of MAUT methods to address the varied criteria effectively.

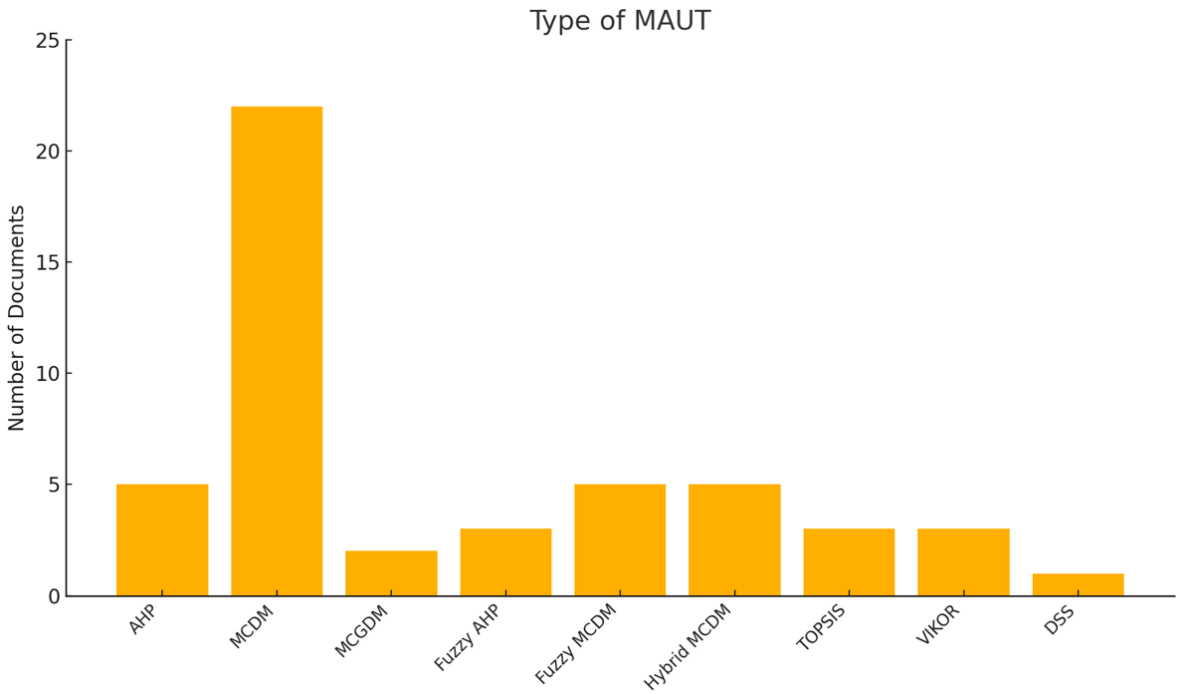

Fig.12: Top occurrence of MAUT tools

5. Conclusions and future work

The review stresses the growing need for MCDM methods to support multiple criteria decision-making for sustainable building materials selection in construction to meet mixed environmental, economic, and social requirements. This need corresponds to the decision-making requirements for handling trade-offs between various criteria. The MCDM research in the period 2019-2023 reflects the development of sustainable construction practices. Solutions to cope with these challenges are, amongst others, the implementation of digital tools, hybrid solutions, adjustment to regional circumstances, data-based decision-making and technology-supported solutions.

Based on a bibliometric and content analysis of 43 articles published over the past five years, this review discusses key trends, leading authors, collaboration networks and methodological issues and advances in the research. Furthermore, findings suggest that MCDM techniques (ranking methods such as AHP, TOPSIS, fuzzy and hybrid) are widely being used to overcome problems associated with material ranking, supplier selection, and LCA, thus indicating the ever-increasing role of MCDM techniques in overcoming sustainability-related uncertainties and inadequacies in sustainable material selection.

In addition, this study illustrates the ability of MCDM methods, including their hybridization, to deal with the conflicting nature of the criteria contained in the selection of sustainable materials, and to enable decision makers to identify the trade-off between the environmental, economic, and social dimension in an organized and transparent way, through the use of modern techniques such as entropy and fuzzy TOPSIS. Furthermore, with the advent of digital technologies such as the internet of things, artificial intelligence, and big data analytics, MCDM applications have been improved in terms of real-time data processing, data accuracy, and decision-making clarity. MCDM is currently being used in the analysis of the environmental impacts of materials from the production phase through to their end-of-life. It is also used to meet sustainability and life-cycle objectives at every stage of a project's life. Contextualization of the MCDM models has also taken a regional basis, which considers climatic, economic and cultural specificities of a region. Influenced by the need for contextualization, research collaboration in Asia, Europe and the Middle East has also resulted in the

development and adoption of the contextualized frameworks.

Despite these advancements, difficulties remain, such as a lack of standardization around sustainability metrics, which further leads to problems in confidently comparing evaluations across projects and regions, and results in less efficient MCDM applications in developing benchmarks for projects. Despite the rising popularity of digital and hybrid solutions in the MCDM space, real-world, practical examples are few and far between, leaving a large gap between technological potential and practical application, and most systems are insufficient for large- and medium-scale projects. Therefore, there is a need for scalable and adaptable MCDM models to reflect active economic, environmental, and social changes, with cultural and social dimensions still under-represented in decision-making models, thereby reducing the comprehensiveness of their applicability. These gaps in literature offer ample opportunities for research to improve the use of MCDM methods in achieving sustainable construction.

This review has identified several opportunities for continued research on addressing barriers associated with sustainable material selection, as described below:

- Standardize sustainability metrics and methods and further enable comparisons between regions and types of projects.
- Include cultural and social aspects by integrating community preferences, cultural practices, and social dynamics into decision models.
- Design advanced DSS that integrate real-time data, enabling models to respond dynamically to environmental changes, economic fluctuations, and public sentiment.
- Automate structural element selection to reduce the time required to design and construct alternative load-bearing structures.
- Utilize emerging technologies for supplier selection, implement smart ordering systems to increase performance levels.
- Investigate how low-carbon cementitious materials can have a large impact on a wide variety of concrete construction projects.

The study provides a critical overview of the existing state of the art in sustainable material selection for construction, and a synopsis of the current body of knowledge and gaps. This review provides a way forward to the development of strong, scalable, and resilient MCDM frameworks capable of meeting construction and engineering sustainability and environmental objectives. The findings of this paper outline implications for practitioners and policy makers and help chart a path toward sustainable construction and global sustainability objectives. This will require active collaboration and partnerships at the regional level to drive innovation and create a norm of sustainable construction.

Author Contributions

The conceptualization of the research A.Y., A.Yo., H.K., I.A., Z.B.; methodology, A.Y., A.Yo., H.K., I.A., Z.B.; formal analysis, A.Y., A.Yo., H.K., I.A., Z.B., K.A.; investigation, A.Y., A.Yo., H.K., I.A.; resources, A.Y., A.Yo., H.K., I.A.; data curation, A.Y., A.Yo., H.K., I.A., K.A.; writing—original draft preparation, A.Y., A.Yo., H.K., I.A.; writing—review and editing, A.Y., A.Yo., H.K., I.A. , Z.B., K.A.; visualization, A.Y., A.Yo., H.K., I.A. , Z.B., K.A.; supervision, Z.B.; project administration, A.Y., A.Yo., H.K., I.A. , Z.B.; funding acquisition, Z.B.. All authors have read and agreed to the published version of the manuscript.

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Conflicts of 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.

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