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Article

A Comprehensive Review of Multi-Attribute and Multi-Criteria Decision-Making (MADM/MCDM) Methods in Civil Engineering

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Abstract: Civil engineering decisions are complex by the simultaneous assessment of multiple, sometimes conflicting technical, economic, environmental, and social aspects. Thus, MADM/MCDM techniques for systematic decision-support are growing. This work aims to synthesise, classify, and critique civil engineering MADM/MCDM applications. We used a systematic literature review to filter and assess over 100 peer-reviewed journal publications from major scientific databases. Classical approaches like AHP, TOPSIS, and VIKOR made up 60-70% of reported applications because of their simplicity and interpretability, whereas fuzzy-based and hybrid models made up 30-40%, showing the increased requirement to handle uncertainty and subjective assessments. Applications include construction management, transit planning, and sustainability assessment. A hybrid framework with weighing and ranking produced more reliable decision outputs than single-method solutions. Even when MADM/MCDM methods work, uncertainty modelling, sensitivity analysis, and digital technologies increase decision dependability, according to this research. More research should concentrate on validated hybrid frameworks and real-world benchmarking to enhance civil engineering MCDM-based decision aid.

Keywords: Multi-Criteria Decision Making (MCDM); Multi-Attribute Decision Making (MADM); Fuzzy Decision-Making; Hybrid MCDM Methods; Sustainable Infrastructure.

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1. Introduction

Complex civil engineering projects and infrastructure systems necessitate assessing many alternatives under conflicting criteria. Economic, technical, environmental, social, and safety aspects influence material, structural system, contractor, project selection, transportation planning, site selection, and sustainability evaluation. When dealing with multidimensional problems, single-criterion decision-making procedures oversimplify and may provide biased or worse results. These limits have been addressed by civil engineering research and practice using MADM and MCDM approaches as systematic decision-support tools. Decision-makers may study challenging circumstances, publicly set evaluation criteria, prioritise those criteria, and transparently and consistently evaluate various possibilities using these frameworks. Therefore, MADM/MCDM techniques are essential for rational engineering decision-making [1].

MADM/MCDM relies on organised approaches from decision science and operations research for multi-objective decision-making. Academics understood the importance of non-economic elements including environmental impact, safety, and social acceptability in decision-making as infrastructure systems and civil engineering projects increased. MADM/MCDM techniques are being applied in civil engineering to manage uncertainty, trade-offs, and stakeholder demands. In civil engineering, the Analytic

Hierarchy Process (AHP) is a key MADM/MCDM methodology due to its simple hierarchical structure and ability to handle quantitative and qualitative criteria. Criterion weighting and alternative evaluation in contractor selection, risk assessment, and sustainability analysis apply AHP. Later, ranking-based algorithms like TOPSIS and VIKOR were established to tackle choice issues that demand proximity to ideal or compromise solutions to pick the best. ELECTRE and PROMETHEE were developed for decision-making scenarios where dominance relationships and partial rankings are better than whole orderings [2].

Although popular, traditional MADM/MCDM methods need correct numerical data and deterministic assumptions. Safety, environmental impact, constructability, and long-term sustainability are assessed by civil engineers using unclear, incomplete, or subjective data. To address these challenges, MADM/MCDM frameworks employ uncertainty models, particularly fuzzy set theory. Fuzzy techniques allow decision-makers to use linguistic variables to make real-world choices more realistic and durable. Recent research focuses on hybrid MADM/MCDM models. To optimise strengths and reduce weaknesses, these systems employ many decision-making processes. The majority of hybrid frameworks employ AHP for criteria weighting and TOPSIS or VIKOR for alternative ranking. Civil engineering needs intelligent and data-driven decision-support systems, therefore advanced models utilise MADM/MCDM techniques with optimisation algorithms, AI, and BIM. Research has used MADM/MCDM approaches to civil engineering problems, however review publications often focus on specific methods or applications. Numerous civil engineering fields lack significant theoretical, method, and application investigations. Fractionation makes it hard for researchers and practitioners to locate suitable decision-making techniques for individual scenarios and understand research trends and gaps [2].

To fulfil this requirement, this study examines civil engineering MADM/MCDM methods. Using text and references, the paper thoroughly assesses over 100 peer-reviewed scholarly articles. MADM/MCDM basics, classification of the most popular decision-making techniques, applications across important civil engineering fields, research gaps, and future prospects for advanced decision-support frameworks are covered in this study. The MCDA starts with defining the decision issue and identifying important stakeholders and concludes with robustness evaluation and actionable decision planning [3]. This sets the stage for structured MADM/MCDM approaches to complex civil engineering decision problems. See MCDA/MCDM phases in Figure 1.

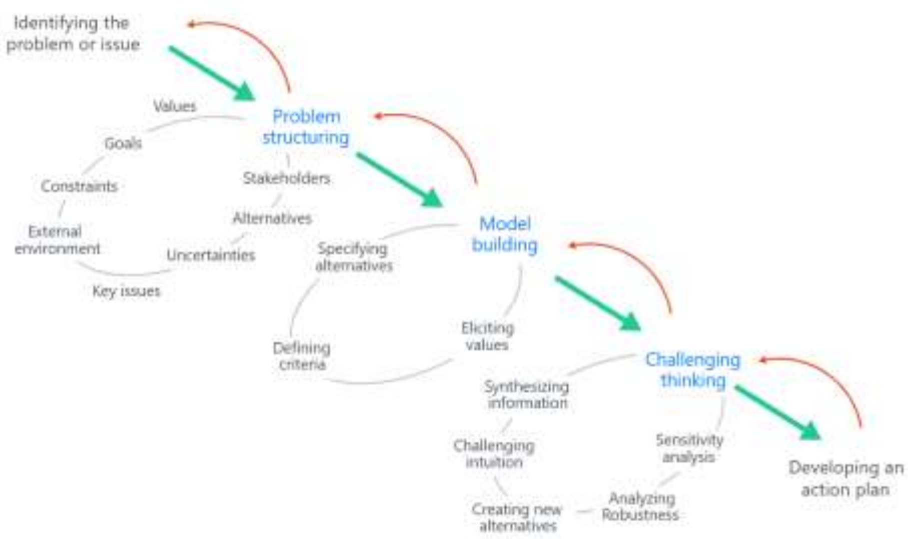

Figure 1. Structured decision-making using MCDA/MCDM encompasses issue structuring, model creation, sensitivity and robustness evaluation, and action plan preparation for systematic and transparent engineering decision-making [3].

2. Materials and Methods

This research uses a simple systematic literature review (SLR) to find, filter, and analyse academic papers on MADM and MCDM in civil engineering and construction. This technique aims to provide openness, replicability, and thorough coverage of the most important academic contributions.

Peer-reviewed MADM and MCDM papers in civil engineering and construction were searched extensively. Scopus, Web of Science, ScienceDirect, SpringerLink, ASCE Library, and IEEE Xplore index high-quality, multidisciplinary research.

We searched for theoretical and practical MCDM advances. Boolean operators and keywords provided the best retrieval accuracy. Civil engineering terms, such as civil engineering, construction management, transport, structural engineering, geotechnical engineering, water resources, infrastructure, and sustainability, were searched for in the core search string. To guarantee relevance and consistency, the search was limited to English journal publications and high-quality conference papers. Not only must MADM/MCDM principles be explained, but they must also be applied to engineering decision challenges in studies. Important research may have been overlooked during the database search; thus, important article reference lists were carefully scrutinised.

To ensure literature relevance, quality, and reliability, exact inclusion and exclusion criteria were employed during screening and selection. High-quality conference and peer-reviewed journal articles using MADM or MCDM methods were included. Civil engineering decision-making challenges in construction management, transportation, structural, geotechnical, water resources, infrastructure planning, and sustainability evaluation must be studied. Chosen study needed criteria formulation, weighting methods, decision matrices, and ranking or evaluation outcomes for meaningful analysis and comparison [4].

Non-civil engineering or built environment studies and those that explained MADM/MCDM theories without implementing them were excluded. Theses, technical reports, book chapters, editorials, and non-indexed publications were deleted for academic rigour. The final synthesis removed papers with insufficient methodological openness or decision-making relevance and duplicate database entries [4].

Progressive screening was used with selection. Search results were collected and duplicates removed. We next reviewed titles and abstracts for unrelated research. Finally, full-text examination validated methodological relevance and synthesis fit. Finally, over 100 publications were retained for the qualitative synthesis to fully examine MCDM techniques, categorization systems, and application areas in civil engineering decision-making [4].

Organised data extraction followed article selection to ensure literature uniformity and comparability. Each article's publication year, authorship, civil engineering application domain, MADM/MCDM method(s), fuzzy or hybrid extensions, decision-making objectives (ranking, selection, prioritisation, or assessment), and evaluation criteria (quantitative, qualitative, or uncertainty-based) were recorded. The data were classified topically for comparison and trend analysis. To identify common decision-making processes and their main applications, studies were categorised by application subject and methodological approach. Criterion weighting, uncertainty-handling, and validation methods were further tested for robustness and agreement with other studies. We synthesised using quality and descriptive analysis. Examination of approach patterns, similarities, and differences indicated repeated restrictions and impediments. Integrative synthesis classified MADM/MCDM techniques, identified research trends, and identified civil engineering decision-making methodological gaps for future study [5].

Civil engineers must evaluate several options under opposing criteria, making decision-making multi-dimensional. Economic cost, construction time, technical performance, safety, environmental effect, durability, and sustainability are common factors. Single-criterion techniques cannot handle such complexity, especially when judgements entail ambiguity and subjective judgement. Thus, civil engineering research and practice relies on MADM and MCDM methodologies for organised, transparent, and logical decision-making [6].

The MADM evaluates a restricted number of possibilities depending on numerous qualities or criteria. Ranking or picking the best based on performance is the aim. Civil engineering decision difficulties include contractor, material, construction method, and location. Many discrete decision problems are addressed by MADM, while MCDM encompasses continuous decision problems with an unbounded solution space. Most civil engineering literature utilises MCDM to refer to several techniques that address many criteria simultaneously. When evaluating many solutions under various criteria, civil engineers use these expressions interchangeably despite their conceptual distinctions [7].

Multi-Criteria Decision-Making (MCDM) issues in civil engineering use fundamental components to structure competing solutions under several, often conflicting criteria. Decision-makers may choose design schemes, construction methods, materials, contractors, or infrastructure projects. Civil engineering choices usually have clear options. Second, the evaluation criteria compare choices. Common issues include cost, construction time, technical performance, safety, environmental impact, durability, and sustainability. These criteria may be quantitative, qualitative, or hybrid, depending on the choice. The third major piece, the decision matrix, compares options to criteria. Normalisation ensures comparability when the criteria change in size and units. Fourth, the criteria weights show each criterion's subjective, objective, or hybrid importance. Criterion evaluations and weights are used to rank, prioritise, or pick alternatives. These support civil engineering MCDM decision-making models [7].

Civil engineering decisions frequently include quantitative and qualitative aspects. Quantify initial cost, life-cycle cost, construction duration, load capacity, and emissions. Quality aspects including constructability, safety culture, stakeholder acceptance, and perceived environmental risk are assessed by experts. Traditional MCDM implies precise criteria judgements. Decision-makers usually have limited, inaccurate, and subjective evidence. MCDM frameworks address uncertainty due to the difference between real-world decision circumstances and accurate modelling assumptions [7].

Alternative evaluation and ranking depend on criteria weighting in Multi-Criteria Decision-Making (MCDM). Criteria weights indicate the importance of economic, technical, environmental, social, and safety elements in civil engineering decisions. Even little weight changes might affect decisions. So, adopting the correct weighting technique offers accurate and unambiguous results. MCDM criterion weighting might be subjective, objective, or hybrid. Subjective weighting systems weight criteria by expert opinion and stakeholder preferences. AHP, ANP, and Delphi-based approaches are frequently utilised in civil engineering because they include qualitative information and experience insights. Expert prejudice and inconsistency may hinder these methods. Objective weighing calculates criteria weights using facts rather than judgment. Variability and information-based entropy weighting, standard deviation, and CRITIC weight decision matrices. Objective methods reduce subjectivity but may overlook practical and environmental concerns. Hybrid weighing techniques transcend the limitations of individual procedures and improve robustness and dependability. Sensitivity analysis may assess decision result stability under different weightings [8].

Civil engineering is unpredictable because of material variability, site inspection restrictions, changing environmental conditions, construction uncertainty, and human judgment. Traditional crisp MCDM approaches may miss these uncertainties, skewing ranking confidence [9].

This constraint is overcome by MCDM frameworks utilising uncertainty modelling approaches like:

1. Used fuzzy set theory for numbers and words.
2. Interval numbers indicate uncertainty.
3. With statistical data, use probabilistic and stochastic procedures.

Fuzzy-based MCDM methods are popular in civil engineering because they mimic subjective and inaccurate evaluations while preserving interpretability.

MADM/MCDM approaches in civil engineering follow a systematic decision-making process from issue formulation to option selection. Defining the issue, finding alternatives, picking criteria, calculating weights, building the decision matrix, using MADM/MCDM, ranking, and verifying outcomes are common procedures [2]. The basic decision-making process is shown in Figure 2.

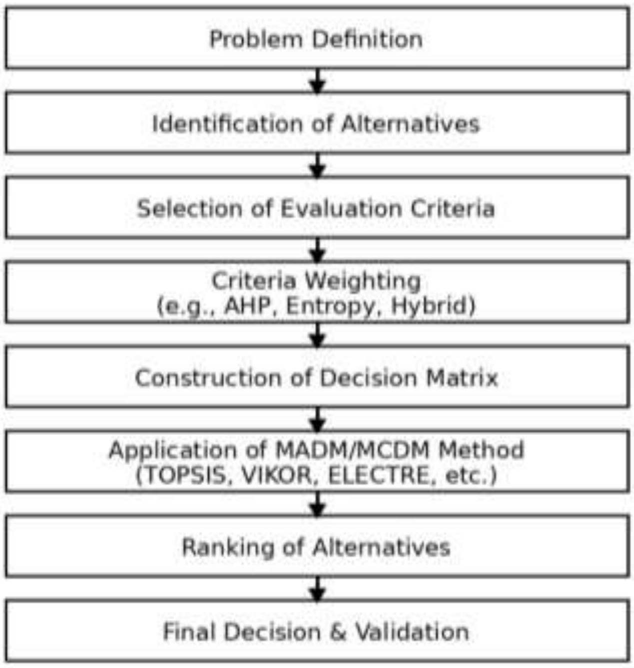

Figure 2. General framework of MADM/MCDM application in civil engineering [2].

MADM/MCDM in civil engineering encompasses issue description, alternative identification, criterion selection and weighting, decision matrix creation, MCDM technique application, alternative ranking, and final decision validation.

3. Results

Multiple MCDM approaches arise in civil engineering decision-making situations, according to evaluated research. AHP, TOPSIS, and VIKOR are still widely used because of their simplicity, interpretability, and applicability for engineering ranking jobs. ANP and DEMATEL are also used in complicated decision contexts with criterion interdependencies. Recently, hybrid and uncertainty-handling models, especially fuzzy-based extensions, have been integrated to increase robustness and realism [10].

MCDM is mostly used in civil engineering to make decisions with competing criteria. The main applications include contractor and project selection, sustainability assessment, risk-based decision-making, infrastructure prioritisation, transportation planning, and material evaluation. These sectors need organised ranking and prioritisation owing to cost, quality, time, safety, and environmental performance trade-offs [11].

Increasing use of uncertainty-based modelling (such as fuzzy MCDM), hybrid frameworks combining weighting and ranking methods, expanding applications in sustainable and resilient infrastructure, and rising interest in integrating MCDM with digital decision-support tools like BIM-based platforms are visible [12].

Table 1. Mapping of common MCDM methods and dominant civil engineering applications.

MCDM method	**Typical role in decision-making**	**Common civil engineering applications**
AHP	Criteria weighting and ranking	Contractor selection, material selection, project prioritization
ANP	Weighting with interdependent criteria	Complex project evaluation, sustainability assessment
BWM / SWARA	Efficient criteria weighting	Sustainability weighting, performance assessment
DEMATEL	Cause–effect analysis of criteria	Risk assessment, safety analysis, critical factor modeling
ELECTRE	Outranking with threshold logic	High-uncertainty selection and screening problems
Hybrid/Fuzzy MCDM	Uncertainty handling and robustness	Risk-based decisions, expert-based qualitative evaluation
PROMETHEE	Outranking and preference modeling	Multi-stakeholder infrastructure decisions
TOPSIS	Ranking alternatives based on ideal solutions	Technology/material selection, infrastructure alternatives
VIKOR	Compromise ranking under conflicting criteria	Transportation planning, sustainability evaluation

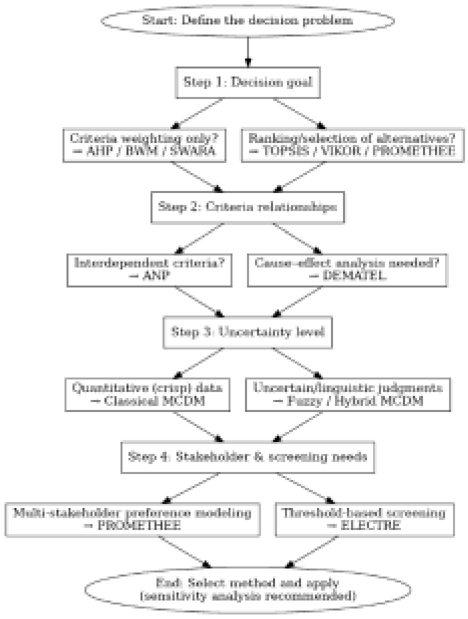

Figure 3. A practical guideline for selecting MCDM methods in civil engineering problems.

This guideline provides a practical contribution by supporting method selection based on the characteristics of civil engineering decision problems, thereby improving the applicability of the reviewed findings.

This section classifies multiple attribute and multi-criteria decision-making (MADM/MCDM) approaches used in civil engineering literature. Classifying these approaches helps researchers and practitioners choose the right methods for the decision issue, data, uncertainty level, and desired outcomes. According to the reviewed papers, civil engineering MADM/MCDM techniques fall into four categories: classical (crisp) methods, outranking methods, fuzzy-based and uncertainty-aware methods, and hybrid/integrated decision-making approaches. Civil engineering decision challenges can entail competing goals including cost, safety, and sustainability. Thus, the choice of an MCDM method depends on whether alternatives are discrete and limited, criteria are quantitative, qualitative, or mixed, uncertainty and subjectivity must be modelled, and a complete ranking or partial dominance relation is needed [13].

Traditional MADM/MCDM methods employ deterministic numerical inputs and assume decision-makers provide accurate criteria weights. The simplicity, interpretability, and computational efficiency of these methods make them popular in civil engineering applications including contractor selection, material selection, project prioritisation, and transportation planning. A common classical criterion weighing method is the Analytic Hierarchy Process (AHP), which uses pairwise comparisons and hierarchical decomposition. AHP helps decision-makers appraise circumstances that need quantitative and qualitative criteria. AHP may have judgement discrepancies, making consistency ratio (CR) assessment important. Popular TOPSIS rates options by their closeness to an ideal answer and distance from a negative-ideal choice. TOPSIS is simple and suitable for large decision matrices, however normalisation and weighting impact it. To compromise, VIKOR weighs group usefulness against individual regret. Sustainability assessment and complex consensus-based decisions use VIKOR [14].

Outranking techniques focus on dominance links between alternatives, whereas traditional ranking systems employ aggregated utility evaluations. These methods work for civil engineering problems with several criteria and no ranking. The ELECTRE family ranks alternatives using concordance and discordance. Infrastructure planning, environmental management, and strategic decision-making employ ELECTRE when eliminating inferior options is more important than ranking. PROMETHEE ranks pairwise dominance using preference functions and preference flows. PROMETHEE is utilised in equipment selection, urban planning, and construction management, but preference functions and thresholds must be established carefully [15].

Civil engineering decisions are hampered by incomplete data, subjective assessments, and unpredictability. Fuzzy logic and uncertainty-aware techniques solve this problem in MCDM frameworks. Fuzzy expansions of traditional approaches include AHP, TOPSIS, and VIKOR. These approaches help decision-makers assess criteria using linguistic variables and fuzzy numbers. These strategies are used in safety, risk, and sustainability assessments when numerical data is insufficient. MCDM frameworks have also used interval numbers, grey systems, and probabilistic ways to address uncertainty, but fuzzy logic is still the most common owing to its interpretability and technical applicability [16].

In recent research, hybrid decision-making frameworks that combine approaches have gained popularity. Hybrid models provide robustness, uncertainty reduction, and decision reliability. A typical hybrid structure uses AHP for criteria weighting and TOPSIS or VIKOR for alternative ranking. These combinations are employed in challenging civil engineering problems that need reliable weighing and ranking. Advanced integrated frameworks incorporate MCDM, AI, simulation, and BIM. Sustainable infrastructure planning, construction scheduling, and multi-objective design optimization use integrated decision-support systems increasingly [16].

Table 2. Classification of MADM/MCDM Methods Applied in Civil Engineering.

Category	**Representative Methods**	**Main Idea**	**Typical Civil Engineering Applications**	**Strengths**	**Limitations**
Classical (Crisp)	AHP, TOPSIS, VIKOR, SAW, WPM	Deterministic evaluation and ranking	Contractor/material selection, project prioritization	Simple, interpretable, widely used	Limited handling of uncertainty
Fuzzy/Uncertainty-aware	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy VIKOR, Grey MCDM	Linguistic modeling and uncertainty representation	Risk/safety assessment, sustainability evaluation	Realistic modeling of ambiguity	Higher computational effort
Hybrid/Integrated	AHP–TOPSIS, AHP–VIKOR, BIM–MCDM, AI–MCDM	Combination of methods for robustness	Complex project decisions, digital engineering	Strong decision support, flexible	Requires expertise and validation
Outranking	ELECTRE, PROMETHEE	Dominance relations and preference flows	Infrastructure planning, environmental decisions	Handles mixed criteria well	Parameter calibration needed

To support method selection in civil engineering research and practice, it is useful to compare popular MCDM methods based on data type, ability to handle uncertainty, complexity, and applicability. Table 2 presents a comparative analysis of commonly applied methods [17].

Table 3. Comparative Comparison of Frequently Used MADM/MCDM Methods.

Method	**Data Type**	**Uncertainty Handling**	**Output**	**Computational Complexity**	**Notes for Civil Engineering Use**
AHP	Mixed (Qn + Ql)	Limited (crisp) / High (fuzzy)	Weights + ranking	Low–Moderate	Excellent for criteria weighting
ELECTRE	Mixed	Moderate	Outranking/partial ranking	High	Requires thresholds and tuning
Fuzzy MCDM	Mixed (linguistic	High	Ranking + uncertainty modeling	High	Better realism

	+ numeric)				under ambiguity
Hybrid models	Mixed	High–Very high	Robust ranking/selection	High–Very high	Strong performance but complex
PROMETHEE	Mixed	Moderate	Ranking via flows	Moderate	Flexible preference functions
TOPSIS	Mainly quantitative	Low (crisp) / High (fuzzy)	Ranking	Low	Sensitive to normalization
VIKOR	Mainly quantitative	Low (crisp) / High (fuzzy)	Compromise ranking	Moderate	Useful for consensus solutions

This categorisation shows that conventional MADM/MCDM approaches are still popular owing to their simplicity and interpretability. Fuzzy-based and hybrid techniques are being used in civil engineering decision issues due to ambiguity and subjective judgements. MCDM may also be integrated into intelligent decision-support systems thanks to BIM and AI. The next part examines key civil engineering MADM/MCDM applications based on this categorization [18].

Civil engineers make complex judgements with conflicting criteria using MADM/MCDM algorithms. Construction management, transportation, structural, geotechnical, water resources, and sustainability assessment are applications. Complex civil engineering systems, real-world data ambiguity, and stakeholder preferences are driving the usage of fuzzy, hybrid, and integrated decision-support frameworks. This section covers the key application areas and prominent MADM/MCDM methods in each [19].

Construction management is one of MADM/MCDM's most challenging applications due to multi-stakeholder decision contexts and the need to balance cost, time, quality, safety, and sustainability. MCDM is used in contractor selection, construction technique evaluation, supplier selection, risk assessment, and project prioritization [20].

Contractor selection is key to project success. Cost, technical competence, experience, financial stability, equipment availability, safety records, and managerial abilities are usually examined. AHP is often used for criteria weighing since it can pairwise compare qualitative and quantitative assessments. TOPSIS and VIKOR assess contractors' closeness to ideal or compromise solutions. Due to uncertainty, qualitative evaluations including safety culture, reputation, and management performance employ fuzzy methods [21].

Construction methods and equipment must be selected carefully to increase output, save costs, and enhance safety. Productivity, cost, feasibility, risk, resource availability, environmental impacts, and expertise are common domain decision difficulties. Flexibility and interpretability make TOPSIS and PROMETHEE popular, whereas hybrid AHP–TOPSIS models improve dependability for complex criteria weighting [22].

Prioritising projects under budgetary limits requires balancing economic incentives, urgency, feasibility, risk, and sustainability. In multi-stakeholder environments, VIKOR seeks compromise solutions, whereas fuzzy MCDM techniques rationalize faulty risk factors and safety ratings [23].

Table 4. Major MADM/MCDM Applications in Construction Management.

Application Area	**Typical Decision Problem**	**Widely Used Methods**	**Example Criteria**

Contractor selection	Ranking contractors	AHP, TOPSIS, VIKOR, Fuzzy AHP/TOPSIS	Cost, experience, safety, quality, finance
Equipment selection	Selecting equipment	AHP–TOPSIS, PROMETHEE	Productivity, cost, safety
Method selection	Best construction method	TOPSIS, VIKOR, PROMETHEE	Time, feasibility, risk, impact
Risk assessment	Evaluating risks	Fuzzy MCDM, AHP	Probability, severity, mitigation
Supplier selection	Choosing suppliers	AHP, TOPSIS, PROMETHEE	Cost, delivery time, reliability

Transport engineers consider mobility, safety, affordability, environment, and equity. MCDM is used for route selection, project prioritisation, pavement management, transport sustainability, and multi-modal planning [24].

Route selection involves evaluating alignments based on building costs, travel time, land acquisition, environmental impact, and safety. TOPSIS and VIKOR rank alternatives, but outranking is superior for elimination and domination [25].

Transport authorities prioritise projects based on congestion, accidents, economic benefits, feasibility, resilience, and emissions. Hybrid AHP–VIKOR frameworks rank stakeholders with varied priorities well using criteria weighting [26].

Table 5. Major MADM/MCDM Applications in Transportation Engineering.

Application Area	Example Problem	Common Methods	Key Criteria
Mode selection	Selecting transport mode	AHP, PROMETHEE	Time, comfort, emissions
Pavement management	Maintenance prioritization	AHP, TOPSIS	Condition, traffic, budget
Project prioritization	Ranking investments	AHP, VIKOR, Hybrid	Benefit, feasibility, risk
Route selection	Highway/rail alignment	TOPSIS, VIKOR, PROMETHEE	Cost, time, environment, safety

In structural engineering, MADM/MCDM methods support decision-making related to structural system selection, material selection, seismic strengthening prioritization, and design strategy evaluation. The criteria commonly considered include safety, stiffness, ductility, durability, cost, constructability, and lifecycle performance [27].

Selecting a structural system for buildings and bridges involves evaluating alternatives such as steel frames, reinforced concrete, composite systems, and modular solutions. AHP and TOPSIS are commonly used to weight criteria and rank systems, while fuzzy models capture uncertainty in qualitative criteria such as constructability and resilience [28].

Material selection is a critical structural decision involving trade-offs between mechanical performance, cost, durability, environmental impact, and availability. TOPSIS and VIKOR are widely used for ranking materials, and fuzzy MCDM approaches are applied when material performance data are uncertain or when sustainability criteria are subjective [28].

Table 6. Key MADM/MCDM Applications in Structural Engineering.

Application Area	Decision Problem	Common Methods	Example Criteria
Material selection	Rank materials	TOPSIS, VIKOR	Strength, durability, CO_2
Retrofit prioritization	Rank strengthening options	AHP, VIKOR	Risk, cost, resilience

System selection	Choose structural system	AHP, TOPSIS, Fuzzy MCDM	Safety, cost, ductility

Geotechnical engineering decisions often involve high uncertainty due to limited subsurface information and variability in soil properties. MADM/MCDM methods have been applied to site selection, ground improvement method selection, foundation type selection, slope stabilization prioritization, and geotechnical risk assessment [28].

Site selection and foundation type determination involve criteria such as soil bearing capacity, settlement, groundwater conditions, construction feasibility, cost, and risk. AHP-based weighting and TOPSIS/VIKOR ranking are common. Fuzzy approaches help represent uncertainty in geotechnical parameters [29].

Selecting ground improvement techniques requires evaluating alternatives such as compaction, grouting, soil replacement, and reinforcement based on cost, feasibility, environmental impact, and effectiveness. PROMETHEE and hybrid models can be effective when comparing multiple intervention strategies [30].

Table 7. Key MADM/MCDM Applications in Geotechnical Engineering.

Application Area	**Example Problem**	**Common Methods**	**Example Criteria**
Site selection	Choose best site	AHP, TOPSIS	Safety, cost, soil risk
Foundation type	Rank foundation options	AHP–TOPSIS, VIKOR	Settlement, feasibility
Ground improvement	Select improvement method	PROMETHEE, TOPSIS	Effectiveness, cost, impact
Slope stabilization	Prioritize stabilization	Fuzzy MCDM	Risk, urgency, cost

Water resources management involves multi-objective decisions under uncertainty and competing stakeholder demands. MADM/MCDM methods have been applied to reservoir operation, water allocation, treatment technology selection, flood risk management, and watershed planning [31].

Water allocation decisions consider criteria such as reliability, equity, economic efficiency, environmental sustainability, and resilience to drought. AHP supports criteria weighting, while VIKOR can identify compromise solutions among stakeholders [32].

Treatment technology selection involves balancing cost, efficiency, operational complexity, and environmental compliance. In flood management, MCDM methods support prioritizing mitigation measures based on risk reduction, cost, feasibility, and social acceptance [32].

Table 8. Key MADM/MCDM Applications in Water Resources Engineering.

Application Area	**Example Problem**	**Common Methods**	**Example Criteria**
Water allocation	Allocate resources	AHP, VIKOR	Equity, reliability, cost
Treatment selection	Choose technology	TOPSIS, PROMETHEE	Cost, efficiency, compliance
Flood mitigation	Prioritize measures	VIKOR, Fuzzy MCDM	Risk, feasibility, benefit

Sustainability assessment has become a major focus in civil engineering due to climate change, resource limitations, and global sustainability goals. MADM/MCDM methods support evaluation of sustainable materials, green buildings, infrastructure resilience, and lifecycle performance.

Sustainable decision-making involves economic, environmental, and social criteria, often requiring lifecycle-based evaluation. Hybrid frameworks (AHP–TOPSIS, AHP–VIKOR) are frequently adopted, while fuzzy-based approaches enhance realism by modeling uncertainty in sustainability indicators [33].

Table 9. Sustainability-Oriented MADM/MCDM Applications.

Application Area	Example Problem	Common Methods	Example Criteria
Green material selection	Rank materials	TOPSIS, VIKOR	CO_2, cost, durability
Sustainable buildings	Evaluate alternatives	AHP, Hybrid MCDM	Energy, comfort, impact
Infrastructure resilience	Prioritize strategies	Fuzzy MCDM	Risk, adaptation, cost

The Analytic Hierarchy Process (AHP) remains one of the most widely used MADM techniques in civil engineering, especially for criteria weighting in problems involving both quantitative and qualitative factors. AHP implementations often include structured data collection, consistency ratio (CR) verification, and expert validation mechanisms such as Delphi rounds [34]. The typical workflow of AHP implementation and consistency verification is illustrated in Figure 4.

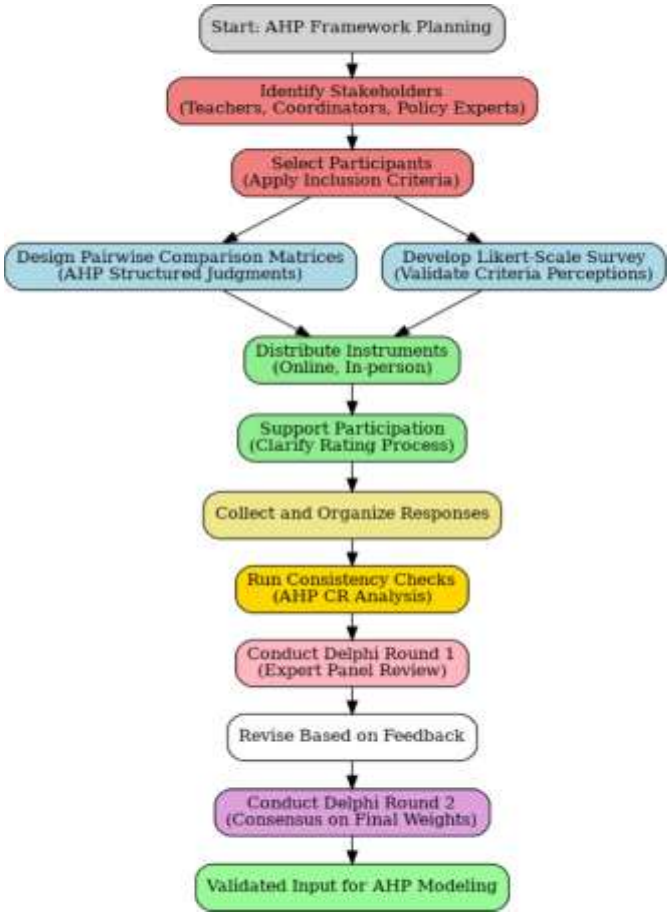

Figure 4. AHP framework planning and data collection procedure for criteria weighting and validation [34].

This figure summarizes the main steps of AHP implementation, including identifying stakeholders, collecting judgments through pairwise comparisons, applying consistency checks, and refining judgments through expert consensus processes. A hierarchical representation is also central to MADM/AHP modeling, in which the decision goal is placed at the top level, evaluation criteria are located at the intermediate level, and alternatives (or indicators) occupy the final level [33]. A hierarchical representation of MADM/AHP modeling is illustrated in Figure 5.

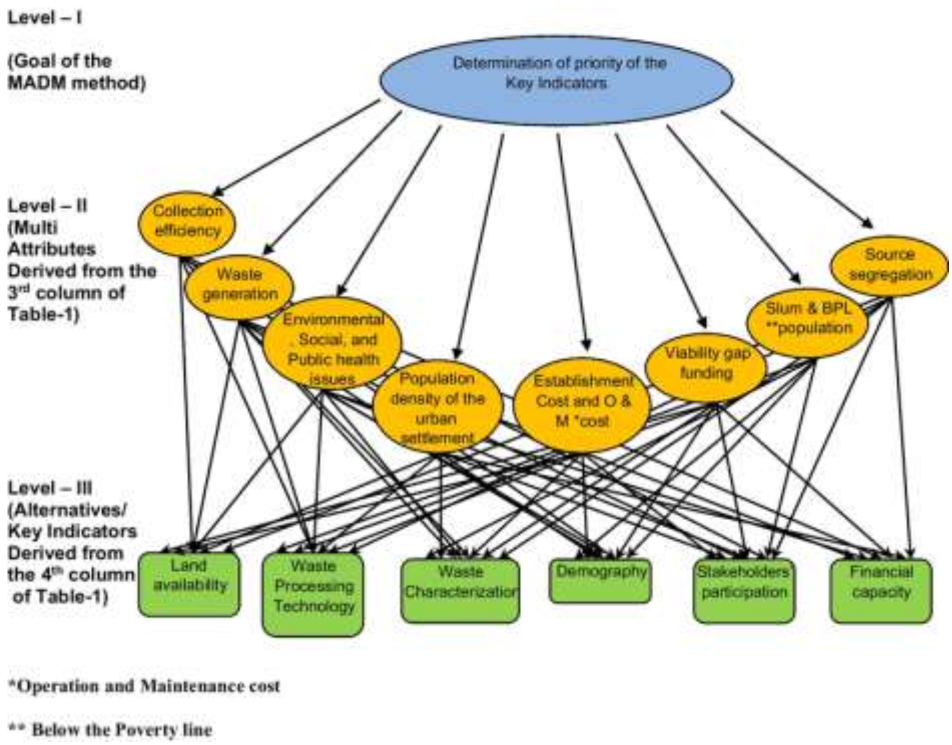

Figure 5. Hierarchical structure of the MADM decision-making problem (Goal–Criteria–Alternatives).

4. Discussion

Research gaps exist in civil engineering methods. Insufficient real-world validation of MCDM results. Practicality is limited by theoretical rankings that lack project performance, expert agreement, or post-implementation data. Uncertainty-weighting criteria differ greatly. Weighting considerably influences decision results, however many studies use expert opinion without sensitivity or robustness analysis. Trust in ranking stability under decision-maker preferences decreases. Literature suggests no uniform criteria for contractor selection, sustainability review, or infrastructure prioritising. Criterion definitions and measurement scales vary, limiting research comparability and transferability.

Few comparative or hybrid methods exist, hence single-method applications are overused. MCDM approaches may rank differently, reducing decision reliability without cross-method testing. Finally, Building Information Modelling, AI, and real-time monitoring systems are not interconnected. These issues must be solved for powerful, clear, and practical civil engineering MCDM frameworks.

Future civil engineering MADM/MCDM research should increase methodological robustness, practical validation, and technological integration. Validated hybrid frameworks with weighing, ranking, and uncertainty-handling are essential. The same decision concerns must be studied using many MCDM methods to determine ranking stability and decision confidence. Prioritise interval type-2 fuzzy sets, probabilistic MCDM, and resilient decision-support for dynamic and incomplete data. These methodologies reflect real-world engineering conditions to better risk assessment, sustainability evaluation, and infrastructure resilience design.

BIM, digital twins, and lifecycle assessment platforms should be used with MCDM methods. Integration enhances data availability, minimises subjectivity, and enables real-time project decision support. AI and machine learning automate criteria weighting, optimise alternative selection, and enhance predictive decision-making. Future research should employ established criteria frameworks, transparent reporting, and complete sensitivity analysis to improve reproducibility and cross-study comparability. Building reliable and sustainable civil engineering decision-support systems involves increasing the link between theoretical MCDM models and practical implementations.

5. Conclusion

This review synthesised civil engineering MADM/MCDM methods. Single-criterion approaches fail when engineering decisions include several economic, technical, environmental, and social considerations, hence MCDM-based decision-support frameworks are popular. According to the literature, AHP, TOPSIS, and VIKOR are still used because to their simplicity and transparency. Fuzzy and hybrid methods improved to manage ambiguity, subjective assessments, and poor data in engineering problems. These complex frameworks operate effectively in construction management, transit planning, sustainability assessment, and infrastructure prioritisation. Although methodology has improved, subjective weighting, sensitivity analysis, and decision result validation remain. To increase reliability and practical application, future research should include hybrid and uncertainty-aware models, uniform evaluation criteria, and robust validation methods. MCDM methods combined with BIM and AI may produce intelligent, data-driven decision-support systems. MADM/MCDM will increase civil engineering decision-making openness, consistency, and sustainability.

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