

**Strategic Management Approaches for Sustainable
Handling of Construction and Demolition Wastes Through
a Q-Rung Orthopair Probabilistic Hesitant Fuzzy Set
Decision Model**

دراسة الإستراتيجيات المستدامة للتعامل مع مخلفات البناء والهدم من خلال
دراسة النموذج

الإحتمالي للمجموعات الضبابية المترددة المعرفة بـ q-Rung Orthopair

by

HEND HASSAN ABDULLA KHALFAN GHAILANI

**A thesis submitted in partial fulfilment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY IN COMPUTER SCIENCE**

at

The British University in Dubai

April 2024

الجامعة
البريطانية في
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Abstract

Sustainable management of construction and demolition wastes (CDWs) has become a pressing global issue in social, environmental, and economic contexts, involving complex technological, engineering, management, and regulatory challenges. Recently, many CDW management strategies have been developed based on the barrier attributes of reuse distribution. However, no strategy can simultaneously address all barrier attributes of reuse distribution. Furthermore, no research has assessed and modelled the identified CDW management strategies to determine optimality. On this basis, the presence of multiple barrier attributes, varying attribute priority, and a wide range of data allow for the modelling of CDW management strategies under complex multiple-attribute decision-making problems.

This study develops the fuzzy-weighted zero inconsistency (FWZIC) and fuzzy decision by opinion score method (FDOSM)-based multiplicative multiple objective optimizations by ratio analysis (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS) to address this problem. The developed q-ROPHFS–FWZIC method prioritized and weighed the main and sub-barrier attributes of reuse distribution in CDW management strategies. The developed q-ROPHFS–FDOSM is used to score the CDW management strategies. Then, the MULTIMOORA method is used to model 51 CDW management strategies to determine the optimum one. Results showed that Strategy46 modelled first in six q values because it had the most essential attributes (i.e. cost, market, value-for-money, experience, infrastructure, management, risk, and trust). Strategy17 and Strategy20 are the least sustainable strategies because they had only one attribute (i.e. experience). Sensitivity analysis, systematic modelling, and comparison analysis are conducted to validate and evaluate the stability and robustness of the proposed methods. The implications of this study

would likely benefit a variety of stakeholders involved in the construction industry, including construction companies, architects, engineers, policymakers, and members of the public.

Keywords: construction and demolition waste, FDOSM, FWZIC, MULTIMOORA, multiple attribute decision-making

خلاصة

أصبحت الإدارة المستدامة لمخلفات البناء والهدم قضية عالمية ملحة في السياقات الاجتماعية والبيئية والاقتصادية ، وهي تنطوي على تحديات تكنولوجية وهندسية وإدارية وتنظيمية معقدة. في الآونة الأخيرة ، تم تطوير العديد من إستراتيجيات التعامل مع أضرار الإصابات الشديدة على أساس سمات الحاجز لتوزيع إعادة الاستخدام. ومع ذلك ، لا يمكن لأي إستراتيجية أن تعالج في نفس الوقت جميع المعايير المعيقة لتوزيع وإعادة الاستخدام. علاوة على ذلك ، لم يتم أي بحث بتقييم ونمذجة إستراتيجيات إدارة مخلفات البناء والهدم المحددة لتحديد الأمثلية والأنسب. على هذا الأساس ، فإن وجود العديد من العقبات في السمات، وأولوية السمة المتغيرة ومجموعة واسعة من البيانات تسمح بنمذجة إستراتيجيات إدارة التنازل عن أضرار التعارض في ظل مشاكل صنع القرار المعقدة ذات السمات المتعددة. تعمل هذه الدراسة على تطوير عدم تناسق الطريقة الضبابية (FWZIC) وإتخاذ قرار غامض من خلال الطريقة المطروحة (FDOSM) – حيث يتم استخدام الطريقتين المذكورتين مسبقاً لتحسين الطريقة الأخيرة المعتمدة لتعدد الأهداف قائم على تحليل النسبة النهائية وتسمى (MULTIMOORA) بإستخدام مجموعة q -rung orthopair الاحتمالية المترددة (q-ROPHFS) إلى معالجة هذه المشكلة. حيث أعطت طريقة q-ROPHFS-FWZIC التي تم تطويرها الأولوية والوزن للسمات الرئيسية والعائق لتوزيع إعادة الاستخدام في إستراتيجيات إدارة مخلفات البناء والهدم. حيث يتم إستخدام q-ROPHFS-FDOSM المطور لتسجيل إستراتيجيات إدارة المخلفات والهدم. بعد ذلك ، يتم إستخدام طريقة MULTIMOORA لنمذجة 51 إستراتيجية لإدارة مخلفات البناء والهدم لتحديد الطريقة الأنسب. أظهرت النتائج أن الاستراتيجية 46 صُممت أولاً في ستة قيم q حيث كانت تحتوي على أهم السمات (أي التكلفة والسوق والقيمة مقابل المال والخبرة والبنية التحتية والإدارة والمخاطر والثقة). الإستراتيجية 17 والإستراتيجية 20 هي الإستراتيجيات الأقل إستدامة لأن لها سمة واحدة فقط (أي الخبرة). يتم إجراء تحليل الحساسية والنمذجة المنهجية وتحليل المقارنة للتحقق من صحة وتقييم ثبات وقوة الطرق المقترحة. من المحتمل أن تفيد الآثار المترتبة على هذه الدراسة مجموعة متنوعة من أصحاب المصلحة المشاركين في صناعة البناء ، بما في ذلك شركات البناء والمهندسين المعماريين والمهندسين وصانعي السياسات وأفراد من الجمهور.

Dedication

This thesis is dedicated to my family, whose unwavering support and encouragement have been the guiding light throughout this journey. Your love, understanding, and sacrifices have fuelled my determination to reach this milestone. I am forever grateful for your belief in me and for being my constant source of inspiration. This accomplishment is as much yours as it is mine. Thank you for being the foundation upon which my academic pursuits stand.

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List of Abbreviations

BDW	Building and Demolition Waste
BIM	Building Information Modelling
CDWs	Construction and Demolition Wastes
DMs	Decision-Makers
EDM	Expert Decision Matrix
FDOSM	Fuzzy Decision by Opinion Score Method
FS	Fuzzy Set
FWZIC	Fuzzy-Weighted Zero-Inconsistency
GHG	Greenhouse Gas
IFS	Intuitionistic FS
MADM	Multiple Attribute Decision-Making
MULTIMOORA	Multiplicative Multiple Objective Optimisation by Ratio Analysis
q-ROFSs	Q-Rung Orthopair Fss
q-ROPHFAM	Q-ROPHF Arithmetic Mean
q-ROPHFNs	Q-ROPHF Numbers
q-ROPHFEAM	Q-ROPHF Einstein Arithmetic Mean
q-ROPHFS	Q-Rung Orthopair Probabilistic Hesitant FS
q-ROPHFS–FDOSM	Q-Rung Orthopair Probabilistic Hesitant–FDOSM
q-ROPHFS–FWZIC	Q-Rung Orthopair Probabilistic Hesitant–FWZIC
SEJ	Structured Expert Judgment

Chapter 1: Introduction

1.1 Background

Construction and demolition waste (CDW), also known as building and demolition waste (BDW), refers to waste generated during construction, renovation, and demolition activities, such as site clearance, demolition-related activities, roadwork, and building renovation (Kabirifar et al., 2020). CDW may also encompass materials unexpectedly produced by natural disasters, such as tsunamis, hurricanes, floods, and earthquakes (Menegaki et al., 2018). These wastes typically include concrete, asphalt, wood, and other materials and account for approximately 30%–40% of the total solid waste (Jin et al., 2017). The generation of CDW is a significant concern in the construction industry due to its adverse effects on the environment and society, as well as its impact on industry efficiency (Meng et al., 2018). Around 35% of CDWs worldwide end up in landfills, with landfill disposal being the predominant method in many regions, alongside persistent issues of unauthorized dumping (Duan & Li, 2016; Seror et al., 2018).

According to various studies, a considerable quantity of CDWs is produced annually (Villoria Sáez & Osmani, 2019). In 2016, the European Union produced approximately 2.538 billion tons of waste, with the construction industry contributing 36.4% (Cosgun et al., 2020). Similarly, the construction industry accounts for a significant portion of landfilling in various countries, including the United Kingdom, Brazil, the United States, Australia, Hong Kong, and Canada (Ajayi et al., 2016; Yu et al., 2013; Yeheyis et al., 2016). The accumulation of CDWs poses serious challenges for sustainable urban growth due to limited landfill space, toxic gas emissions, energy consumption, and water pollution (Jin et al., 2019). Thus, there is a pressing

need to reduce, reuse, and recycle CDWs to alleviate pressure on landfills and improve waste diversion practices (Jin et al., 2017).

Efforts towards sustainable management of CDWs have become increasingly critical on a global scale, encompassing social, environmental, and economic considerations (Jin et al., 2019). However, this task involves complex technological, engineering, management, and regulatory issues (Jin et al., 2019). The preservation of the environment, economy, natural resources, and society relies on effective CDW management. While several studies have focused on CDW management strategies, particularly on reduction, reuse, and recycling, there is a lack of structured classification, particularly regarding efficient management (Huang et al., 2018). Moreover, limited attention has been given to systematically identifying and classifying attributes contributing to efficient CDW management.

After prevention, the reuse of construction elements is considered the most effective solution to reduce waste production and decouple economic growth from resource consumption (Rakhshan et al., 2020). Reuse is favoured over recycling according to the waste hierarchy; however, the majority of CDWs are recovered through recycling rather than reuse (Rakhshan et al., 2020). Although recycling diverts waste from landfills, it is resource- and energy-intensive, leading to significant environmental pressures, including greenhouse gas emissions (Rakhshan et al., 2021). In contrast, reusing construction elements has lower environmental impacts compared to recycling the same materials (Rakhshan et al., 2020). However, the reuse of construction elements poses challenges in waste demolition.

In recent years, the field of Construction and Demolition Waste (CDW) management has faced several challenges, particularly in the effective reuse and recycling of materials to minimize environmental impact. These challenges include the lack of a structured

classification system for CDW management strategies, insufficient attention to barrier attributes affecting reuse distribution, and the complexities involved in balancing economic, environmental, and social factors. My previous work, published in Elsevier journal (Ghailani , Zaidan et al., 2023), addresses these challenges by developing a comprehensive framework for evaluating and benchmarking CDW management strategies, with a focus on maximizing the reuse of construction elements while minimizing resource and energy consumption. This research provides a foundation for the current thesis, particularly in exploring a holistic approach to sustainable CDW management that systematically considers all relevant barrier attributes. The insights gained from this study are further expanded upon in this thesis, where I develop a decision-modelling approach that integrates technological advancements, regulatory frameworks, and social engagement to optimize CDW management strategies for sustainable urban development. The term reuse distribution in CDW management involves sorting, processing, and reallocating materials from construction and demolition projects for use in other construction activities, reducing the need for new resources and lowering environmental impacts. Strategies for CDW management that are built around specific barriers—such as economic, environmental, organizational, regulatory, social, and technical challenges—focus on overcoming these hurdles to improve reuse. Economic barriers might include high recycling costs, while regulatory issues could involve compliance, and technical challenges may relate to ensuring the safety and quality of recycled materials. Addressing these barriers in a targeted way allows for more effective and sustainable reuse of CDW materials. Recent research has focused on sustainable approaches to CDW management, emphasizing economic, environmental, organizational, regulatory, social, and technical aspects (Rakhshan et al., 2020). Efficient recycling methods not only reduce landfill burdens but also conserve

valuable resources like metals, concrete, and wood (Rakhshan et al., 2020). Furthermore, reusing salvaged materials in future construction projects minimizes raw material consumption, lowers project costs, and fosters community goodwill by demonstrating responsible waste handling (Rakhshan et al., 2020). Sustainable CDW management is crucial for resource conservation, cost efficiency, and community engagement in construction and demolition projects.

Despite the existence of various strategies, no superior strategy has addressed all barrier attributes of reuse distribution comprehensively. While researchers have considered these attributes in developing CDW management strategies, none have systematically assessed and modelled the identified strategies based on all barrier attributes of reuse distribution. Recent studies have identified development barrier attributes for reuse distribution, including economic, environmental, organizational, regulatory, social, and technical aspects, as well as their sub-attributes (Rakhshan et al., 2020). Formulating a sustainable management system for construction and demolition activities remains imperative for addressing these challenges effectively.

Additionally, advancements in technology, such as automated sorting systems and improved material recovery facilities, have the potential to enhance the efficiency of CDW management. Digital tools, like Building Information Modelling (BIM), can facilitate better planning and tracking of materials, promoting reuse and recycling efforts (Cheng & Ma, 2020). Policies and regulations also play a crucial role in CDW management by setting guidelines and standards for waste reduction, encouraging the use of recycled materials, and providing incentives for sustainable practices (Lu & Yuan, 2011). Public awareness and

education campaigns are essential to foster a culture of sustainability within the construction industry and among the public (Poon et al., 2004).

Overall, the multifaceted nature of CDW management requires a holistic approach that integrates technological innovation, regulatory frameworks, economic incentives, and social engagement to achieve sustainable development goals related to waste management and urban sustainability.

1.2 Problem Statement

The problem addressed in this research stems from two distinct gaps: a gap in existing research and a gap in theoretical understanding. Many researchers have developed 51 strategies for reusing (CDW) and have identified six attributes representing barriers to development in this context, which are (economic, environmental, organizational, regulatory, social, and technical aspects) (Ferreira et al., 2015; Klang et al., 2003). In addition to three development sub-attributes of the economic attribute which are cost, market, and value-for-money (da Rocha et al., 2009; Chileshe et al., 2015). Reuse Distribution is described as the process of recycling construction and demolition waste (CDW) materials. The aim of this process is to minimize wastage and the best use of the resources by recycling the used materials in construction. Reuse distribution can be defined as the handling of these materials in a way that they are sorted, processed and assimilated into other projects in a way that reduces the use of virgin resources and the impacts of waste disposal on the environment. It also helps in the conservation of resources in nature and reduction of the overall quantity of CO₂ emissions in construction works.

As for CDW management, development is the enhancement and implementation of measures that would advance the management of construction and demolition waste. This entails the analysis of factors that hamper CDW management and the development of practices that can be sustained. Development is about creating and improving the methods and instruments for handling, recycling, and reuse of CDW. Development aims at eradicating challenges that are economic, environmental, organizational, regulatory, social and technical to improve sustainable and economically viable construction practices.

Examining development sub-attributes under the economic attribute reveals key dimensions such as cost, market, and value-for-money within a sustainable (CDW) management strategy. The cost sub-attribute delves into the financial implications, scrutinizing expenses related to recycling equipment, transportation, and labour (Kabirifar et al., 2020). An illustrative development within this sub-attribute involves comparing the initial investment for a CDW recycling facility with long-term cost savings derived from reduced landfill fees and diminished reliance on new materials (S.O. Ajayi et al., 2016). Shifting to the market sub-attribute, the focus centres on understanding demand and supply dynamics for recycled CDW materials. pertinent example here is the analysis of current and projected future demand for recycled concrete aggregates in the local construction market, guiding strategies to align production with market needs and potentially boosting the utilization of recycled materials (Kabirifar et al., 2020). Additionally, the value-for-money sub-attribute evaluates the balance between costs and benefits, where a development sub-attribute might assess the quality and performance of structures constructed using recycled materials compared to traditional ones, influencing decisions by showcasing the long-term value and durability of sustainable CDW practices. These examples collectively underscore how the development sub-attributes under

the economic attribute contribute to a comprehensive evaluation and enhancement of a sustainable CDW management strategy (Dantata et al., 2005; Ferreira et al., 2015; Klang et al., 2003).

None of the authors has addressed all attributes comprehensively; rather, some authors have taken certain attributes into account while working on management strategies, leaving others overlooked (Mahpour, 2018; Klang, Vikman, & Brattebø, 2003). Despite the existence of these strategies, no superior strategy has simultaneously addressed all barrier attributes of reuse distribution. All researchers have considered these attributes in the development of CDW management strategies (Ferreira et al., 2015; Rakhshan et al., 2021; Klang et al., 2003; Chileshe et al., 2015). However, no research has assessed and modelled the identified CDW management strategies to determine which are the most, least sustainable based on all barrier attributes of reuse distribution, and from here, and this considered a research gap. Effectively addressing CDW requires the removal of the identified barriers. Failure to do so will result in increased waste, escalating costs, and missed opportunities for advancing sustainable development. A comprehensive understanding of these barriers is essential for improving CDW management, thereby achieving enhanced economic, environmental, and social performance.

Three assessment concerns must be addressed to fill this research gap. First, multiple barrier attributes of reuse distribution must be considered (Alnoor et al., 2022; Zaidan et al., 2020). The barrier attributes of reuse distribution in the CDW management strategies are analyzed and identified. According to reference (Rakhshan et al., 2020), six main barrier attributes of reuse distribution (i.e. economic, environmental, organizational, regulatory, social, and technical aspects) are selected to evaluate the CDW management strategies for

reuse. The economic attribute has three sub-attributes: cost, market, and value-for-money. The environmental attribute has only one sub-attribute: energy-and-GHG (Greenhouse Gases). The organizational attribute has four sub-attributes: contracts, experience, infrastructure, and management. The regulatory attribute has two sub-attributes: compliance and incentive. Social attributes have six sub-attributes: awareness, perception, risk, sustainability, trust, and willingness. The technical attribute has four sub-attributes: deconstruction, design, health and safety and information. Second, these attributes must be prioritized based on their importance level (Mahmoud et al., 2022; Jumaah et al., 2018), The importance of criteria is crucial when comparing strategies, as the strength and relevance of these criteria play a major role in decision-making. Third, variance in data is another concern that must be considered when assessing and modelling CDW management strategies (Albahri et al., 2022; Alamleh et al., 2022) Hence, identifying the most and least sustainable strategies for managing CDW becomes a complex issue in the realm of multiple attribute decision-making (MADM). Scholars have devised several MADM methodologies to select the most suitable option from a range of alternatives (Jumaah et al., 2018; Qahtan et al., 2023).

This paper highlighted the consequences of the lack of proper solution to the management of CDW in different areas that have an impact on the stakeholders of the construction sector. In the economic sense, ineffective waste management means that there are extra costs incurred in the disposal of wastes to the landfill sites and are not able to benefit from the reusing of the materials in other projects hence the projects are not financially sustainable. Environmentally, lack of strategies results in poor practices like; increased landfill usage, inefficient resource usage hence, more harm to the environment. At the organizational level, matters of non-compliance and reduced productivity affect the functioning of an organization

and its adherence to the set rules and regulations. Therefore, the lack of such strategies may result in drastic reductions in public trust and the populations' concern with, as well as their willingness to fund and participate in, sustainable endeavors. In a technical way, poor solutions can lead to the compromise of health and safety in the construction industry which is a threat to the lives of construction workers and safety of constructions sites. These issues are still pertinent in the management of CDW and solving them would go a long way in making CDW ecological universally. To address the challenges, MADM involves assessing a set of alternatives using multiple, sometimes contradictory, criteria to determine the most fitting, precise, and accurate selection. Its aim is to rank these alternatives based on preferences. Many types of research specialized in MADM research related to (CDW). Still, none of them are specialized MADM which is focused on the CDW strategies which is considered as a research gap. Currently, various (MADM) techniques have been developed and applied in diverse fields. These techniques are presented as effective solutions to aid decision-makers in addressing complex challenges encountered in practical situations (Asadabadi, Chang, & Saberi, 2019; Shahri et al., 2021).

Ranking method can refer to different concepts depending on the context. In general, a ranking method involves assigning a position or order to a set of items based on certain criteria or attributes. One commonly utilized ranking method based on fuzzy set theory is the "Fuzzy VIKOR" method. Fuzzy VIKOR is an extension of the classical VIKOR method, incorporating fuzzy logic to address uncertainty and vagueness in decision-making processes. In Fuzzy VIKOR, decision matrix entries and weights are represented by fuzzy numbers, allowing for the consideration of imprecise information. The methodology involves steps such as forming a fuzzy decision matrix, normalizing it, and calculating the fuzzy weighted normalized decision

matrix using fuzzy weights assigned to each criterion. Positive and negative ideal solutions are identified, and fuzzy distance measures are employed to assess the proximity of each alternative to these ideals (Abdulkareem et al., 2020). Closeness coefficients are then determined based on the fuzzy distances, facilitating the ranking of alternatives in accordance with their degrees of preference. Fuzzy VIKOR is particularly valuable in decision-making contexts characterized by uncertainty, providing a systematic approach for handling imprecision and enabling the ranking of alternatives in a compromised and optimized manner (Alsalem et al., 2019).

This study proposed method is subjected to an objective comparison analysis with the VIKOR ranking method. The weighting results of barrier attributes of reuse distribution determined by q-ROPHFS–FWZIC are fed into the VIKOR method. The group scorings of the CDW management strategies determined by q-ROPHFS–FDOSM are transmitted into the VIKOR method and serves as the decision matrix. Subsequently, a comparison is made between the ranking outcomes of the VIKOR technique and the proposed approach. Summary of the comparison of ranking outcomes between the MULTIMOORA and VIKOR methods. The q-ROPHFS–FWZIC method utilized seven distinct q values (i.e. 4-10) to derive the weighting outcomes, necessitating the execution of VIKOR based on these values.

According to (Alsalem et al., 2019) BWM determined evaluation criteria weights, while VIKOR assessed and ranked the models. In (MADM), a weighting method is essential alongside a ranking method to account for varying attributes importance. Weighting ensures that different attributes contribute proportionately to the decision outcome, accommodating subjective judgments, balancing trade-offs, and enhancing decision accuracy. Therefore, many MADM weighting methods are utilized by researchers (e.g. AHP, BMW and ANP). In

tackling inconsistency concerns, a new (MADM) weighting method called the fuzzy-weighted zero-inconsistency (FWZIC) was introduced, as discussed in Reference (Mohammed et al., 2022).

The FWZIC method, proposed by (Krishnan et al., 2021; Mohammed et al., 2022) determines weight coefficients for criteria with zero inconsistency, regardless of their quantity. This method precisely computes both local and global weight coefficients for each criterion at a specific hierarchical level, as outlined by (Mohammed et al., 2022). Additionally, FWZIC assesses the importance level of each criterion in decision-making based on expert preferences, according to (Krishnan et al., 2021). Applied in domains like many-objective optimization algorithms (Mohammed et al., 2022) and smart e-tourism data management (Krishnan et al., 2021), FWZIC successfully resolves inconsistency issues and is considered the most effective criteria weighting method for evaluating CDW management development attributes.

FWZIC has been adapted into various fuzzy sets, such as q-rung orthopair, dual-hesitant, neutrosophic, Pythagorean, cubic Pythagorean, interval type 2 trapezoidal, T-spherical, and Pythagorean m-polar FSs, to tackle these challenges. Despite these advancements, concerns regarding vagueness and uncertainty in information persist as ongoing issues. While there's been research on fuzzy sets, there's a gap in studies focusing on (MADM) for ranking, weighting, and scoring (CDW) strategies.

MADM is recognizing the superior performance of q-rung orthopair fuzzy sets (q-ROFSs) compared to earlier fuzzy sets, reference (Zhang et al., 2017) introduced the concept of q-rung orthopair hesitant fuzzy sets (q-ROHFS) and its operational principles. In further development, reference (Attaullah et al., 2022) enhanced q-ROHFS by incorporating

probability considerations, resulting in the creation of q-rung orthopair probabilistic hesitant fuzzy sets (q-ROPHFS). This study aims to innovate and advance the Fuzzy-Weighted Zero-Inconsistency (FWZIC) method using q-ROPHFS. To the authors' knowledge, the integration of q-ROPHFS into FWZIC-based MULTIMOORA methods has not been previously applied in any case study. The q-ROPHFS-FWZIC method is designed to prioritize barrier attributes in (CDW) management strategies based on their respective levels of importance that leads to reasonable outcomes.

The techniques chosen in this research, particularly the use of the q-ROPHFS–FWZIC and Fuzzy VIKOR methods, were selected for their ability to address specific challenges inherent in evaluating CDW management strategies. These challenges include managing the multiple attributes (economic, environmental, organizational, regulatory, social, and technical) that create barriers to effective CDW reuse and recycling.

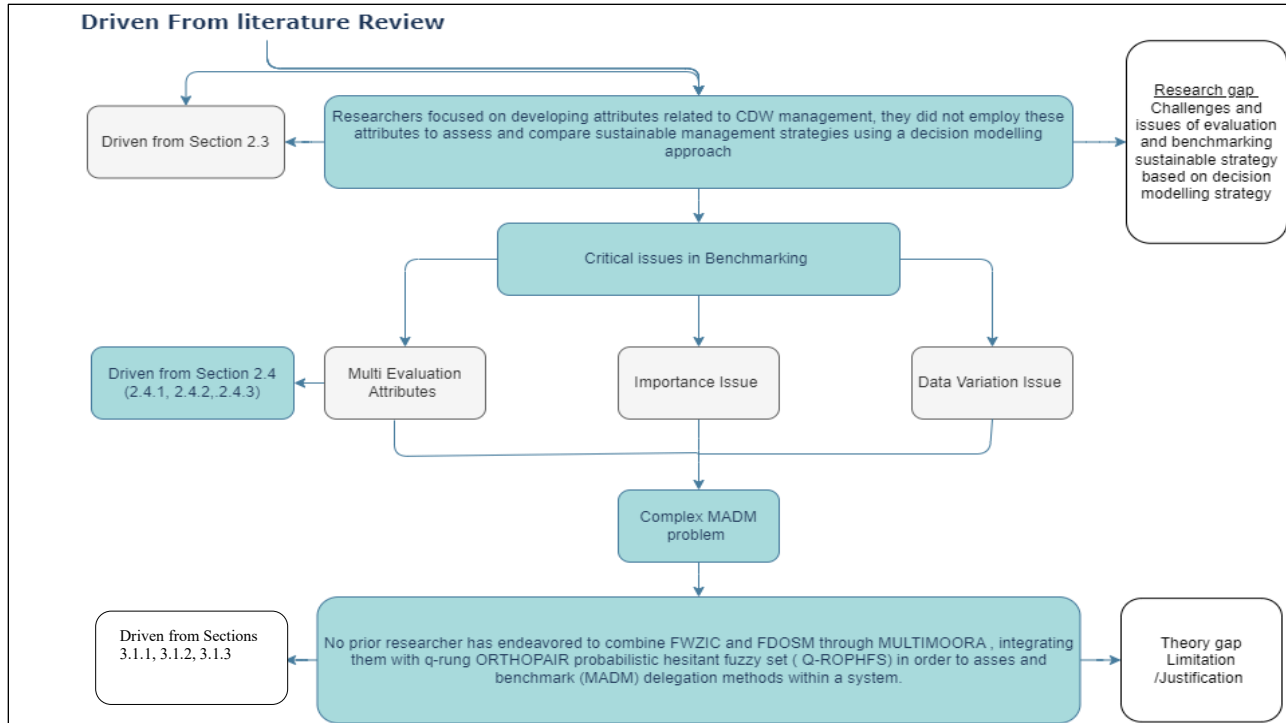
Fuzzy VIKOR was selected to handle uncertainty and vagueness in decision-making, a common issue in assessing CDW strategies where data may be imprecise or incomplete. This method allows for ranking alternatives based on their proximity to ideal solutions, which is useful in identifying the most sustainable CDW strategies when the decision criteria involve ambiguous or imprecise information.

Q-ROPHFS–FWZIC was chosen due to its ability to address inconsistency in criteria weighting. Weighting is critical when prioritizing the multiple attributes (such as cost, market, value-for-money, etc.) because it ensures that each barrier is considered proportionately in the decision-making process. The q-ROPHFS framework enhances the ability to process and analyze hesitant or uncertain information, which is common in real-world applications where expert opinions may vary.

The comparison with VIKOR serves as a validation step to ensure the robustness of the q-ROPHFS–FWZIC method by evaluating the consistency of its results with another well-established ranking method.

The decision to use these specific techniques over others lies in their superior ability to handle uncertainty, prioritize diverse criteria, and resolve issues related to inconsistency, making them highly suitable for evaluating the complex, multi-dimensional nature of CDW management strategies. Other techniques may not have provided the same level of precision in managing vagueness, nor the same degree of flexibility in addressing multiple criteria.

Based on what was analyzed above and a collection of the limitations mentioned earlier and Constraints, the integration of (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS) was not addressed which can be considered a theoretical gap. The specific problem statements are depicted in detail in Figure 1.

Figure 1*Problem Statement Configurations***1.3 Research Quesztions**

Subsequent questions have been devised to guide the trajectory of this research.

- i. **RQ-1:** What evaluation techniques are available for assessing sustainable management strategies in CDW?
- ii. **RQ-2:** What are the criteria that can be used to evaluate and rank sustainable management strategy in CDW?
- iii. **RQ-3:** What are the suitable requirement and techniques for creating a Decision Modelling based approach for sustainable management strategies in CDW to surmount the recognized difficulties and obstacles?

- iv. **RQ-4:** How can an integrated framework be developed to include Sustainable Management Strategies in CDW and development attributes?
- v. **RQ-5:** How the proposed modelling approach can be evaluated and validated?

1.4 Research Objectives

The aim of the research is to develop a modelling approach and benchmarking framework for evaluating Sustainable Management Strategies in (CDW). Therefore, the objectives of this study are as follows:

- i. To investigate the existing evaluation techniques of Sustainable Management Strategies in CDW highlight the evaluation weaknesses.
- ii. To formulate the decision matrices based on the intersection of Sustainable Management Strategies in CDW systems with the CDW attributes.
- iii. To formulate and develop an extension of FWZIC method under an integration of (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS).
- iv. To develop decision-modelling approach for Sustainable Management Strategies in CDW using the formulated decision matrices and the integration of (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS).
- v. To validate the results of the proposed decision modelling approach for Sustainable Management Strategies in CDW using Sensitivity and Correlation Analysis, Systematic modelling, and comparison analysis.

1.5 Connection Among Research Objectives, Questions and Problem

The research questions are outlined to give form and orientation to the investigation in this study, and the research aims to furnish answers to these questions. Each objective corresponds to one or two questions. Moreover, the specific and overarching issues are intertwined with several study objectives and questions. The distinct and comprehensive research challenges stemming from the outlined research questions and their alignment with the research objectives are depicted in Table 1.

Table 1

Connection Among Researches

Research Questions	Research Objectives	Research problem mapping	
		Specific Problem	General problem
RQ-1: What evaluation techniques are available for assessing sustainable management strategies in CDW?	To investigate the existing evaluation techniques of Sustainable Management Strategies in CDW highlight the evaluation weaknesses.		
RQ-2: What are the criteria that can be used to evaluate and rank sustainable management strategy in CDW?	To formulate the decision matrices based on the intersection of Sustainable Management Strategies in CDW systems with the CDW attributes.		
RQ-3: What are the suitable requirements and techniques for creating a Decision	To formulate and develop an extension of FWZIC method under an integration of (FWZIC) method and	Multi Evaluation Criteria	Decision Modelling based approach for sustainable

Modelling based approach for sustainable management strategies in CDW to surmount the recognized difficulties and obstacles?	(FDOSM)-based multiplicative (MULTIMOORA) with the q-rung-orthopair probabilistic hesitant fuzzy set (q-ROPHFS).	Importance of criteria Data variation	management strategy in CDW /Critical issues in Benchmarking
RQ-4: How can an integrated framework be developed to include Sustainable Management Strategies in CDW and development attributes?	To develop decision-modelling approach for Sustainable Management Strategies in CDW using the formulated decision matrices and the integration of (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS).		
RQ-5: How the proposed modelling approach can be evaluated and validated?	To validate the results of the proposed decision modelling approach for Sustainable Management Strategies in CDW using Sensitivity and Correlation Analysis, Systematic modelling, and comparison analysis.		

As per Table 1, the initial question is addressed by the first objective, the subsequent question by the second objective, the third question by the third objective, and the fourth question by the fourth objective. The final question by the fifth objective. Additionally, the first specific problem, termed 'Multi Evaluation Attributes,' is associated with three objectives (second, third, and fourth objectives) and three questions (third, fourth, and fifth questions). In contrast, the second specific problem, labelled 'importance issue,' is linked to the third objective and the fifth question. The last specific problem, identified as 'data variation issue,' is

tied to the third and fourth objectives, as well as the fifth question. Ultimately, the overarching research concern, encompassing the 'Decision Modelling based approach for sustainable management strategy in CDW/Critical issues in Benchmarking,' correlates with three research objectives (second, third, and fourth objectives) and three questions (third, fourth, and fifth questions).

1.6 Scope of the Study

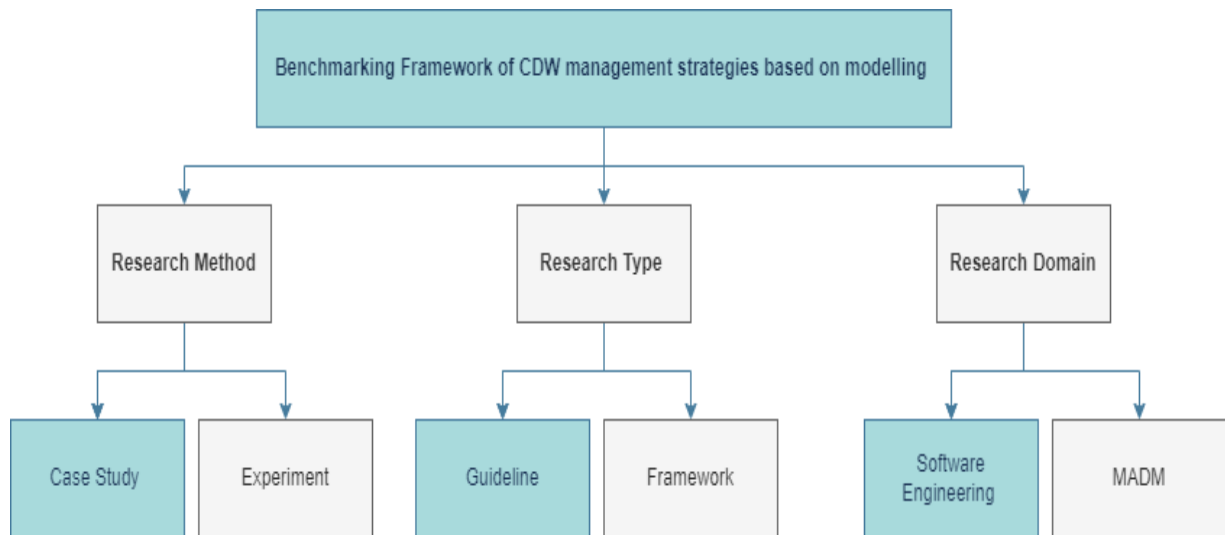
This research identifies the existing techniques for decision Modelling- based approach for sustainable management strategy in CDW. Thus, the scope of this study is determined by the following considerations:

- i. The primary focus of this research is the creation of a decision modelling-based approach for establishing sustainable management strategies in (CDW), employing the principles of (MADM).
- ii. This research centres on presenting decision matrices designed to assess the decision modelling-based approach for achieving sustainable management strategies in (CDW).
- iii. The scope of this study does not involve constructing a decision modelling-based approach for sustainable management strategies in CDW. Instead, CDW serves as a case study within the experiment to generate data, demonstrating the feasibility of our proposed decision modelling approach.
- iv. This study does not assert that the assessment and benchmarking of the decision modelling-based approach for sustainable management strategies in CDW are being claimed.

Figure 2 illustrates the overarching outline and perspective of our research, encompassing the research methodology, type, and domain. The research type pertains to the research outcomes. This study anticipates yielding two distinct outcomes. The initial outcome involves a framework developed through a series of steps that enhance the process of benchmarking the Modelling-Approach for sustainable management strategies in CDW, thereby aiding in the selection of the most secure option. The second outcome comprises a comprehensive guideline for benchmarking and selecting sustainable management strategies in CDW, designed to accommodate the sector's evolving expansion.

Figure 2

General Scheme and Scope of the Study



In addition, the combined MADM technique (weighting and benchmarking methods) can be used to test the performance of sustainable management strategy in CDW to assist construction service providers in making better decisions.

1.7 Significance of the Study

The study's findings offer benefits to diverse stakeholders in the construction industry (Kabirifar et al., 2020), encompassing construction companies, architects, and engineers (Cosgun et al., 2020), policymakers, and the public. For construction companies, the study suggests prioritizing social, economic, and regulatory concerns to enhance sustainable Construction and Demolition (CDW) management strategies. Focusing on risk reduction and complying with regulations could foster public trust and support (Dunant et al., 2018). Architects and engineers could design structures that minimize CDW generation, emphasizing risk reduction (Seror et al., 2019) and technical attributes like health and safety (Napi et al., 2019; Qahtan et al., 2022). Policymakers should concentrate on enforcing compliance and reducing CDW management costs, (Pun et al., 2006) leading to sustainable industry practices. Public members stand to gain an environmentally friendly urban environment, benefiting from reduced risks and improved compliance, resulting in cleaner surroundings, lower emissions, and resource preservation.

Overall, the study's findings have far-reaching implications, promoting sustainable CDW management to benefit the environment, economy, natural resources, society, and public health.

1.8 Main Terminology

Two basic terms in this study and the details are as follows:

- i. **A modelling approach** in the context of Construction and Demolition Waste (CDW) refers to a systematic method or framework used to represent, analyze, and manage

various aspects of CDW management. This approach often involves creating models that represent different elements of the CDW lifecycle, such as waste generation, collection, transportation, recycling, and disposal.

- ii. **MADM** refers to a decision-making process that involves evaluating multiple alternatives based on multiple criteria or attributes. In the context of Construction and Demolition Waste (CDW), MADM involves assessing and comparing different waste management strategies or solutions using a set of criteria that could include environmental impact, cost, feasibility, social acceptance, and more.

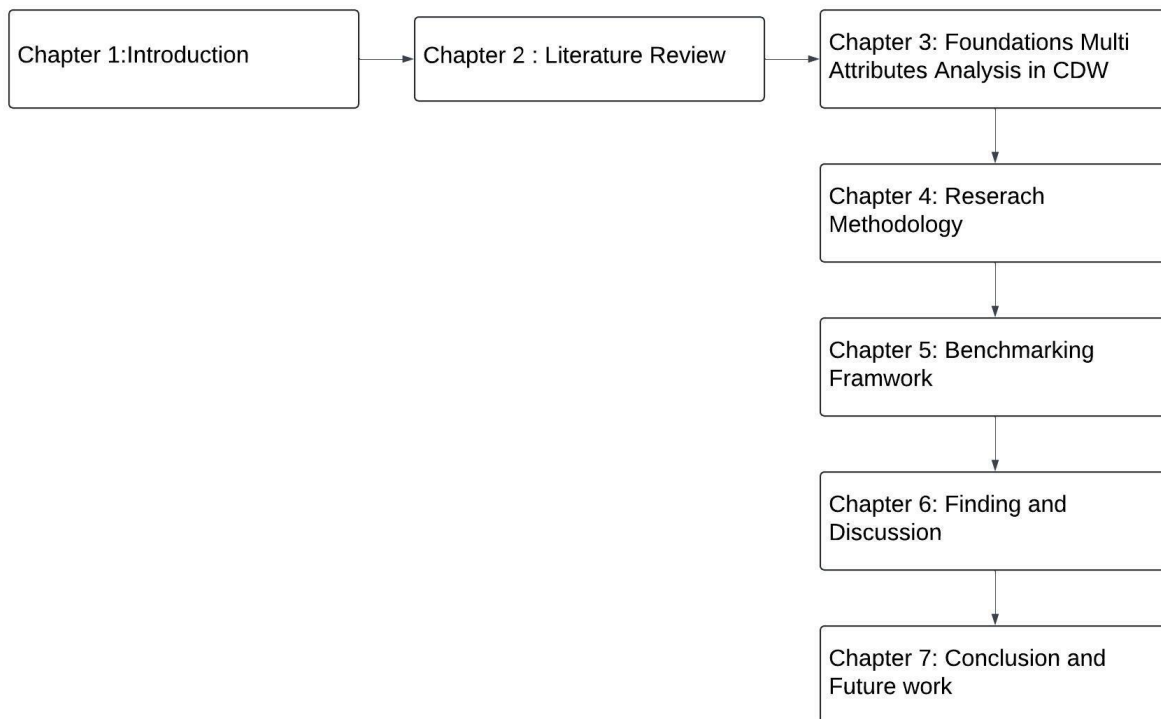
1.9 Structure of Thesis

This thesis is organized into seven chapters, offering a comprehensive exploration of Sustainable Management Strategies in Construction and Demolition Wastes. **The initial chapter** introduces the research's context, significance, outlines research objectives and questions, establishes connections among these elements and the research problem, and defines the study's scope. **Chapter 2** and **3** delves into a taxonomy of literature review on construction and demolition systems, including a critical review, challenges within CDW strategies management systems, the theoretical background, FWZIC and FDOSM methods, and validation and evaluation procedures. The **fourth chapter** elucidates the investigation phase, the proposed benchmarking framework for CDW management strategies, the decision matrix identification phase, formulation and development processes, and validation and evaluation phases. **Chapter 5** addresses the identification of decision matrices, attributes of barriers, CDW strategies management identification, formulation, and development, the q-ROPHFS-FWZIC method, and the utilization of the q-ROPHFS-FDOSM and

MULTIMOORA methods, culminating in results and discussion. **Chapter 6** encompasses modelling results, validation and evaluation outcomes, discussions. Chapter 7 concluded the thesis and discuss the recommendations, and a future review of the study. This research contributes valuable insights to the field of Sustainable Management Strategies in Construction and Demolition Wastes, enriching the existing body of knowledge and providing a foundation for future research. The detailed structure of the thesis is illustrated in Figure 3.

Figure 3

Structure of the Thesis



1.10 Chapter Summary

The chapter delves into the issue of Construction and Demolition Waste (CDW), generated from construction, renovation, and demolition activities. CDW includes materials like concrete, asphalt, and wood and constitutes a significant portion of total solid waste. The adverse environmental and societal effects of CDW generation are highlighted, along with the inefficiencies of current practices. Notably, a considerable amount of CDW ends up in landfills worldwide, leading to environmental concerns. CDW's impact on sustainable urban growth due to limited landfill space, toxic emissions, energy use, and water pollution is emphasized. The necessity of reducing, reusing, and recycling CDW for sustainability is discussed. However, many existing studies lack comprehensive classification and systematic evaluation of CDW attributes, particularly in relation to efficient management.

The chapter underscores the importance of sustainable CDW management strategies across economic, environmental, organizational, regulatory, social, and technical aspects. Reuse is favoured over recycling, but the latter dominates due to its resource-intensive nature. The reuse of construction elements is a challenge in waste demolition. The study identifies a gap in the existing research regarding a lack of a comprehensive strategy that simultaneously addresses all barrier attributes of reuse distribution. It proposes the integration of various methods to address this gap. The research objectives are laid out, including investigating evaluation techniques, formulating decision matrices, developing an extension of the FWZIC method, and creating a decision modelling-based approach for CDW management. The chapter outlines the research questions and their alignment with objectives and problems. The

scope of the study is defined, focusing on developing a modelling approach and benchmarking framework for sustainable CDW management.

The study's significance is outlined, offering benefits to stakeholders such as construction industry players, architects, engineers, policymakers, and the public. Overall, the chapter provides an overview of the complex issue of CDW, its challenges, and the research goals to address these challenges for sustainable management.

Chapter 2: Literature Review

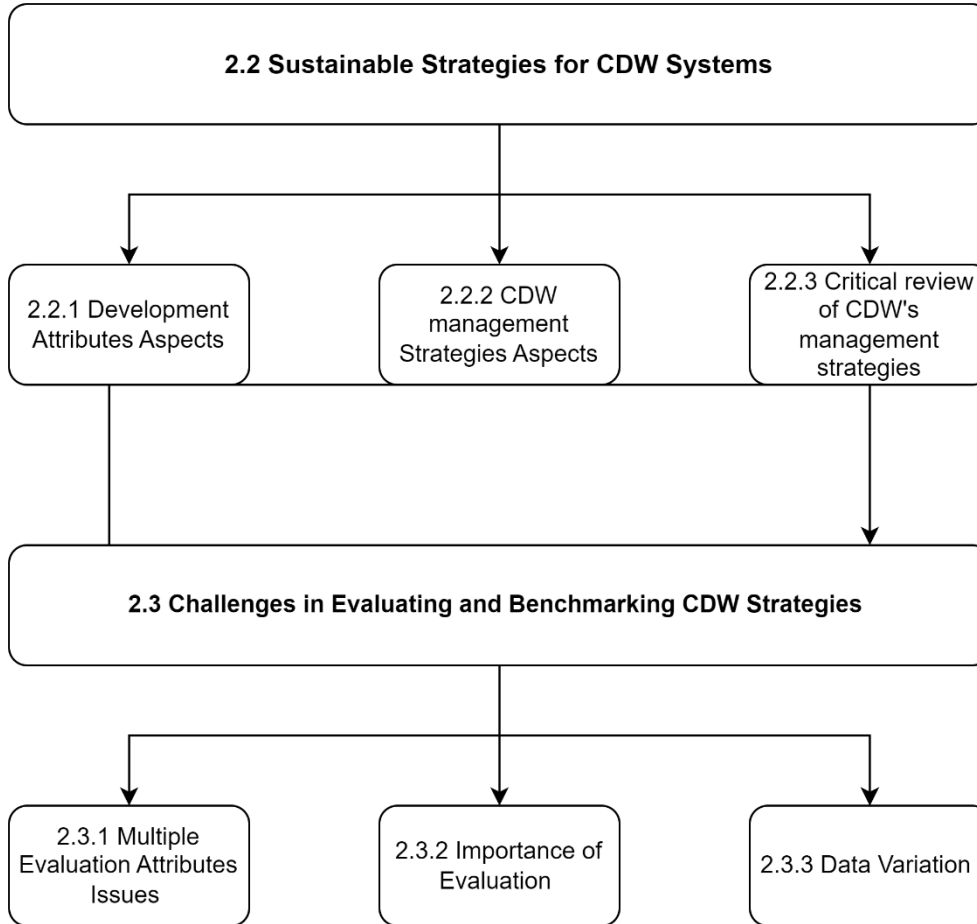
2.1 Introduction

The review aims at determining the most effective practices, techniques and strategies used in the current literature. An extensive search approach is employed, and the databases employed are Google Scholar, Scopus, Web of Science, and PubMed. These are used to refine the search by using specific terms like ‘sustainable CDW management’, ‘waste reduction’, and ‘circular economy in waste management’. The criteria for the selection of articles are the articles published in peer-reviewed journals, conference papers, and case studies during the period of 2016-2022 that are associated with sustainable approaches in CDW management. The application of the most recent and relevant research is made possible by the selected time frame of 2016-2022, which reflects the current practices, technologies, and policies. Peer-reviewed sources are used because they are more reliable and contain research information that is credible. Thus, focusing on CDW management means that the focus is on getting information on sustainability. The combination of empirical and theoretical research gives a comprehensive outlook of the field by integrating practice with theory.

In Section 2.2, we present a taxonomy of the literature review focusing on the sustainable management system in (CDW), along with the attributes of their development. Following this, Section 2.3 delves into an analysis of the critical aspects of the sustainable management system in CDW. The discussion highlights key elements such as resource conservation, waste minimization, and the circular economy paradigm, elucidating their significance in addressing the challenges posed by CDW. Additionally, Section 2.4 explores the challenges and issues pertaining to the sustainable management system in CDW,

addressing concerns such as regulatory compliance, stakeholder engagement, and technological innovation. A comprehensive discussion on benchmarking practices in CDW management is also provided, emphasizing the importance of performance measurement and continuous improvement in driving sustainability outcomes.

Figure 4 below gives the structure of the literature review with two sections the definitions and empirical literature, and the theoretical literature part. The separation of these sections allows for a clear and organized presentation of two distinct but interconnected aspects of the literature: the materials necessary for determining the overall picture of the real situation of CDW management systems sustainability and their properties, on the one hand, and the theoretical conclusions that can be drawn to predict further actions.

Figure 4*Framework of the Literature Review*

2.2 Sustainable Strategies for CDW Systems

Sustainable Strategies means the methods and practices that aim at improving the social, environmental, and economic sustainability (Hermundsdottir & Aspelund, 2022). Thus, the strategies are hereby understood as activities and measures that are to reduce the adverse effects of construction and demolition waste on the environment while at the same time, enhancing the social and economic benefits. For instance, one of the strategies that have been

considered useful is the circular economy model which is a management of waste with an intention of recycling them. This approach tries to minimize the consumption of resources and to connect the cycles of the product life by giving the chance of recycling and reusing the material from the demolition sites. This in turn helps in cutting down on waste that is dumped into the landfills and the exploitation of new resources. This strategy can be said to be superior, and it covers more than one attribute of sustainability like the environmental aspect, the economic aspect and the social aspect. They are useful in managing CDW because they cover all the facets of sustainability; thus, providing an all-encompassing approach to the problem.

This section of literature concentrates on the development of CDW systems that are used to reuse distribution. The search was carried out by utilizing index databases spanning the years from 2016 to 2022, a total of around 20,900 research papers were generated and spread across various databases such as ACM Digital, Google Scholar, IEEE, IGI Global, Science Direct, and Scopus. These papers revolved around Security Modules of Delegation Methods in Mobile Cloud Computing and the associated security concerns. Following this initial compilation, a series of refinement steps were undertaken, including eliminating duplicates and applying specific inclusion and exclusion criteria. These criteria encompassed factors such as relevance to the security issues, usage of English language, publication in reputable journals or conferences, avoidance of outdated information, and adherence to the precise subject matter. Subsequently, a meticulous abstract screening process was employed to verify the alignment of each paper with the designated topic. As a result of these stringent selection measures, a final set of 51 papers were chosen for further analysis and consideration.

The scope of this study analysed the selected papers based on two aspects, which are (i) CDW management strategies (ii) six barriers' attributes. Figure 5 shows the Taxonomy of literature review on construction and demolition system development use decision-methodology for Approaching sustainable management strategies based on barrier attributes of reuse distribution.

The criteria for selecting research papers from 2016 to 2022 were carefully designed to ensure relevance, quality, and alignment with the research objectives. The chosen time frame captures the most up-to-date studies on CDW systems and reuse distribution strategies, reflecting recent advancements in the field. Reputable databases such as ACM Digital, Google Scholar, IEEE, IGI Global, Science Direct, and Scopus were used to guarantee access to peer-reviewed, high-quality research. Inclusion criteria focused on papers relevant to security concerns in CDW, written in English, published in reputable journals or conferences, and containing current, non-outdated information. Duplicates and irrelevant studies were excluded to avoid redundancy and narrow the focus to pertinent material. A meticulous abstract screening process further ensured that selected papers specifically addressed CDW management strategies and the six barrier attributes. This rigorous approach resulted in a final selection of 51 papers, ensuring a reliable, focused, and comprehensive analysis of the subject matter.

Besides, the authors identified 51 CDW management strategies for reuse and six development barrier attributes for reuse distribution (e.g. economic, environmental, organizational, regulatory, social, and technical aspects). The 51 variants mentioned above relate to the strategies and methods that have been found during the literature review. These variants are a broad spectrum of activities, each targeted at a specific area and carried out

about CDW management. The three development sub-attributes of the economic attribute are cost, market, and value-for-money. The only sub-attribute of the environmental attribute is energy-and-GHG. The four development sub-attributes of the organizational attribute are contracts, experience, infrastructure, and management. The development sub-attributes of the regulatory attribute are compliance and incentive. The six development sub-attributes of the social attribute are awareness, perception, risk, sustainability, trust, and willingness. The four development sub-attributes that comprise the technical attributes are deconstruction, design, health and safety, and information.

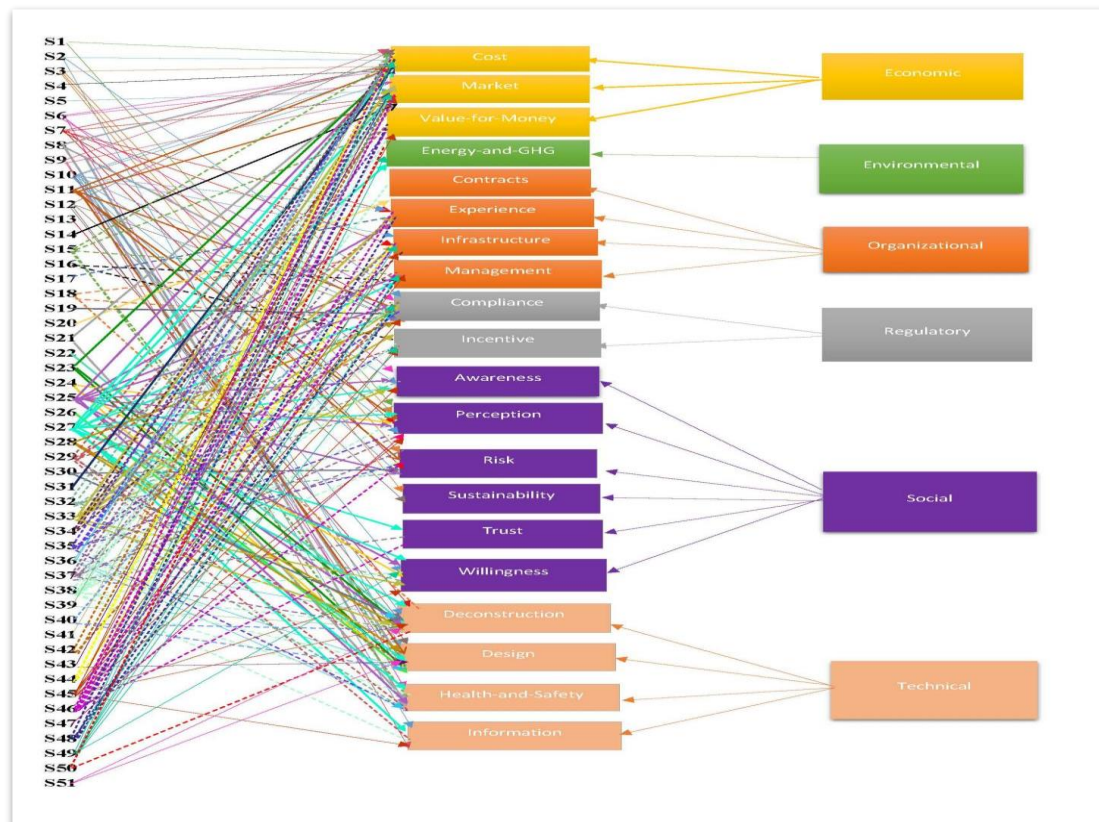
Likewise, future research could move deeper into the specific methodologies used in the development and implementation of these CDW management strategies. Additionally, exploring case studies or real-world applications of these strategies in various construction projects could provide valuable insights into their effectiveness and practicality. Moreover, investigating the synergies and potential conflicts between different CDW management strategies, especially in the context of addressing multiple barrier attributes simultaneously, could offer a more nuanced understanding of their interrelationships and trade-offs. This could pave the way for the refinement and optimization of existing strategies, or the development of incoming approaches suitable to specific contextual requirements and constraints.

These technologies have the potential to improve data collection, monitoring, and analysis, facilitating more informed decision-making and efficient use of resources. Interdisciplinary collaborations involving urban planners, and environmental and social scientists can enrich the understanding of CDW management from multiple perspectives, leading to more holistic and integrated solutions. Exploring the policy frameworks and regulatory incentives that support sustainable CDW practices can also provide valuable

insights into how government interventions can support and accelerate the adoption of effective CDW management strategies. By addressing these areas, future research can contribute to the development of more robust, adaptive, and sustainable CDW management systems.

Figure 5

A Taxonomy of Research Literature



2.2.1 Development Attribute Aspects

Based on our analysis and the proposed taxonomy (as discussed in Section 2.2 and illustrated in Figure 5, the literature employs six primary attributes representing development barriers (e.g. economic, environmental, organizational, regulatory, social, and technical aspects) to enhance construction and demolition waste (CDW) strategies. Furthermore, a total of 20 sub-attributes (i.e., cost, market, and value-for-money, energy-and-GHG, contracts, experience, infrastructure, management, compliance, incentive, awareness, perception, risk, sustainability, trust, willingness, deconstruction, design, health and safety, and information) are utilized for the evaluation and enhancement of CDW strategies. The subsequent section provides a comprehensive and detailed examination of how these attributes are applied in various contexts within CDW strategies.

The management of sustainable strategies for Construction and Demolition Waste systems is a complex process that should consider economic, environmental, organizational, regulatory, social, and technical aspects. Economically, sustainable CDW management should target the lowest possible cost or attractive source of income. Resource conserving measures reduce expenses related to the collection, transportation, and processing of waste, which is achieved through the application of technology. According to Karaca & Tleuken (2024), it is effective to adopt cost-effective CDW by prohibiting the use of outdated technology in recycling wastes. Recycling technologies ‘high acquisition costs can be offset by the long-run gains derived from utilizing them. However, one must acknowledge that stimulating the market to buy recycled materials can also yield major economic benefits. It is, therefore, possible to create a demand-driven market by creating standards regarding recycled products

and encouraging their use in the construction of new buildings. This not only benefits recycling businesses but also creates sources of income. However, the CDW sector can also generate many jobs for collection and sorting as well as processing and selling, which, in turn, can foster the economy. Training interventions are crucial for preparing these workers, which therefore improve both employment and efficiency in the sector.

Chen et al. (2018) research shows that CD is among the most voluminous waste streams worldwide. The study further indicates that CDW accounts for approximately 50% of waste in the United Kingdom, and its inappropriate treatment has contributed significantly to environmental pollution. The sustainability of CDW mainly focuses on cutting down the impact of construction activities on the environment. This entails a reduction in the amount of waste that is sent to the landfills through increased recycling and reuse, saving the limited spaces in the landfills and preserving the land. In addition, the recycling and reusing of CDW reduces the use of natural resources in construction, including timber, sand, and gravel, as the demand for raw materials is reduced; hence, they do not have to be extracted and processed. These measures are very important for the management of biological diversity and the prevention of further deterioration of the environment occasioned by activities such as mining and logging. Also, it is worth highlighting another nevertheless multifaceted advantage that is most associated with environmental safety: a decrease in greenhouse gas emissions. These simple changes to one's lifestyle reduce the requirement of creating new material, thus reducing the emissions involved in such processes and promoting the fight against climate change.

From the organizational perspective, better CDW management and proper handling demands extensive cooperation with several entities, such as construction companies, waste

disposal firms, and several authorities. Having adequate delegation of work enables performance and duties to be properly aligned throughout the organization. Organizations must take greater responsibility for the construction of structures; now that the life cycle of a building has adopted the adage design for deconstruction, this will aid in the easier recovery and recycling of material at the times the building is quite done. Also, employee training and development assist with achieving high employee engagement levels, as well as generating a competent human resource team that can efficiently establish and execute sustainable measures. Organizational commitment to sustainability can also be fortified by the inclusion of sustainability objectives into corporate guidelines or performance standards.

Regulations are instrumental in the effective CDW management and development of sustainable strategies. They create clear requirements that manufacturers and businesses have to adhere to with regard to waste management, which helps in establishing practical and standard guidelines for the manner in which waste has to be managed. Such measures comprise legal requirements to recycle specific amounts of waste, recycling benchmarks that must be met, and legal consequences to be faced for non-adherence. Also, for the same reason, the relevant legislation can offer attractive packages, including tax exemptions or subsidies, to relevant stakeholders with the expectation that these will finance sustainable initiatives.

Another policy instrument is the Extended Producer Responsibility (EPR) program, which shifts the performers' responsibility to producers for a product throughout the entire supply chain back to natural resource units and includes recycling or disposal (Santos et al., 2024). Such policies make sure that today's environmental costs are reflected in product design and waste disposal, and they promote sustainability.

On the social aspect, the best practice and more sustainable approach to CDW management may pose a substantial opportunity to bring about community values. People must be encouraged through awareness creation and publicizing of campaigns that advocate for sustainability and individual and corporate participation in recycling. The social impacts pertain to the handling and utilization of CDW since dangerous compounds are present in these construction wastes. A proper work environment that must be provided for the waste management workers is also crucial. Furthermore, the actual people's engagement in CDW projects can result in increased social capital and local development. For instance, incorporating recycled materials in most community projects like public structures or homes will be of immense benefit to the people of the respective communities as it will strengthen resilience in terms of available resources.

Technically, the implementation and use of improved and better technologies in recycling play a prominent role in the successful management of CDW. High-tech sorting devices and novel processors will greatly enhance the efficiency and quality of the recovered materials (Karaca & Tleuken, 2024). They help track the generation, composition, and recycling of CDW, as well as assist in planning and decision-making. In addition, the design of components for easy deconstruction must be adopted within the construction industry so as to enhance the proper disassembly and recovery of the used materials. In addition to improving recyclability, such strategies add more value to the given materials' application by promoting circularity.

Understanding the nuanced interplay between these attributes is crucial for developing effective CDW management strategies that address diverse CDW challenges needs. For instance, while economic considerations such as cost and market dynamics influence the

feasibility and profitability of CDW management practices, environmental attributes like energy consumption and greenhouse gas emissions are essential for assessing the ecological effects of these strategies. Similarly, organizational attribute such as experience, infrastructure, and management capabilities play a significant role in determining the operational efficiency and scalability of CDW initiatives. Regulatory attribute, including compliance with waste management regulations and incentives for sustainable practices, shape the legal and policy framework within which CDW strategies operate. Social attribute such as awareness, perception, and trust impact public acceptance and support for CDW initiatives, while technical attributes like deconstruction attribute, design, and health and safety sub attribute determine the practical feasibility and safety of implementing these strategies.

Moreover, recognizing these attributes' inherent complexity and interconnectedness is essential for developing holistic and integrated approaches to CDW management. By adopting a multidimensional perspective that considers economic, environmental, social, organizational, regulatory, and technical attributes, stakeholders can design more flexible and sustainable the construction and demolition waste (CDW) strategies that maximize resource efficiency, minimize environmental impact, and promote social equity. This comprehensive understanding can inform the development of targeted interventions, policy frameworks, and decision-making tools that address the diverse challenges and opportunities associated with CDW management in a rapidly develop global context.

In fact, future research could explore the dynamic nature of these attributes and their implications for long-term CDW management strategies. By examining how economic, environmental, and social trends influence the effectiveness of CDW initiatives over time, researchers can identify potential risks and opportunities for adaptation and innovation.

Additionally, incorporating stakeholder perspectives and participatory approaches into CDW research can enhance the relevance and applicability of findings, fostering greater collaboration and engagement among industry, government, and civil society actors.

Ultimately, advancing our understanding of CDW management attributes and their interactions can contribute to the development of more sustainable, inclusive, and resilient built environments that meet the needs of present and future generations.

Overall, by embracing the complexity and interconnectedness of CDW management attributes, stakeholders can develop more strong and effective strategies for addressing the challenges of waste reduction, resource recovery, and sustainable development in the built environment. Through interdisciplinary collaboration, innovative technologies, and participatory decision-making processes, the vision of a circular economy where waste is minimized, resources are conserved, and communities thrive can become a reality.

2.2.2 CDW Strategies Management Aspects

On the authority of Strategy1, the author has conducted economic and social attributes, where the cost sub-attribute refers to the disposal costs, material costs, and construction costs, followed by the perception sub-attribute under the social attribute. On the other hand, strategy 2 has been managed by the author in sub-attribute cost under economic attribute, sub-attribute compliance under regulatory attribute, and sub-attribute design under technical attribute.

Strategy 3 developed by the author evaluated two main attributes; economic and social, where it used sub-attribute cost under the economic attribute and sub-attributes sustainability, risk, and perception under the social attribute. Strategy 4 has analysed the cost sub-attribute from the main attribute economic. Similarly, to strategy 4, strategy 5 has conducted only one

attribute, which is the sub-attribute market from economic attribute. Unlike the previous strategies, strategy 6 has studied five sub-attributes from the main attributes, which are sub-attribute health and safety from technical attribute, sub-attribute awareness from social attribute, sub-attribute compliance from regulatory attribute, and sub-attributes cost and market from economic attribute. Likewise, strategy 7 evaluated seven sub-attributes from four main attributes, where has discussed the sub-attributes cost and market from economic attribute, sub-attributes experience and infrastructure from organizational attribute, compliance sub-attribute from regulatory attribute, and sub-attribute perception and risk from social attribute. Strategy 8 has assessed the sub-attribute cost under the economic attribute and sub-attribute compliance from the regulatory sub-attribute and the sub-attribute design and health and safety from the technical attribute. Whereas Strategy 9 evaluated the sub-attribute cost and market from the main attribute economic and the sub-attribute design and information from the main attribute technical. Furthermore, strategy 10 has tested five main attributes and twelve sub-attributes which it listed as sub-attributes cost and market from economic attribute, sub-attribute experience and infrastructure from organizational attribute followed by sub-attribute compliance from regulatory attribute, sub-attribute awareness, perception, risk, and willingness from social attribute, finally, sub-attribute design and information from technical attribute.

These findings offer a comprehensive overview of the strategies employed by the author in evaluating CDW management practices across various attributes and sub-attributes. By systematically examining the alignment between strategies and attributes, researchers can gain valuable insights into the effectiveness and applicability of different management approaches in addressing key sustainability concerns. Additionally, the detailed analysis of

sub-attributes provides a nuanced understanding of the specific dimensions considered within each strategy, highlighting areas of focus and potential improvement. This information can guide future research efforts aimed at refining and optimizing CDW management strategies to achieve greater sustainability outcomes.

Moreover, the comparison of strategies reveals the diversity of approaches utilized in previous studies, reflecting the complexity of CDW management and the multifaceted nature of sustainability considerations. By identifying commonalities and differences among strategies, researchers can identify gaps in current practices and opportunities for innovation. This comparative analysis lays the groundwork for future studies aimed at developing integrated frameworks or standardized methodologies for evaluating CDW management strategies, thereby advancing the state-of-the-art in sustainable construction practices. Through continued collaboration and interdisciplinary research, the construction industry can work towards more holistic and effective solutions for managing CDW and promoting environmental stewardship.

These findings offer a comprehensive overview of the strategies employed by the author in evaluating CDW management practices across various attributes and sub-attributes. By systematically examining the alignment between strategies and attributes, researchers can gain valuable insights into the effectiveness and applicability of different management approaches in addressing key sustainability concerns. Additionally, the detailed analysis of sub-attributes provides a nuanced understanding of the specific dimensions considered within each strategy, highlighting areas of focus and potential improvement. This information can guide future research efforts aimed at refining and optimizing CDW management strategies to achieve greater sustainability outcomes.

Furthermore, the comparison of CDW strategies includes different of methods utilized in previous studies, reflecting the sophistication of CDW management and the multifaceted nature of sustainability considerations. By identifying commonalities and differences among strategies, researchers can pinpoint gaps in current practices and opportunities for innovation. This comparative analysis lays the groundwork for future studies aimed at developing integrated frameworks or standardized methodologies for evaluating CDW management strategies, thereby advancing the state-of-the-art in sustainable construction practices. Through continued collaboration and interdisciplinary research, the construction industry can work towards more holistic and effective solutions for managing CDW and promoting environmental stewardship.

In addition to assessing existing strategies, future research could explore novel approaches for evaluating CDW management practices. For instance, incorporating emerging technologies such as artificial intelligence and machine learning could enhance the predictive capabilities of decision-making models, enabling more accurate assessments of sustainability impacts and potential outcomes. Furthermore, there is a need for longitudinal studies that track the effectiveness of CDW management strategies over time, allowing researchers to assess their long-term sustainability and adaptability in response to evolving environmental and regulatory conditions. Additionally, exploring the role of stakeholder engagement and community involvement in shaping CDW management practices could provide valuable insights into the social dynamics and governance structures that influence sustainability outcomes. By addressing these research gaps and exploring new avenues for inquiry, scholars can contribute to the ongoing evolution of sustainable CDW management practices and support the transition towards a circular economy paradigm in the construction industry.

Accordingly, strategy 11 has assessed three main attributes and six sub-attributes, which are sub-attribute cost and market from economic attribute, sub-attribute compliance from regulatory attribute, sub-attribute perception and risk from social attribute, and sub-attribute risk from technological attribute. While strategy 12 has performed in the cost sub-attribute, compliance sub-attribute from regulatory attribute and sustainability sub-attribute under social attribute, and design sub-attribute under technical attribute. Dissimilar to the previous strategies, strategy 13 has managed on only one sub-attribute that is deconstruction from technical attribute. As well as strategy 13, strategy 14 was developed by market sub-attribute from economic attribute. Whilst strategy 15 evaluated the cost and value of the money sub-attribute from the economic attribute, management sub-attribute from organizational and design, and health and safety from the technical attributes. Strategy 16 assessed the management sub-attribute from organizational attribute and sub-attribute incentive from regulatory attributes. Moreover, strategy 17 tested experience sub-attributes from organizational attribute. Strategy 18 has evaluated sub-attribute infrastructure from organizational attribute then compliance sub-attribute from regulatory and deconstruction sub-attribute from technical attribute. In this stage, strategy 19 is performed in the compliance sub-attribute under the regulatory attribute. Strategy 20 was developed by testing the experience sub-attributes from the organizational attributes.

Furthermore, strategy 21 assessed in cost sub-attribute from the economic and health and safety sub-attribute from the technical attribute. With reference to strategy 22 used deconstruction sub-attribute from technical attribute. Strategy 23 assessed with cost-sub-attribute from economic and deconstruction and design sub-attributes from technical attribute. In strategy 24 perception and Willingness sub-attribute from social attribute and design sub-

attribute from technical attribute have been tested. Besides strategy 25 has been evaluated in most of the attributes, in cost sub-attribute from economic attribute, experience, and management sub-attribute from organizational attribute, compliance sub-attribute from regulatory, awareness, perception, risk, and willingness sub-attribute from social attribute, and finally deconstruction and health and safety sub-attribute from technical attribute. Strategy 26 has been performed in the design sub-attribute from the technical attribute. Strategy 27 has assessed five main attributes and twelve sub-attributes where is cost and market sub-attribute from the economic attribute, the energy, and GHG sub-attribute from the environmental attribute, the compliance sub-attribute from the regulatory attribute, awareness, perception, risk, and willingness sub-attribute from social attribute, and deconstruction design, health, and safety and information sub-attribute from technical attribute. In a typical case, strategy 28 evaluated the compliance sub-attribute from regulatory, and deconstruction, and the design sub-attribute from the technical attribute. However, cost and value of money sub-attribute, experience sub-attribute, management from organizational attributes, and incentive sub-attribute from regulatory, design, health and safety, and information sub-attribute from technical attributes have been evaluated in strategy 29. Strategy 30 has been assessed in two sub-attributes from two main attributes, which are the risk sub-attribute from social and the deconstruction sub-attribute from technical.

Strategy 31 developed in one sub-attribute from the main attribute economic, which is cost. In strategy 32 author has assessed the cost and market sub-attribute from economic attributes, the compliance sub-attributes from regulatory, awareness, perception, risk, and willingness sub-attributes from social attributes, and the health and safety sub-attribute from technical attributes. Strategy 33 has been conducted in market sub-attribute from economic

attribute, experience, and infrastructure sub-attribute from organizational attribute, compliance, and incentive sub-attribute from regulatory, awareness and willingness sub-attribute from social attribute, and deconstruction sub-attribute from technical attribute. While strategy 34 has tested the cost and market sub-attributes from the economic attributes and the infrastructure sub-attribute from the organizational attribute. Likewise, strategy 35 has been evaluated by many attributes, like cost, market, value for money sub-attribute from economic, compliance, incentive sub-attribute from regulatory attribute, although, perception and risk sub-attribute from social attribute, and health and safety sub-attribute from technical attribute (Rakhshan et al., 2021). On other hand, strategy 36 has been proposed by using cost and market sub-attributes from economic attributes, then deconstruction, design, and health and safety sub-attributes from technical attributes. Strategy 37 has evaluated by multi attributes, starting with the cost and market sub-attribute from the economic attribute, and experience and infrastructure from the organizational attribute, then compliance from the regulatory attribute, also, perception, risk, and trust sub-attribute from the social attribute, finally deconstruction sub-attribute from technical attribute. Dissimilar to the previous strategy 37, strategy 38 has assessed all main attributes except environmental attribute, where it evaluated the cost, market, and value of money sub-attributes from economic attributes; then contracts sub-attribute from organizational attributes, in addition to compliance and incentive sub-attribute from regulatory attribute, the awareness, perception, risk, and willingness sub-attribute from social attribute, lastly, the deconstruction, design, health and safety and information sub-attribute from technical attribute. Whereas strategy 39 tested two attributes only which are the cost sub-attribute from the economic attribute and the deconstruction sub-attribute from the technical attribute. Similarly, to strategy 39, strategy 40 has been conducted in two attributes:

infrastructure sub-attribute from organizational and deconstruction and design sub-attribute from technical attribute.

Furthermore, strategy 41 assessed cost sub-attribute from economic attributes only. While strategy 42 has evaluated two main attributes, which are, the cost and market sub-attribute from the economic attribute, and the compliance sub-attribute from the regulatory attribute. Moreover, strategy 43 evaluated the market sub-attribute from the economic attribute and the design sub-attribute from technical attribute. Additionally, strategy 44 has been rated in cost sub-attribute from economic attribute and infrastructure sub-attribute from organizational attribute. Besides, the cost, market, and value of money sub-attribute from economic, the infrastructure, management sub-attribute from organizational attribute and compliance, incentive sub-attribute from regulatory, perception, willingness sub-attribute from social, and deconstruction and information sub-attribute from technical have been conducted all in strategy 45. Meanwhile, strategy 46 has used a variation of sub-attributes from the main attributes; firstly, the cost, market, and value of money sub-attribute from economic, secondly, the experience, management, and infrastructure sub-attribute from organizational attribute, thirdly, risk and trust sub-attribute from social attribute. Further, strategy 47 has been proposed by the author in one attribute that is the perception sub-attribute from social attribute. About strategy 48 has sophisticated by the cost and value of money sub-attribute from the economic attribute, then the experience and infrastructure sub-attribute from the organizational attribute, and the compliance sub-attribute from the regulatory attribute. Strategy 49 assessed in cost, market sub-attribute from economic attribute, moreover, energy and GHG sub-attribute from environmental attribute, and infrastructure and management sub-attribute from organizational, compliance and incentive from regulatory, final sub-attribute is

willingness from social attribute. Strategy 50 has evaluated two attributes only, the energy and GHG sub-attribute from environmental and the deconstruction sub-attribute from technical attributes. Eventually, strategy 51 was developed by assessing two sub-attributes from one attribute, which is the deconstruction and design sub-attribute from the technical attribute.

2.2.3 Critical Review of CDW's Management System

The researchers focused on developing CDW management strategies. They attempted to develop six attributes (e.g. Economic, environmental, organizational, regulatory, social, and technical) per attribute has different sub-attributes (Ferreira et al., 2015; Klang et al., 2003). As mentioned previously, nearly 51 CDW strategies, as an outcome to determine the scope of the research, are presented in six attributes and 20 Sub-attributes.

A total of six attributes are present in the illustration of 51 CDW management strategies as shown in Table 2, where the YES/NO approach indicates whether the development attributes are included or not.

Table 2 illustrates our analysis of the 51 CDW management strategies for reuse in terms of the presence or absence of the development barrier attributes for reuse distribution in each strategy.

Twelve strategies (e.g. Strategy₄ (Dantata et al., 2005) Strategy₅ (Pun et al., 2006) , Strategy₁₃ (Jaillon et al., 2010), Strategy₁₄ (Rogers, 2011), Strategy₁₇ (Coelho et al., 2012), Strategy₁₉ (Höglmeier et al., 2013) , Strategy₂₀ (Gangoellis et al., 2014), Strategy₂₂ (Jaillon et al., 2014), Strategy₂₆ (Ferreira et al., 2015), Strategy₃₁ (Cooper et al., 2016), Strategy₄₁ (Gálvez-Martos et al., 2018) and Strategy₄₇ (Mahpour , 2018) out of the 51 strategies had only one attribute, which represents 5% of the attributes. Strategy₄ (Dantata et al, 2005), and

Strategy₃₁ (Cooper et al., 2016), had the cost sub-attribute. Strategy₅ (Pun et al., 2006), Strategy₁₄ (Rogers, 2011) and Strategy₄₁ (Gálvez-Martos et al., 2018) had the market sub-attribute. Strategy₁₃ (Jaillon et al., 2010) and Strategy₂₂ (Jaillon et al., 2014) had the deconstruction sub-attribute. Strategy₁₇ (Coelho et al., 2012) and Strategy₂₀ (Gangolells et al., 2014) had the experience sub-attribute. Strategy₁₉ (Höglmeier et al., 2013), Strategy₂₆ (Ferreira et al., 2015) and Strategy₄₇ (Mahpour, 2018) had compliance, design, and perception sub-attributes, respectively.

Table 2*Summary of CDW Management Strategies*

CDWs management strategies/Attributes	Economic			Environmental Energy-and-GHG	Organizational				Regulatory		Social						Technical				The percentage of attributes existence in each strategy
	Cost	Market	value-for-money		Contracts	Experience	Infrastructure	Management	Compliance	Incentive	Awareness	Perception	Risk	Sustainability	Trust	Willingness	Deconstruction	Design	Health-and-safety	Information	
Strategy ₁	Yes	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	10 %
Strategy ₂	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	15 %
Strategy ₃	Yes	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	20 %
Strategy ₄	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₅	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₆	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	Yes	No	25 %
Strategy ₇	Yes	Yes	No	No	No	Yes	Yes	No	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	35 %
Strategy ₈	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	20 %
Strategy ₉	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes	20 %
Strategy ₁₀	Yes	Yes	No	No	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	60 %
Strategy ₁₁	Yes	Yes	No	No	No	No	No	No	Yes	No	No	Yes	Yes	No	No	No	No	Yes	No	No	30 %
Strategy ₁₂	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	Yes	No	No	Yes	Yes	No	No	25 %
Strategy ₁₃	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	5%

Strategy ₁₄	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₁₅	Yes	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	No	25%
Strategy ₁₆	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	No	No	10%
Strategy ₁₇	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₁₈	No	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	Yes	No	No	No	15%
Strategy ₁₉	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₂₀	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₂₁	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	10%
Strategy ₂₂	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	5%
Strategy ₂₃	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	15%
Strategy ₂₄	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	15%
Strategy ₂₅	Yes	No	No	No	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	No	50%
Strategy ₂₆	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	5%
Strategy ₂₇	Yes	Yes	No	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	60%
Strategy ₂₈	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	Yes	No	No	15%
Strategy ₂₉	Yes	No	Yes	No	No	Yes	No	Yes	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	40%
Strategy ₃₀	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	No	No	10%
Strategy ₃₁	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₃₂	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No	40%
Strategy ₃₃	No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	40%
Strategy ₃₄	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	15%
Strategy ₃₅	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	Yes	No	No	No	No	No	Yes	No	40%
Strategy ₃₆	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No	25%

	s	s															s	s	s		%
Strategy ₃₇	Yes	Yes	No	No	No	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No	45%
Strategy ₃₈	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	70%
Strategy ₃₉	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	10%
Strategy ₄₀	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	15%
Strategy ₄₁	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	5%
Strategy ₄₂	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	15%
Strategy ₄₃	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	10%
Strategy ₄₄	Yes	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	10%
Strategy ₄₅	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	No	Yes	55%
Strategy ₄₆	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	No	No	No	No	No	40%
Strategy ₄₇	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	5%
Strategy ₄₈	Yes	No	Yes	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	No	No	No	25%
Strategy ₄₉	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	No	No	No	40%
Strategy ₅₀	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	10%
Strategy ₅₁	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	10%

Note. Summary of the Previous Work on CDW Management Strategies for Reuse in Terms of the Presence or Absence of Development Barrier Attributes.

Nine strategies (e.g. Strategy₁ (MacKinnon, 2000), Strategy₁₆ (Arif et al., 2012), Strategy₂₁ (Sansom et al., 2014), Strategy₃₀ (Ajayi et al., 2015), Strategy₃₉ (Yeung et al., 2017), Strategy₄₃ (Brütting et al., 2019), Strategy₄₄ (Sea-Lim et al., 2018), Strategy₅₀ (Brambilla et al., 2019) and Strategy₅₁ (Basta et al., 2020) out of the 51 strategies had two attributes, which represent 10% of the attributes. Strategy₁ (MacKinnon, 2000) had cost and perception sub-attributes, Strategy₁₆ (Arif et al., 2012) had management and incentive sub-attributes, Strategy₂₁ (Sansom et al., 2014) had cost and health-and-safety sub-attributes, and Strategy₃₀ (Ajayi et al., 2015) had risk and deconstruction sub-attributes. Strategy₃₉ (Yeung et al., 2017), Strategy₄₃ (Brütting et al., 2019), Strategy₄₄ (Sea-Lim et al., 2018), Strategy₅₀ (Brambilla et al., 2019) and Strategy₅₁ (Basta et al., 2020) had cost and deconstruction, market and design, cost, and infrastructure, energy-and-GHG and deconstruction and design and deconstruction sub-attributes, respectively.

Another eight strategies (e.g. Strategy₂ (Chini et al., 2001), Strategy₁₈ (Özkan, 2012), Strategy₂₃ (Pongiglione et al., 2014), Strategy₂₄ (Durão et al., 2014), Strategy₂₈ (Huuhka et al., 2015), Strategy₃₄ (Chinda et al., 2016), Strategy₄₀ (Machado et al., 2018) and Strategy₄₂ (Huang et al., 2018) out of the 51 strategies had three attributes, which represent 15% of the attributes. Strategy₂ (Chini et al., 2001) had the cost, compliance, and design sub-attributes, Strategy₁₈ (Özkan, 2012) had the infrastructure, compliance, and deconstruction sub-attributes, Strategy₂₃ (Pongiglione et al., 2014) had the cost, deconstruction, and design sub-attributes, Strategy₂₄ (Durão et al., 2014) had the perception, willingness and design sub-attributes, and Strategy₂₈ (Huuhka et al., 2015) had the compliance, deconstruction and design sub-attributes. Strategy₃₄ (Chinda et al., 2016) had the cost, market, and infrastructure sub-attributes, Strategy₄₀ (Machado et al., 2018) had the infrastructure, deconstruction, and design sub-

attributes, and Strategy₄₂ (Huang et al., 2018) had the cost, market, and compliance sub-attributes.

Three strategies (e.g. Strategy₃ (Klang et al., 2003), Strategy₈ (Guy, 2006) and Strategy₉ (Gorgolewski, 2008) out of the 51 strategies were identified as having four attributes, which represent 20% of the overall attributes. Strategy₃ satisfied the cost, perception, risk, and sustainability sub-attributes (Klang et al., 2003). Strategy₈ met the cost, compliance, design, and health-and-safety sub-attributes (Guy, 2006). Strategy₉ (Gorgolewski, 2008) satisfied the cost, market, design, and information sub-attributes. Moreover, five strategies (e.g. Strategy₆ (Pun et al., 2006), Strategy₁₂ (Nordby et al., 2009), Strategy₁₅ (Forsythe, 2011), Strategy₃₆ (Tatiya et al., 2018) and Strategy₄₈ (Zaman et al., 2018) out of the 51 strategies had five attributes, which represent 25% of the attributes. Strategy₆ (Pun et al., 2006) satisfied the cost, market, compliance, awareness and health-and-safety sub-attributes. Strategy₁₂ (Nordby et al., 2009) satisfied the cost, compliance, sustainability, deconstruction, and design sub-attributes. Strategy₁₅ (Forsythe, 2011) satisfied the cost, value-for-money, management, design, and health-and-safety sub-attributes. Strategy₃₆ (Tatiya et al., 2018) satisfied the cost, market, deconstruction, design, and health-and-safety sub-attributes. Strategy₄₈ (Zaman et al., 2018) satisfied the cost, value-for-money, experience, infrastructure, and compliance sub-attributes.

Furthermore, Strategy₁₁ (da Rocha et al., 2009) satisfied six sub-attributes (e.g. cost, market, compliance, perception, risk, and design), which represent 30% of the attributes. Strategy₇ (Shaurette, 2006) satisfied seven sub-attributes (e.g. cost, market, experience, infrastructure, compliance, perception, and risk), which represent 35% of the attributes. Six strategies (e.g. Strategy₂₉ (Yeung et al., 2015), Strategy₃₂ (Rameezdeen et al., 2016), Strategy₃₃

(Chileshe et al., 2015), Strategy₃₅ (Chileshe et al., 2016), Strategy₄₆ (Dunant et al., 2018) and Strategy₄₉ (Nußholz et al., 2019) out of the 51 strategies had eight attributes, which represent 40% of the attributes. Strategy₂₉ (Yeung et al., 2015) satisfied the cost, value-for-money, experience, management, incentive, design, health-and-safety, and information sub-attributes. Strategy₃₂ (Rameezdeen et al., 2016) satisfied the cost, market, compliance, awareness, perception, risk, willingness, and health-and-safety sub-attributes. Strategy₃₃ (Chileshe et al., 2016) satisfied the market, experience, infrastructure, compliance, incentive, awareness, willingness, and deconstruction sub-attributes. Strategy₃₅ (Chileshe et al., 2016) satisfied the cost, market, value-for-money, compliance, incentive, perception, risk, and health-and-safety sub-attributes. Strategy₄₆ (Dunant et al., 2018) satisfied the cost, market, value-for-money, infrastructure, experience, infrastructure, management, risk and trust sub-attributes. Strategy₄₉ (Nußholz et al., 2019) satisfied the cost, market, energy and GHG, infrastructure, management, compliance, incentive, and willingness sub-attributes.

Moreover, Strategy₃₇ (Dunant et al., 2017) satisfied nine sub-attributes (e.g. cost, market, experience, infrastructure, compliance, perception, risk, trust, and deconstruction), which represent 45% of the attributes. Strategy₂₅ (Chileshe et al., 2015) satisfied ten sub-attributes (e.g. cost, experience, management, compliance, awareness, perception, risk, willingness, deconstruction, and health-and-safety), which represent 50% of the attributes. Strategy₄₅ (Rose et al., 2018) satisfied 11 sub-attributes (e.g. cost, market, value-for-money, infrastructure, management, compliance, incentive, perception, willingness, deconstruction, and information), which represent 55% of the attributes. Strategy₁₀ (Gorgolewski et al., 2008) and Strategy₂₇ (Huuhka et al., 2015) had 12 attributes, which represent 60% of the attributes. Strategy₁₀ (Gorgolewski, 2008) satisfied the cost, market, experience, infrastructure,

compliance, awareness, perception, risk, willingness, deconstruction, design, and information. Strategy₂₇ (Huuhka et al., 2015) satisfied the cost, market, energy-and-GHG, compliance, awareness, perception, risk, willingness, deconstruction, design, health-and-safety, and information. Finally, Strategy₃₈ (Densley Tingley et al., 2017) satisfied 14 sub-attributes that represented 60% of the 20 attributes, which were cost, market, value-for-money, contracts, compliance, incentive, awareness, perception, risk, willingness, deconstruction, design, health-and-safety, and information.

Despite the existence of these strategies, no superior strategy has simultaneously addressed all barrier attributes of reuse distribution. All researchers have considered these attributes in the development of CDW management strategies. However, no research has assessed and modelled the identified CDW management strategies to determine which are the most and least sustainable based on all barrier attributes of reuse distribution.

Moving forward, future research could focus on developing an integrated framework that incorporates multiple decision-making methodologies to comprehensively evaluate CDW management strategies. By combining techniques such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and fuzzy logic, researchers can create a holistic approach that considers various dimensions of sustainability and addresses the complexities inherent in CDW management decision-making. Additionally, exploring advanced optimization algorithms, such as genetic algorithms or particle swarm optimization, could further enhance the effectiveness and efficiency of the decision-making process, enabling stakeholders to identify optimal CDW management strategies that balance economic, environmental, and social considerations.

Addition, future research endeavours could focus on conducting case studies or field experiments to validate the proposed decision-making framework in real-world contexts. By applying the framework to diverse CDW management scenarios and assessing its performance against practical outcomes, researchers can enhance the framework's robustness and applicability. Additionally, engaging stakeholders from different sectors, including construction companies, regulatory agencies, and community organizations, in the validation process can provide valuable insights and foster buy-in for the adoption of sustainable CDW management practices. Overall, continued research efforts aimed at refining and implementing integrated decision-making frameworks have the potential to significantly advance the field of sustainable CDW management and contribute to the transition towards a circular economy paradigm.

2.3 Challenges in Evaluation and Benchmarking CDW Strategies

In earlier sections, we discussed the endeavors of different researchers in formulating strategies for managing (CDW), which encompass six specific attributes related to barriers development. However, despite these endeavors, there exists a noticeable void in the application of these attributes to assess and compare the efficiency of diverse CDW management strategies. The difficulty in conducting such evaluations and comparisons stems from the diverse array of attributes employed in these strategies.

In fact, to the challenges, the dynamic nature of the construction and demolition waste (CDW) management landscape creates further complexities to the evaluation and benchmarking of CDW strategies. As environmental regulations improve and societal expectations shift towards sustainability, CDW management strategies must continuously

adapt to meet changing requirements and standards. This dynamic environment necessitates a flexible evaluation framework capable of accommodating emerging trends and evolving priorities in CDW management. Likewise, the global nature of CDW challenges requires evaluation methods that are adaptable to diverse geographic, economic, and cultural contexts. Strategies that prove effective in one region may not necessarily yield the same results elsewhere, highlighting the need for nuanced evaluation approaches that account for local variations in waste generation, disposal infrastructure, and regulatory frameworks.

Despite, the integration of advanced technologies and innovative practices into CDW management introduces new dimensions to the evaluation and benchmarking process. Emerging technologies such as artificial intelligence, machine learning, and blockchain hold promise for enhancing the efficiency, transparency, and accountability of CDW management systems. However, assessing the effectiveness of these technologies and determining their optimal integration into existing CDW strategies present novel challenges. Additionally, the proliferation of circular economy principles in the construction industry introduces new considerations for evaluating CDW strategies. Strategies aimed at maximizing resource recovery, promoting material reuse, and minimizing waste generation must be evaluated not only based on traditional metrics such as cost-effectiveness and regulatory compliance but also on their contributions to broader sustainability objectives and circularity goals.

Addressing these multifaceted challenges requires interdisciplinary collaboration and a comprehensive approach to CDW management evaluation. By integrating insights from fields such as environmental science, engineering, economics, and policy studies, researchers can develop comprehensive evaluation frameworks that capture the complexity of CDW management systems. Moreover, fostering knowledge exchange and collaboration among

stakeholders, including policymakers, industry practitioners, researchers, and community representatives, is essential for ensuring the relevance, applicability, and scalability of CDW management evaluation efforts. Through concerted efforts and innovative approaches, the construction industry can overcome the challenges of evaluating and benchmarking CDW strategies and advance towards more sustainable and flexible waste management practices.

Hence, examine these strategies from a singular perspective would not yield a comprehensive comprehension.

Three assessment concerns must be addressed to fill this research gap as shown in Figure 6. First, multiple barrier attributes of reuse distribution must be considered (Alnoor et al., 2022; Zaidan et al., 2020). Second, these attributes must be prioritized based on their importance level (Mahmoud et al., 2022; Jumaah et al., 2018). Third, variance in data is another concern that must be considered when assessing and modelling CDW management strategies (Albahri et al., 2022; Alamleh et al., 2022).

2.3.1 Multiple Evaluation Attribute Issue

Assessing and benchmarking CDW management strategies becomes challenging due to the presence of various evaluation attributes. Nevertheless, it is crucial to account for these attributes in the benchmarking process to identify the most suitable strategy (Alamoodi, Albahri, et al., 2022; Dawood et al., 2021; Salih et al., 2021). Benchmarking involves the consideration of six attributes, namely economic, environmental, organizational, regulatory, social, and technical. Figure 8 illustrates how the attributes of CDW management strategies, and the contribution process can impact the selection.

Each attribute makes the assessment process intricate. It is important to comprehend these factors to build efficient benchmarking strategies that would encourage enhancements and sustainable CDW practices. One of the main problems in assessing CDW management options from an environmental point of view is the variety of impact indicators. In this respect, there are several factors that need to be taken into consideration, including emissions of greenhouse gases, resource consumption, and the overall impact on the environment. Each of these factors is different in terms of how it is measured and compared, which creates additional challenges in the evaluation process. Likewise, many of the environmental impacts of CDW management, like landfill avoidance and the preservation of natural resources, are long-term. That is, the nature of environmental gains is consistent with the long-term and, therefore, should not be compared to short-term oriented measures (Iodice, Garbarino, Cerreta, & Tonini, 2021). Another key challenge is data availability. To some extent, the results of the evaluation may be incomplete due to the scarcity of information on a comprehensive assessment of the environmental situation. For example, it is difficult to gather specific information regarding emissions at every stage of waste management. Moreover, there are some gaps in terms of the measures of “environmental performance”, especially when comparing the geographical areas and systems. It is for this reason that without standardization, it becomes difficult to determine clear criteria by which varying impacts on the environment can be accurately assessed and compared with other organizations.

The economic aspects of CDW management are diverse. The expenses related to CDW collection, transportation, and recycling differ due to economic conditions in specific regions. For instance, the economic environment is bound to be different depending on the number of charges, which may include labour cost per employee or landfill fees, amongst other regions.

Also, the recycled product market remains somewhat unpredictable, meaning that the overall economic profitability of recycling is less stable due to variations in market conditions and the price of recycled products.

Comparability across regions is further hampered due to the differing economics of the various areas. It also means that certain direct comparisons can be misleading when the basic conditions of the economy differ greatly. Another crucial problem is indirect costs that lie outside of the financial indicators: degradation of the environment and human health. These hidden costs, therefore, confound the economic analysis of CDW management measures, so once again, a broader view pertinent to the indirect bearing of CDW management strategies is needed (Gherman et al., 2023)

The role of social attributes in CDW management strategies is significant, yet comparing and measuring them is rather difficult. Public acceptance and involvement are core fundamentals of these strategies, even though these elements are, in most cases, coloured by cultural practices. Despite, the fact that people nowadays are more open to social interaction, there might be certain differences in terms of acceptance and participation due to geographical location, thus impacting CDW opportunities and outcomes.

Other issues that cannot be overlooked include health and safety measures. Workers' and the public's health and safety, in general, comprise standards such as efficient and safe handling and processing of hazardous substances. Assessing these aspects altogether is quite challenging since it warrants prospective health outcome evaluations. The cultural factor also poses a challenge when implementing benchmarking results because cultural practices regarding waste management vary across regions. It is also important to note that some components of CDW are socially equitable. It is also critical to assess such strategic initiatives

to ensure that they are not prejudicial to the lives of specified audience groups, which again poses another challenge in the evaluation process.

The management of CDW should be accompanied by sound organizational structures that will enable proper communication management, construction firms, waste management companies, and regulatory bodies. Nevertheless, contemporary systems can be characterized by scattered responsibilities and poor hierarchy. Thus, it is possible to state that clearer roles and responsibilities are crucial for increasing the efficiency and effectiveness of work, as well as mechanisms for effective communication and cooperation.

Organizational commitment to sustainability also presents a challenge in assessing and benchmarking Analog-to-Digital Converter (ADC) management strategies. Many organizations remain slow in implementing sustainable practices into their business activities because they are perceived to be expensive and complicated. Applying sustainability in construction – this is because planning for deconstruction, for example, assists in increasing the rates of materials recovery and recycling at the time of demolition of the structure. On this note, it is also important to ensure that there is training and development of employees regarding CDW since the workforce needs to be skilled for this purpose. CDW management performance is affected by the level of organizational commitment, the level of expertise, and the number of resources available; this leads to the development of dissimilarities, which do not allow for the standardization of strategies and benchmarking of organizations (Nikmehr, Hosseini, Wang, Chileshe, & Rameezdeen, 2021).

CDW management systems are vital, and the application of updated technology is very useful in making them efficient. Consequently, the general level of technology implementation is quite diverse and depends on specific geographic zones. Some places have developed

systems and the latest recycling technologies; there are places that use old techniques. Such a trend impacts the effectiveness of CDW management, hence making it challenging to set some standards in the field.

Moreover, the role of information technology is dynamic in that new techniques and instruments are being developed all the time to address CDW management. However, these innovations can help to increase the rates and quality of the recovered materials, although these changes make it impossible to set reasonable rates. The usage of technologies implies that higher recycling rates and better material recovery can be attained in that region, thereby creating challenges for benchmarking against less technologically developed areas. The compatibility of technologies must be considered since they can be quite incomparable as they come with different scales of work, efficiency levels, and fields of application.

Regulations are critical in determining the kind of systems that are in place for managing CDW. Firm regulation policies require proper waste management practices, hence pressuring the necessary integration and conformity. Nevertheless, enforcement remains sporadic, and most areas do not have all-encompassing rules governing all aspects of CDW's life cycle. Promises of tax credits or grants for organizations that implement sustainable logistics practices make them pay attention and work according to the strategies provided. As mentioned, another efficiency of the regulation tool is the extended producer responsibility (EPR), which means that producers are chargeable for their product's disposal and recycling after usage (Santos et al., 2024). Nevertheless, measures to put these schemes into action entail the capacity of an effective regulator and the ability to enforce relevant legislation, which differs. The present rules differ from country to country, and this factor also makes the assessments' comparison difficult. Ideas that are encouraged in one region may not be possible

or even lawful in another. It largely hinders the ability to develop clear standards that are valid across many areas and hampers inter-regional comparison. The benchmarking task may also experience a challenge if there are many changes in policies within long-term plans, as consistency will be affected.

However, addressing the multiple evaluation attribute issue requires a nuanced approach. One potential avenue for future research is the development of a comprehensive framework that integrates diverse evaluation criteria into a unified decision-making model. This framework could incorporate advanced mathematical techniques, such as multi-attribute decision analysis (MADA) or fuzzy logic, to systematically weigh and prioritize the importance of each attribute. By establishing clear criteria and decision rules, such a framework would provide decision-makers with a structured and transparent method for evaluating CDW management strategies across multiple dimensions.

Similarly, exploring the dynamic interrelationships between evaluation attributes could enhance the effectiveness of CDW management benchmarking. For instance, conducting sensitivity analysis or scenario planning exercises could help identify critical thresholds or tipping points where changes in one attribute significantly impact the overall sustainability performance of a strategy. Understanding these complex interactions would enable decision-makers to anticipate potential trade-offs and develop more resilient and adaptive CDW management plans (Canavesi & Minelli, 2021).

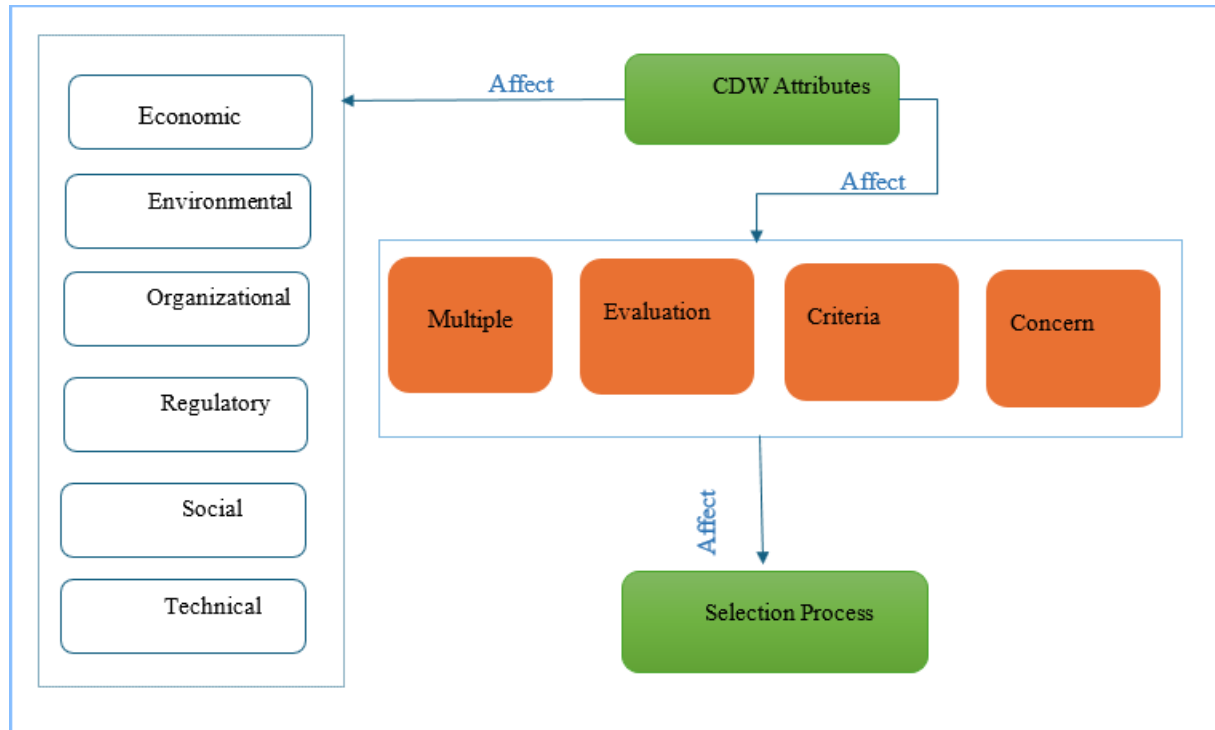
In other words, integrating stakeholder preferences and perspectives into the evaluation process could lead to more informed and inclusive decision-making. Stakeholder engagement methods, such as participatory workshops or surveys, could be used to gather insights on the relative importance of different attributes and the trade-offs stakeholders are willing to accept.

By incorporating diverse stakeholder viewpoints, decision-makers can ensure that CDW management strategies align with broader societal values and priorities, enhancing their legitimacy and acceptance.

After all, leveraging emerging technologies, such as artificial intelligence and machine learning, could facilitate more data driven and predictive CDW management benchmarking. These technologies could analyse vast amounts of data from various sources, including construction projects, waste streams, and environmental sensors, to identify patterns, trends, and potential risks. By harnessing the power of big data and predictive analytics, decision-makers can anticipate future challenges and opportunities, enabling proactive and strategic decision-making in CDW management.

Figure 6

CDW Management Strategies: Evaluating Multiple Attributes



In this situation, choosing the best Construction and demolition waste CDW strategy is artful because Strategy1 might come out on top for the economic aspect, while Strategy2 could take the lead in terms of the environment. This raises a question: which strategy should be considered the top-ranked? Hence, relying on a single attribute for benchmarking CDW management systems seems unfair, and it's more reasonable to consider multiple evaluation criteria instead.

To address this complexity, future research could explore and investigate deeply in the development of a comprehensive decision support system that integrates various evaluation criteria and methodologies. Such a system could employ advanced techniques like multi-attribute decision analysis (MADA) or integrated assessment models (IAMs) to provide

holistic evaluations of CDW management strategies. By incorporating diverse criteria, including economic, environmental, social, and technical factors, into a unified framework, decision-makers can make more informed and balanced decisions that account for the multifaceted nature of CDW management (EPA, 2018).

Likewise, future studies could focus on exploring the dynamic nature of CDW management strategies and their impact over time. This could involve conducting longitudinal analyses to assess how different strategies perform under changing environmental, regulatory, and economic conditions. By tracking the effectiveness and sustainability of CDW management practices over extended periods, researchers can identify trends, patterns, and best practices that contribute to continuous improvement and adaptation in the construction industry. Additionally, investigating the role of emerging technologies, such as artificial intelligence, blockchain, cyber security and computing cloud, in enhancing and maximizing the efficiency and transparency of CDW management system processes, it also could open a new avenue for innovation and optimization in all fields.

2.3.2 Importance of Evaluation

Another issue discussed is the importance of attributes. Attributes are the characteristics or features of alternatives that are used to evaluate them in the decision-making process. However, not all attributes are equally important, and the importance of attributes can vary depending on the decision context. The importance of attributes can be subjective and influenced by personal opinions and biases. Different decision-makers may have different views on the importance of specific attributes, leading to inconsistencies and disagreements in the evaluation process.

Considering the importance of attributes can also vary depending on the decision context and scholars' preferences. For example, the importance of environmental attributes may be higher for scholars who prioritize sustainability, while the importance of cost sub-attributes may be higher for scholars who prioritize economic efficiency. Another example, decision-makers can use these evaluations to choose the strategy that aligns with their specific goals and priorities, fostering better decision-making in CDW management. Additionally, by evaluating CDW attributes, organizations can identify areas where resource optimization is possible, minimizing waste and reducing costs. For example, an evaluation may highlight opportunities to improve the efficiency of CDW recycling processes, leading to reduced waste disposal expenses and increased revenue from recycled materials. CDW attributes evaluation is instrumental in promoting sustainability in construction and demolition processes. Through assessments of environmental and social attributes, organizations can adopt strategies that minimize the ecological impact of waste disposal and enhance community well-being (Lagerkvist, Edenbrandt, Tibbelin, & Wahlstedt, 2020).

Additionally, exploring the dynamic nature of attributes over time could provide insights into how the relative importance of different attributes changes in response to evolving socio-economic, regulatory, and technological factors. Long term studies tracking attribute importance trends and their impact on decision outcomes could inform adaptive decision-making strategies and develop the resilience of CDW management systems to near and far future challenges and uncertainties. Additionally, investigating the interplay between attributes and stakeholders' preferences through participatory decision-making processes could facilitate

consensus-building and stakeholder engagement, fostering more inclusive and sustainable CDW management practices.

Figure 7

Importance of Evaluation Issue

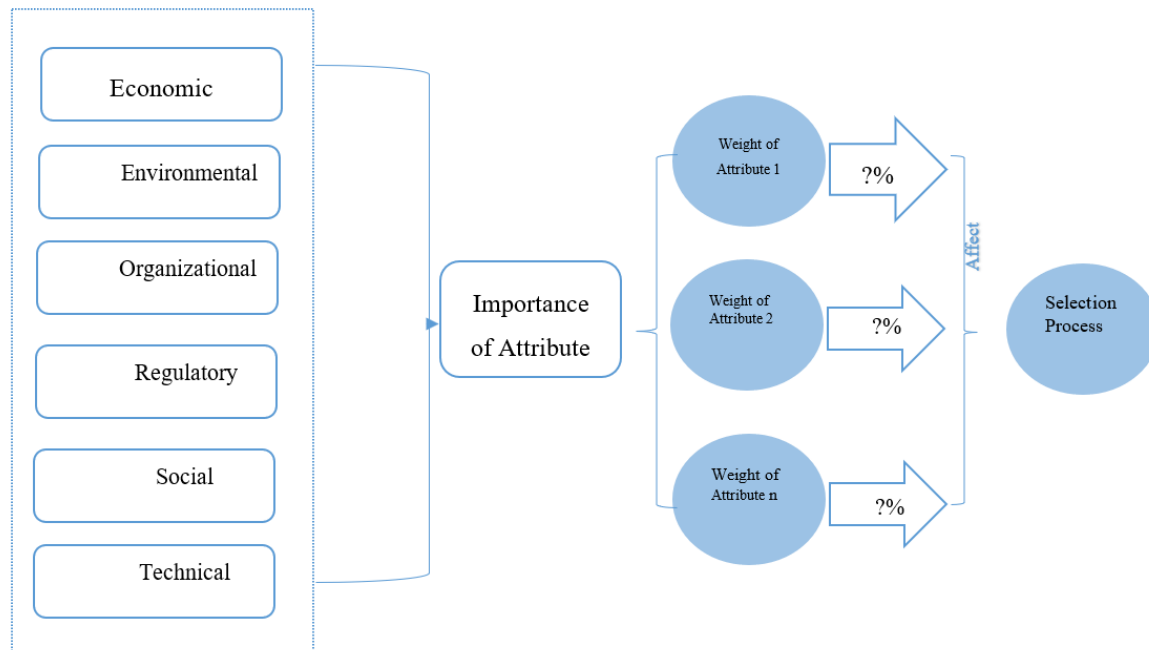


Figure 7 provides a visual representation of how each set of attributes should be evaluated to determine its relative importance compared to other attributes. This approach helps to address the challenge of attribute importance by assigning a relative weight to each attribute based on its relevance to the MADM in the context of the evaluation process. Moreover, future research could delve deeper into understanding the dynamic nature of these attribute weights and their implications for decision-making under evolving conditions. By incorporating techniques from dynamic decision-making and adaptive management,

researchers can develop frameworks that account for changes in attribute importance over time and adapt strategies accordingly (Zhou et al., 2020).

Furthermore, exploring the application of machine learning algorithms and artificial intelligence (AI) techniques in the context of CDW management could open new avenues for research. These technologies have the potential to analyse vast amounts of data, identify patterns, and predict outcomes with greater accuracy and efficiency. By leveraging AI-driven approaches, researchers can develop predictive models for assessing the environmental impact of CDW management strategies, optimizing resource allocation, and identifying potential risks and opportunities. Additionally, AI-based decision support systems can assist stakeholders in making informed decisions by providing real-time insights and recommendations based on continuously updated data and evolving priorities. Integrating Artificial Intelligence (AI) into CDW management frameworks could enhance their effectiveness, responsiveness, and adaptability in addressing complex sustainability challenges.

Additionally, future research could explore the integration of participatory approaches and stakeholder engagement strategies in the development and implementation of CDW management frameworks. By involving a diverse range of stakeholders, including local communities, industry representatives, policymakers, and environmental advocates, researchers can ensure that CDW management strategies are socially inclusive, culturally sensitive, and aligned with the needs and preferences of various stakeholders. Participatory methods, such as community-based decision-making processes, co-design workshops, and citizen science initiatives, can foster collaborative problem-solving, build trust, and promote collective ownership of sustainability initiatives. Additionally, engaging stakeholders throughout the CDW management lifecycle can enhance transparency, accountability, and

legitimacy, ultimately leading to more equitable and sustainable outcomes (Bal, Bryde, Fearon, & Ochieng, 2019)

Correspondingly, future research could investigate the potential synergies and trade-offs between CDW management strategies and broader sustainability goals, such as climate change mitigation, biodiversity conservation, and social equity. Adopting a holistic and integrated approach to sustainability assessment, researchers can examine the interconnectedness of CDW management with other environmental and social issues, identify opportunities for co-benefits, and mitigate unintended consequences. For example, exploring the carbon sequestration potential of recycled construction materials, the ecological impacts of demolition practices, and the social implications of waste disposal sites can inform more comprehensive and integrated sustainability strategies. By considering the interdependencies between CDW management and broader sustainability objectives, researchers can develop more effective and contextually relevant policy interventions, business practices, and community initiatives to advance sustainable development agendas.

2.3.3 Data Variation

As the variability in data increases, the complexity of benchmarking tasks for CDW management strategies grows accordingly. Decision-makers encounter significant challenges when comparing alternatives (CDW management strategies) due to varying data across different attributes. Consequently, addressing this issue becomes crucial as it streamlines the selection process when dealing with extensive data (Al-Humairi et al., 2022; O. S. Albahri et al., 2022; Alnoor et al., 2022a).

Several factors lead to variability in data: geographical location, variation in construction materials, disparities in set waste management policies, and inequality in technology. All these factors make benchmarking of CDW management strategies a rather complicated affair. Thus, geographical differences impact the variability of the data. While some areas may have different kinds of construction and demolition activities, construction wastes in these regions likely differ and vary in quantity. For instance, regions with extended constructions, such as in the urban zones, might come up with different varieties of waste compared to areas with comparatively low buildings in the rural setting. This regional variability envisages that effective CDW management requires programs that can be customized based on each region's needs and characteristics.

Fluctuations in the construction materials are also a major source of data variation. Operational methods and choices of materials for constructing projects lead to various forms of waste. That is, structural areas that primarily utilize concrete and masonry will produce different wastes compared to areas densely populated with wood and steel. This diversity in the material also makes the benchmarking process a bit challenging, as some strategies may not be suitable for certain kinds of waste.

The individual country waste management policies and laws also pose a challenge. CDW management policies also differ from one nation to another and, in some cases, from one region of a country to another. These are the guidelines concerning the ways and procedures for managing waste, the recycling regulations, the limitations to landfilling systems, and the promotion of waste minimization. The problem of inconsistency in rules of different countries makes comparison and assessment of various CDW management scenarios on a single basis more complex.

Technology is also the other factor that determines the variability of data in that technological advancement, and depending on how it is adopted, it will help minimize the variability of data. From the findings of the available studies, it can be proposed that technological regions reuse more waste and manage waste better than technologically disadvantaged regions (Karaca & Tleuken, 2024). The implementation of technologies, including the adoption of automated sorting systems for the segregation and management of CDW and installations of more complex recycling plants and waste-to-energy plants, are not the same across the regions, thereby affecting the viability and feasibility of the various CDW management plans.

To address the increasing variability in data, future research could explore advanced data analysis techniques and machine learning algorithms tailored to the specific challenges of benchmarking CDW management strategies. Utilizing techniques such as cluster analysis, principal component analysis, and predictive modelling can help identify patterns, trends, and relationships within complex datasets, enabling more informed decision-making processes. Moreover, employing artificial intelligence (AI) and natural language processing (NLP) algorithms can assist in automating data processing tasks, extracting insights from unstructured data sources, and generating actionable recommendations for CDW management stakeholders. By leveraging these cutting-edge methodologies, researchers can enhance the accuracy, efficiency, and scalability of benchmarking efforts in the field of sustainable construction and waste management.

As construction and demolition waste CDW management strategies evolve and diversify, the need for robust benchmarking methodologies becomes increasingly pressing. Future research endeavours could focus on developing dynamic benchmarking frameworks

capable of adapting to the evolving landscape of CDW management practices. By integrating real-time data streams, stakeholder feedback mechanisms, and predictive analytics models, these frameworks can continuously assess the performance of CDW management strategies and identify emerging best practices. Additionally, incorporating multi-criteria decision-making (MCDM) techniques into benchmarking processes can enable decision-makers to consider diverse stakeholder preferences, sustainability goals, and regulatory requirements when evaluating CDW management alternatives.

As well as future studies could explore the application of blockchain technology to enhance transparency, traceability, and accountability in CDW management benchmarking. By leveraging blockchain's immutable ledger and smart contract functionalities, stakeholders can securely record and verify key performance indicators (KPIs), transactional data, and compliance metrics related to CDW management practices. This decentralized approach to data management can foster trust among stakeholders, facilitate information sharing, and streamline auditing processes, ultimately leading to more effective and sustainable CDW management outcomes.

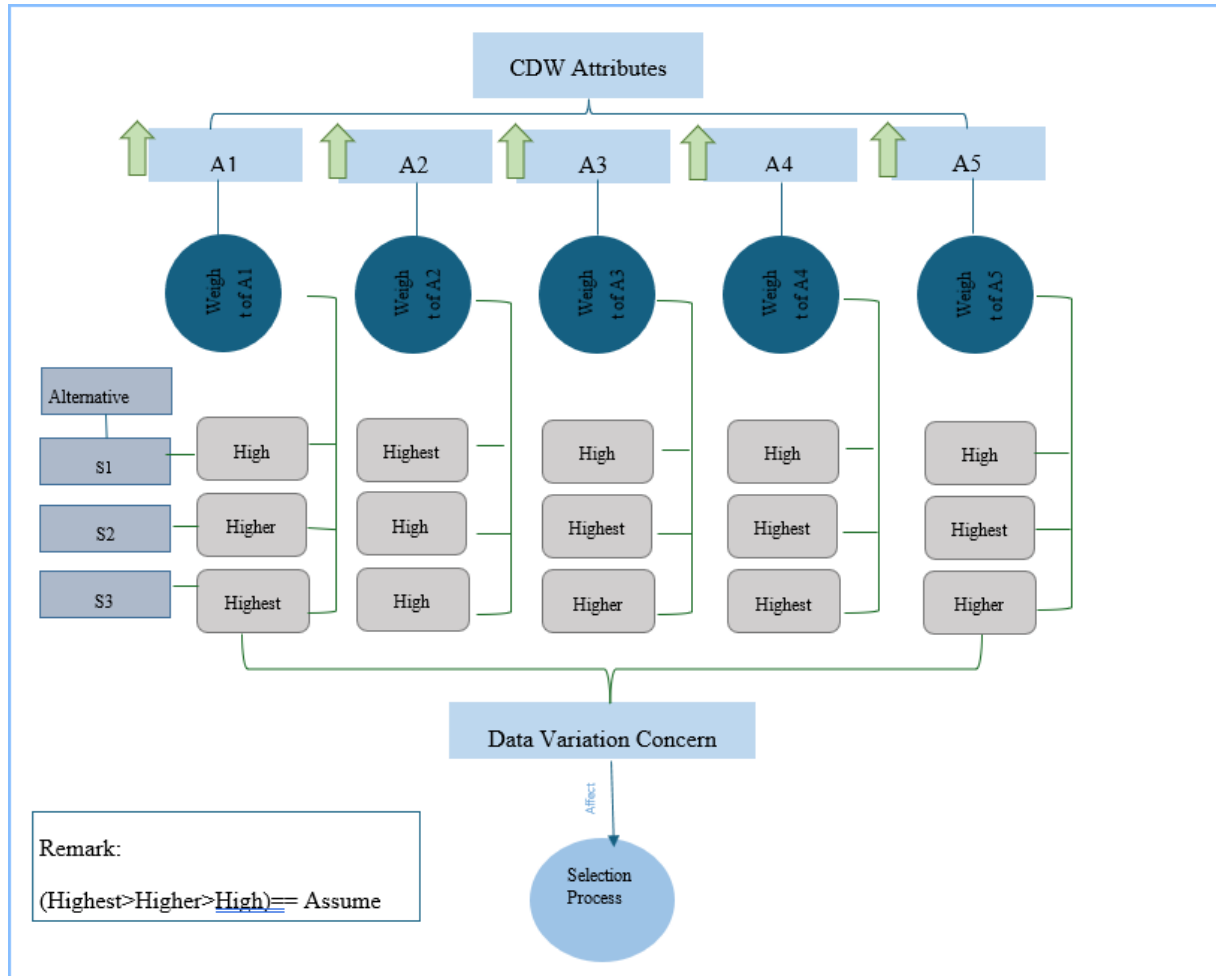
Likewise, considering the global nature of CDW management challenges, future research efforts could prioritize cross-disciplinary collaborations and knowledge sharing initiatives. By fostering partnerships between academia, industry, government agencies, and non-profit organizations, researchers can leverage diverse expertise, resources, and perspectives to tackle complex issues such as waste minimization, resource recovery, and circular economy transitions. Through collaborative research networks and international consortia, stakeholders can collectively develop and disseminate best practices, guidelines,

and policy recommendations to promote sustainable CDW management on a global scale (She, Nilupa Udawatta, Olubukola Tokede, & Liu, 2024).

Figure 8 illustrates that variations in data may occur when measures for maximizing attributes impact the data of the alternatives at different levels (high, higher, and highest), ensuring an enhanced selection process.

Figure 8

Data Variations in CDW Management and Contribution Processes



These issues, as outlined in Sections (2.4.1, 2.4.2, and 2.4.3) can lead to complex decision-making problems when evaluating and benchmarking CDW management strategies. However, the challenge of evaluating and benchmarking the CDW management strategies based on multiple attributes remains unresolved.

2.4 Chapter Summary

This chapter explores a taxonomy of literature reviews on CDW (construction and demolition waste) management strategy development, focusing on decision techniques and their key attributes, as discussed in Sections 2.2 and 2.3. It also conducts a critical assessment of CDW management strategies to uncover a research gap. Despite significant efforts to create more secure and private management methods, none of the reviewed techniques fully addressed all necessary development attributes. Additionally, the evolution of these strategies varies greatly, complicating the selection process for CDW management providers. A key finding is that no existing study has used the Barriers attribute to assess and rank CDW management strategies, revealing a research gap. Section 2.3 further explores challenges related to the multi-attribute benchmarking process, emphasizing three main issues: the use of multiple evaluation criteria, the varying importance of these criteria, and the inconsistencies in available data.

Chapter 3: Foundations Multi-Attributes Analysis in CDW

3.1 Theoretical Background of Multi-Attributes Analysis in CDW

This chapter will review the theoretical foundation of multi-criteria analysis, discussing the principles and methodologies underpinning decision-making frameworks in the context of CDW management. This section provides insights into the various approaches utilized for evaluating and prioritizing sustainability criteria, including analytical hierarchy process (AHP), technique for order preference by similarity to ideal solution (TOPSIS), and weighted sum model (WSM). Moving on to Sections 3.2, 3.2.1, 3.2.2, 3.2.3 and 3.3 present the existing methods of weighting and benchmarking through Multiple Attribute Decision-Making (MADM). These sections elaborate on the diverse techniques employed for assigning weights to decision criteria and comparing alternative CDW management strategies based on performance metrics. The discussion encompasses both traditional MADM methods and innovative approaches tailored to address the unique challenges of CDW management. Overall, this thorough review of the synthesized literature not only reflects existing knowledge but also identifies gaps and opportunities for research and practical futures for the sustainable management of CDW. Studying theoretical themes, disciplines of study, presenters' perspectives, educational initiatives, and economic considerations, this chapter has provided a multifaceted understanding of definitions and opportunities in the field. On this basis, the following chapters substantiate empirical research, tool development, and practical strategies for promoting sustainability in CDW management.

MADM is a subfield of operations research (Abdulkareem et al., 2020) that includes a variety of approaches and applications in different fields (Yang et al., 2022; Chen et al., 2022), such as medicine (Napi et al., 2019; Almahdi et al., 2019), transportation (Qahtan et al., 2022; Simic et al., 2022), management (Khatari et al., 2019), engineering (Deveci et al., 2022) and agriculture (Qahtan et al., 2023; Ibrahim et al., 2023). In the literature, many MADM modelling approaches, such as TOPSIS, VIKOR and fuzzy decision by opinion score method (FDOSM) (Hafezalkotob et al., 2019), have been utilized. However, FDOSM aids the formation of rational decisions with the aid of experts by determining the ideal solutions for each attribute in an opinion matrix. The strengths of FDOSM lie in its ability to (i) overcome the inconsistency issue, (ii) decrease the computation time when performing comparisons, (iii) prevent unnatural comparisons amongst attributes, (iv) address the ambiguity of information by using fuzzy numbers, (v) avoid utilizing normalization methods that can influence the final modelling and (vi) utilize ideal solutions (positive and negative) and the difference level to address the distance issue (Albahri et al., 2021). Therefore, this method has been confirmed to be effective in addressing numerous MADM problems (Alamleh et al., 2022).

FDOSM employs different aggregation operators to determine the score of the alternatives. For instance, the initial FDOSM was solely developed based on direct aggregation (Salih et al., 2020). Reference (Albahri et al., 2021) developed FDOSM based on TOPSIS and VIKOR with distance measurement and compromise model to model the active queue management methods. They concluded that the proposed extension of FDOSM-based VIKOR, by using a compromise model, is the best approach to compare different active queue management methods. However, a more robust MADM modelling method is multiplicative multiple objective optimizations by ratio analysis (MULTIMOORA) (Brauers et al., 2012).

This method is simpler to understand, easier to implement and more stable than TOPSIS and VIKOR (Brauers et al., 2012). In addition, MULTIMOORA requires the least processing time and mathematical operations (Brauers et al., 2012). Furthermore, this method can provide accurate modelling with a comprehensive measurement and simplify the decision-making process (Brauers et al., 2011). Therefore, this study considers the advantages of the MULTIMOORA method and proposes FDOSM-based MULTIMOORA to model CDW management strategies.

Researchers have utilized many MADM weighting methods (e.g. AHP, BWM and ANP) to prioritize the set of attributes. The primary deficiency of these approaches is the inconsistency caused by pairwise comparisons (Hafezalkotob et al., 2019). (Mohammed et al., 2022) addressed the problem of inconsistency by proposing a new MADM weighting method named the fuzzy-weighted zero-inconsistency (FWZIC). This mechanism has been extensively utilized to determine the weight of the assessment attributes with no inconsistency. FWZIC requires neither many mathematical operations nor a substantial amount of time to operate (Mohammed et al., 2022).

Later, FDOSM and FWZIC have been formulated and integrated with multiple FSs (Qahtan et al., 2022), such as q-rung orthopair, dual-hesitant, neutrosophic, Pythagorean, cubic Pythagorean, interval type 2 trapezoidal, T-spherical and Pythagorean m-polar FSs, to overcome these issues. Despite these achievements, informational vagueness and uncertainty remain open issues.

(Torra, 2010) introduced the concept of hesitant FS to overcome the hesitation issue. Rodriguez et al. (Rodríguez et al., 2014) performed an intensive review on hesitant FS and concluded the following: (i) hesitant FS can reduce uncertainty because it is a more flexible

preference structure and generic; (ii) hesitant FS supports the preference elicitation of DMs; (iii) hesitant FS gradually reveals the severe loss of information; and (iv) the probability of occurrence of each element is disregarded. (Zhu, 2014) introduced probabilistic hesitant FS to add the probability into the hesitant FS. Probabilistic hesitant FS not only supports several viewpoints but also gives a probability of occurrence to each viewpoint, thus enhancing the reliability of the information (Zhang et al., 2017).

Given the superiority of q-ROFSs over earlier FSs, (Liu et al., 2019) proposed the concept of q-rung orthopair hesitant FS (q-ROHFS) and its operational laws. (Attaullah et al., 2022) improved the q-ROHFS by including the probability and introduced the q-rung orthopair probabilistic hesitant FS (q-ROPHFS).

MADM is a systematic and structured approach, which can be used for the comparison of the given number of options or strategies for the decision-making by considering several attributes. This is especially applicable in Construction and Demolition Waste (CDW) where there are numerous conditions that must be met to enhance sustainability. Therefore, the MADM approach can be used to solve complex multi-attributes decision making problems by creating a decision matrix based on the intersection of CDW management strategies and the barrier attributes related to reuse distribution.

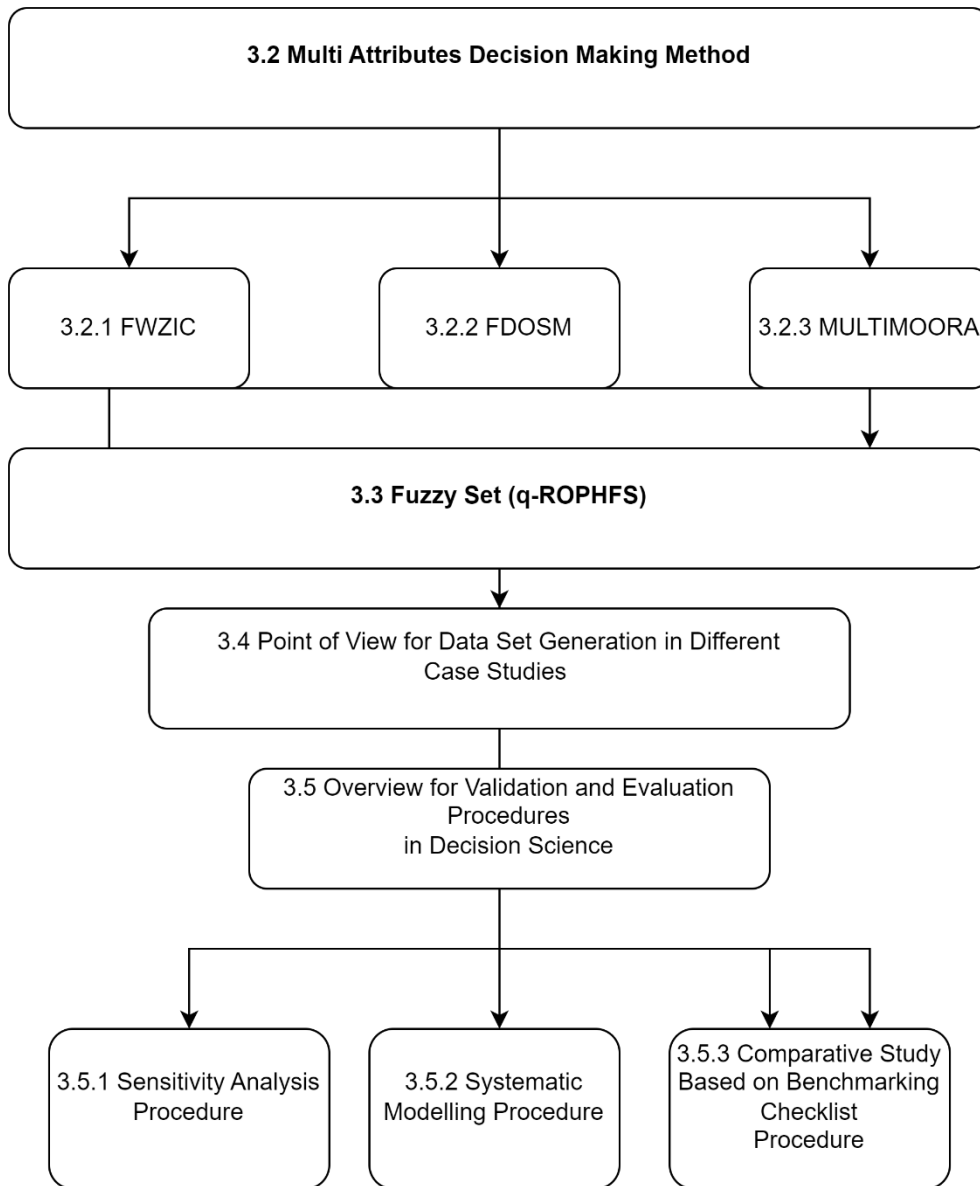
The studies mentioned above offer proof that Multiple Attribute Decision Making (MADM) has been widely employed to tackle challenges in CDW management strategies, particularly in solving complex problems related to decision-making with multiple attributes. This highlights the importance and effective role of MADM in aiding the choice of optimal alternatives.

Expanding on the significance of Multiple Attribute Decision Making (MADM) in the context of Construction and Demolition Waste (CDW) management, it's crucial to recognize the dynamic nature of waste management practices. As industries evolve and environmental regulations become more stringent, the need for robust decision-making tools like MADM becomes increasingly evident. CDW management presents a multifaceted challenge, encompassing social, economic, and environmental dimensions, which necessitates a comprehensive and adaptable approach to decision-making.

Moreover, with the growing emphasis on sustainability and circular economy principles, the role of MADM extends beyond traditional waste management strategies. It becomes instrumental in identifying innovative solutions that not only mitigate the environmental impact of CDW but also contribute to resource efficiency and long-term economic viability. By integrating MADM techniques with emerging technologies such as artificial intelligence and big data analytics, stakeholders can gain deeper insights into waste generation patterns, optimize resource allocation, and forecast future trends in CDW management.

Furthermore, the application of MADM in CDW management underscores the importance of interdisciplinary collaboration. Given the diverse range of stakeholders involved, including policymakers, industry professionals, environmentalists, and community members, MADM serves as a common framework for aligning disparate interests and priorities. Through collaborative decision-making processes facilitated by MADM, stakeholders can collectively evaluate trade-offs, identify synergies, and develop consensus-driven solutions that maximize societal value while minimizing environmental harm.

The future of CDW management lies in the continued innovation and refinement of decision-making methodologies like MADM. By leveraging the strengths of MADM alongside emerging technologies and interdisciplinary collaboration, stakeholders can navigate the complexities of CDW management with confidence, paving the way for a more sustainable and resilient built environment. Figure 9 presents the framework for the Foundations Multi-Attribute Analysis in CDW strategies.

Figure 9*Multi-Attributes Framework*

3.2 Multi Attributes Decision Making Method

Multi-Attribute Decision Making (MADM) is a prominent methodology used in decision science and operations research (Yang et al., 2022; Chen et al., 2022). It provides a structured approach for evaluating and ranking multiple alternatives based on several criteria, which may be quantitative or qualitative in nature (Hafezalkotob et al., 2019). MADM is extensively applied across various fields such as engineering (Deveci et al., 2022), economics, environmental management (Qahtan et al., 2023; Ibrahim et al., 2023), healthcare (Napi et al., 2019; Almahdi et al., 2019), and more.

MADM methods aim to facilitate decision-making by systematically analysing complex decision problems and identifying the most desirable alternatives based on predefined criteria and objectives. These methods provide decision-makers with valuable insights into the trade-offs and implications associated with different options, enabling them to make informed and rational choices. By integrating mathematical models, statistical techniques, and decision analysis tools, MADM approaches offer robust frameworks for addressing decision-making challenges in diverse contexts.

Moreover, MADM techniques can accommodate various types of data, including crisp, fuzzy, and uncertain information, allowing decision-makers to account for ambiguity and imprecision in the decision-making process. This flexibility enhances the applicability of MADM methods to real-world decision problems characterized by inherent uncertainty and complexity. Additionally, MADM approaches often incorporate stakeholders' preferences and priorities through weighting and scoring mechanisms, ensuring that decision outcomes align with stakeholders' objectives and values. Overall, MADM plays a crucial role in supporting

effective decision-making across a wide range of domains, including sustainable management strategies for construction and demolition waste.

The main aspects of MADM that may be employed when evaluating and selecting CDW include the essentials of the method, which is based on certain concepts. Such principles are the Aggregation method, Normalization method, Criteria Weighting method, and multi-criteria Evaluation method. At its simplest, MADM operates based on the assumption that decision-making, as a rule, does not occur based on one factor. Instead, it delineates conditions under which decisions are made and ensures every attribute is considered simultaneously (Liu et al., 2019). In the CDW management context, this region implies the strategies that must be assessed not solely based on pure economic characteristics but also considering the environmental repercussions, social acceptance, technology feasibility, and compliance with legislation. MADM can be said to facilitate a more comprehensive evaluation owing to the holistic approach of encompassing several criteria that are characteristic of multiple criteria decision-making environments.

Criteria vary, and not all of them are of equal importance in the decision-making process. MADM allows the decision-makers to express the level of importance of each criterion with reference to the others. These weights capture the feelings of the people attending the CDW, together with the standards that are set for these discs. For instance, while efficiency could be important to some clients, others may consider other qualities worth the extra price, such as impact on natural resources or fairness. Consequently, MADM is useful in preventing the distortion of criteria that may result in a decision-making process that does not match the stakeholders' objectives and beliefs.

Still, criteria can be measured in different units or have different scales, which makes it difficult to compare them. MADM uses normalization to overcome this challenge since it brings the data to a common scale in relation to the criteria. It converts different measurements into a common form and makes numerical comparisons and summations possible.

Normalization within the management of CDW may include converting the financial cost into monetary value, measuring the impact of a specific environment in terms of emission or consumption of raw materials, or rating the social aspect qualitatively or quantitatively (Aytekin, 2021).

Once criteria are weighted and normalized, MADM models combine them to get an overall value for each feasible solution. This aggregation process summative consolidates the overall measures of performance of each of the criteria for the given/selected alternatives in question. Where certain calculations and comparisons can be made, weighted sum models, TOPSIS, ELECTRE, and other methods can be used according to the specifics of what decision and in what context and stakeholders are made. In CDW management, aggregation enables decision-makers to consider policies considering a suitable criterion that comprises a composite of the economic, environmental, social, technical, and regulatory aspects of waste management so that the most efficient policies can be prioritized.

Due to the qualitative basis of the criteria and the variability of values that become the basis of the decision made, MADM can contain the sensitivity analysis. This process validates the results by studying the characteristics of the decision process based on alterations in the weighting criteria and assumptions. Through sensitivity analysis, decision-makers can determine the vulnerability of a decision to a change in value or preference of any uncertain factor. Applying sensitivity analysis in CDW management analysis can also help the

stakeholders act as a reality check where it assesses the stability of waste management strategies' rankings depending on the changes in the criteria's priorities and input data.

Categories of MADM:

Based on previous studies, MADM methods are generally classified into two main categories:

- i. **Mathematical-Based Approaches:** These methods involve mathematical computations to aggregate criteria and rank alternatives. Common mathematical methods include Simple Additive Weighting (SAW), Weighted Sum Model (WSM), Weighted Product Model (WPM), and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). Table 3 provides an overview of the MADM mathematical methods that are commonly employed.
- ii. **Human-Based Approaches:** These methods rely on the judgment and expertise of decision-makers or experts to assign weights to criteria. The Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) and FWZIC are examples of popular human-based approaches.

These traditional MADM methods have been widely used in various decision-making contexts, including supply chain management, project selection, and resource allocation.

However, there are limitations associated with both mathematical-based and human-based approaches. Mathematical-based methods may oversimplify complex decision environments and fail to capture the subjective preferences of decision-makers accurately. On the other hand, human-based approaches may suffer from bias, inconsistency, and subjectivity due to the reliance on expert judgment. To address these limitations, recent research has focused on

developing hybrid MADM methods that combine the strengths of mathematical and human-based approaches (Beck & Hofmann, 2012).

Hybrid MADM methods integrate mathematical models with subjective assessments from decision-makers, aiming to improve the robustness and accuracy of decision outcomes. These approaches leverage computational algorithms to process quantitative data while allowing decision-makers to provide qualitative input based on their expertise and judgment. By combining objective and subjective information, hybrid MADM methods enable more comprehensive and nuanced decision-making, particularly in complex and uncertain environments. Examples of hybrid MADM methods include fuzzy TOPSIS, fuzzy AHP, and fuzzy MULTIMOORA, which incorporate fuzzy logic to handle uncertainty and vagueness in decision-making processes.

Table 3

MADM Mathematical-Based Approaches

Method	Brief
SAW	The Simple Additive Weighting (SAW) method in Multi-Attribute Decision Making assigns weights to criteria, normalizes data, and calculates a score for each alternative based on these criteria. It's simple and transparent but assumes criteria independence, can be sensitive to weight assignment, and may not handle complex relationships well. (Shahri et al., 2021)
WSM	The Weighted Sum Model (WSM) in Multi-Attribute Decision Making combines criteria by multiplying their values with predefined weights and then summing them up to rank alternatives. It's a straightforward approach but assumes linear relationships between criteria, which may not always reflect real-world complexities. (Shahri et al., 2021).
WPM	While WSM primarily relies on addition for computations, WPM, akin to it, places greater emphasis on multiplication as the primary mathematical operation (A. A.

FDOSM	Zaidan et al., 2015). In WPM, alternatives are assessed using a combination of weights and ratios for each criterion. (Shahri et al., 2021). The Fuzzy decision by opinion score method allows the module of the CDW management strategies under complex multiple-attribute decision-making problems. (FDOSM)-based multiplicative multiple objective optimizations by ratio analysis (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS) to address the problem. The q-ROPHFS–FDOSM scores the CDW management strategies (Mahmoud et al., 2022).
MULTIMOORA	Are multiplicative multiple objective optimisations by ratio analysis which has been developed in this study to develops the fuzzy-weighted zero inconsistency (FWZIC) and fuzzy decision by opinion score method (FDOSM) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS) to address this problem. The MULTIMOORA method is used to model 51 CDW management strategies to determine the optimum one (Alsattar et al., 2022).

Based on the information in Table 3 and our examination, it appears that none of the mentioned techniques have been applied to assess and rank the identified CDW Strategies. Nonetheless, considering its capability to handle both positive and negative ideal solutions, MULTIMOORA stands out as the favoured and most suitable approach for model 51 CDW management strategies and determining the optimal choice. However, it is worth noting that MULTIMOORA does not inherently calculate the weights for the attributes, so an external method or approach is needed to establish these attributes weights.

Within academic literature, human-based methodologies are utilized to fulfil this objective. Table 4 provides an overview of the primary MADM human-based techniques that are commonly applied, encompassing AHP, Analytic Network Process (ANP), best–worst method (BWM), and FWZIC. Each approach is briefly described for clarity.

Table 4*MADM Human-Based Approaches*

Methods	Brief description
AHP	AHP is a widely used Multi-Attribute Decision Making (MADM) method. It decomposes complex decisions into a hierarchical structure of criteria and sub-criteria, allowing decision-makers to assign weights and make pairwise comparisons. AHP calculates a final ranking based on these comparisons. It's valued for its ability to handle complex decision scenarios with multiple criteria and preferences, making it a structured and systematic approach for decision analysis (Hafezalkotob et al., 2019).
ANP	The ANP is an extension of Analytic Hierarchy Process (AHP) in (MADM). ANP considers not only hierarchical relationships but also interdependencies among criteria in a network structure. It enables decision-makers to model complex decision scenarios where criteria influence each other, making it suitable for more intricate and interconnected decision problems (Hafezalkotob et al., 2019).
BWM	The Best-Worst Method (BWM) in (MADM) is a technique that helps decision-makers identify the best and worst aspects or alternatives within a set of options. It involves comparing and ranking alternatives based on their performance in various criteria. BWM is particularly useful for capturing relative preferences and is known for its simplicity and efficiency in decision analysis (Abdulkareem et al., 2020; Alsalem et al., 2019).
FWZIC	FWZIC introduces an innovative and uncomplicated MADM weighting technique capable of assigning criteria weights without any inconsistency. Unlike prior methods, it doesn't require pairwise comparisons, resulting in a more time-efficient process (Mahmoud et al., 2022; Alsattar et al., 2022).

After thorough examination, it appears that none of the methods discussed have been employed to assign weights to the identified attributes for sustainable management strategy in

CDW. However, the FWZIC method (Mahmoud et al., 2022; Alsattar et al., 2022). surpasses previous human-based approaches (such as AHP, ANP, and BWM) by offering a way to determine weights with zero inconsistency. This is elucidated in Table 4. Consequently, it proves to be a viable option for weighing the attributes in the context of sustainable management strategy for CDW.

The suggested approach undergoes an objective comparative analysis with the VIKOR ranking method. The weightings derived from the q-ROPHFS–FWZIC for barrier attributes related to reuse distribution are incorporated into the VIKOR method. Simultaneously, the group scores for CDW management strategies obtained through q-ROPHFS–FDOSM serve as the decision matrix for the VIKOR method. A comparison is then conducted between the ranking results obtained from the VIKOR technique and the MULTIMOORA approach. As mentioned, weighting attributes needed in this method, therefore we have discussed the use of FWZIC method below.

The VIKOR method serves as a ranking approach, and to facilitate the ranking, a weighting method is essential. For this purpose, the FWZIC method is employed. Given that the FWZIC method operates in a fuzzy environment, we utilize the q-ROPHFS method to accommodate this fuzzy setting.

Further exploration into the integration of alternative operators with the q-ROPHFS–FWZIC method could enhance its robustness and effectiveness in handling uncertainty. Additionally, investigating the applicability of the FWZIC method in other decision-making contexts beyond CDW management could provide valuable insights into its versatility and generalizability. Moreover, conducting case studies to validate the proposed approach in real-world scenarios would offer practical evidence of its efficacy and potential benefits for

stakeholders in the construction industry. Through these avenues of future research, the proposed framework can be refined and expanded to better address the complex challenges of sustainable CDW management.

3.2.1 FWZIC Method

The FWZIC method, as proposed by (Krishnan et al., 2021; Mohammed et al., 2022), is employed to ascertain the weight coefficients of attributes exhibiting zero inconsistency, regardless of their quantity. This method achieves this by precisely computing both local and global weight coefficient values for each attribute at a specific hierarchical level, as outlined by (R.T. Mohammed et al., 2022). Additionally, the FWZIC method can evaluate the importance level of each attribute in the decision-making process, based on expert preferences, according to (Krishnan et al., 2021). It has found applications in various domains such as many-objective optimization algorithms (R.T.Mohammed et al., 2022) and smart e-tourism data management applications (Krishnan et al., 2021), successfully resolving inconsistency issues. In fact, it is regarded as the most effective attribute weighting method for evaluating CDW management development attributes.

FWZIC has been developed and incorporated into various fuzzy sets (FSs), including q-rung orthopair, dual-hesitant, neutrosophic, Pythagorean, cubic Pythagorean, interval type 2 trapezoidal, T-spherical, and Pythagorean m-polar FSs, to address these challenges. Despite these advancements, issues related to vagueness and uncertainty in information persist as ongoing concerns.

Recognizing the enhanced performance of q-rung orthopair fuzzy sets (q-ROFSs) in comparison to earlier fuzzy sets, reference (Liu et al., 2019) introduced the concept of q-rung orthopair hesitant fuzzy sets (q-ROHFS) along with its operational principles. Building upon

this, reference (Attaullah et al., 2022) further refined q-ROHFS by incorporating probability considerations, leading to the development of q-rung orthopair probabilistic hesitant fuzzy sets (q-ROPHFS).

The primary objectives of this study are to create and advance FWZIC utilizing q-ROPHFS. To the best of the authors' knowledge, the integration of q-ROPHFS into FWZIC-based MULTIMOORA methods has not been previously applied in any case study. The innovative q-ROPHFS-FWZIC method is designed to prioritize barrier attributes in CDW management strategies based on their respective levels of importance.

Within the realm of (MADM), issues pertaining to vagueness, hesitancy, and uncertainty exert a significant influence on the final scores assigned to alternatives. These challenges typically arise from the opinions of decision-makers. Various approaches can be employed to define and account for the vagueness, hesitancy, and uncertainty of information. Zadeh's fuzzy set theory (Zadeh, 1965) has emerged as a prominent method for addressing these complexities in decision-making problems. As a result, the FWZIC method has been extended to operate within different fuzzy set environments, including neutrosophic fuzzy sets (Alamoodi et al., 2022) Pythagorean fuzzy sets (PyFSs) (Albahri et al., 2022) cubic Pythagorean fuzzy environment (Alamoodi, Albahri, et al., 2022), interval type-2 trapezoidal-fuzzy environment (IT2TR) (Krishnan et al., 2021), dual-hesitant fuzzy environment (Al-Humairi et al., 2022), q-rung orthopair fuzzy environment (q-ROFs) (A.S.Albahri et al., 2022), and T-spherical fuzzy environment (T-SFS) (Alsalem et al., 2021b). Despite these endeavours, the challenges related to vagueness, hesitancy, and uncertainty persist as ongoing concerns in decision-making processes.

When integrated into MADM, the FWZIC method is widely used and implemented in different fields because it smoothly navigates between the problem's inherent uncertainty and complexity stemming from multiple criteria in the decision-making process (Baquer et al., 2022). It may be used in product designing, acquisition, and choosing suppliers for the products. In the case of strategic CDW management, decision-makers can be confronted with the challenge of choosing between different waste management projects largely rooted in the type of infrastructure on offer, such as recycling facilities, landfills, or waste-to-energy plants. By so doing, they can assess such projects in the form of development criteria such as environmental impacts, cost, regulation, and acceptance. Thus, thanks to the application of fuzzy logic, FWZIC smooths all the roughest edges and makes the selection of projects according to the results of their evaluation regarding sustainable development goals, organizational and legal peculiarities, available funding, and stakeholders' preferences.

When it comes to choosing suppliers or partners for CDW recycling and processing facilities, the quality and quantity of the recycled material are important. The FWZIC method enables MADM in the context of supplier selection, integrating the aspects of material quality, processing capability, logistical distribution, and compliance with the necessary laws and standards. Decision-makers can use FWZIC to select those suppliers that can manage CDW sustainably and are reliable and cheap at the same time.

Product innovation is a factor that must be taken into consideration for the development of the circular economy and the minimization of CDW generation. This FWZIC method assists MADM in product design decisions for ranking the design options depending on aspects such as recyclability, durability, material utilization efficiency, and total life-cycle environmental effects. By applying FWZIC, decision-makers can know which designs of a

product are more efficient with resources before generating waste and offering market-demanded products within technical and cost limitations.

To further enhance the applicability and effectiveness of the FWZIC method, future research could delve into exploring hybrid approaches that combine FWZIC with other decision-making techniques, such as Analytic Hierarchy Process (AHP) (Hafezalkotob et al., 2019) or Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). These hybrid methodologies could leverage the strengths of each approach to address the limitations and uncertainties inherent in CDW management decision-making processes.

Moreover, investigating the integration of machine learning algorithms with FWZIC could offer promising avenues for improving the accuracy and efficiency of decision-making in CDW management. Machine learning models could be trained on historical data to identify patterns and trends, thereby providing valuable insights for attribute weighting and strategy selection within the FWZIC framework.

Additionally, extending the scope of FWZIC beyond CDW management to encompass other domains within the construction industry or even beyond could broaden its utility and relevance. By adapting the FWZIC method to address the specific challenges and requirements of different sectors, researchers can contribute to advancing decision-making practices in various fields while also enriching the theoretical foundations of FWZIC.

Furthermore, conducting empirical studies and case analyses to validate the performance and practical applicability of FWZIC-based decision-making frameworks in real-world CDW management scenarios would be crucial for establishing its credibility and reliability. By collaborating with industry stakeholders and practitioners, researchers can

gather valuable feedback and insights to refine and optimize FWZIC-based methodologies for practical implementation and adoption.

3.2.2 *FDOSM Method*

FDOSM assists in making rational decisions with the input of experts by determining ideal solutions for each attribute in an opinion matrix. FDOSM's strengths include resolving inconsistency, saving computation time, preventing unnatural comparisons, handling information ambiguity with fuzzy numbers, avoiding normalization method biases, and using ideal solutions to address distance issues (Albahri et al., 2021). As a result, FDOSM has demonstrated effectiveness in addressing various MADM problems (Alamleh et al., 2022).

However, FDOSM employs different aggregation operators to calculate the scores of alternatives. Initially, FDOSM relied solely on direct aggregation (Salih et al., 2020). In a subsequent development, reference (Albahri et al., 2021) enhanced FDOSM using TOPSIS and VIKOR with distance measurement and a compromise model for modelling active queue management methods. They concluded that this extension of FDOSM-based VIKOR, utilizing a compromise model, is the most effective approach for comparing different active queue management methods.

FDOSM has two main limitations: it can't prioritize attributes by importance, and its original version struggled with information vagueness. To tackle the first issue, researchers have turned to various MADM weighting methods like AHP, BWM, and ANP for attribute prioritization. However, these methods are often plagued by inconsistency stemming from pairwise comparisons (Hafezalkotob et al., 2019). Reference (Mohammed et al., 2022) tackled the issue of inconsistency by introducing a novel MADM weighting method called Fuzzy-

Weighted Zero-Inconsistency (FWZIC). Since then, this approach has been widely used to determine the weight of assessment attributes without inconsistency. Additionally, FWZIC requires minimal mathematical operations and processing time to operate. The different weighted attributes in FWZIC are independent, meaning that adding or removing them does not necessitate recalculations. Moreover, gathering feedback from decision-makers (DMs) in FWZIC is straightforward. Nonetheless, the initial version of this approach was based on a triangular fuzzy set (FS), which struggled to adequately handle the vagueness and uncertainty of information, like FDOSM (Alamleh et al., 2022).

Moreover, future studies could delve deeper into the optimization of FWZIC parameters to enhance its performance in handling vagueness and uncertainty in decision-making processes. Fine-tuning the parameters of FWZIC, such as adjusting the membership functions or exploring alternative fuzzy set structures, could lead to improved accuracy and robustness in attribute weighting. Additionally, conducting sensitivity analyses to assess the impact of parameter variations on decision outcomes would provide valuable insights into the stability and reliability of the FWZIC method (Mohammed et al., 2022).

Furthermore, exploring the integration of FWZIC with other decision-making models or techniques could open new avenues for enhancing the efficiency and effectiveness of decision support systems in various domains. For instance, combining FWZIC with machine learning algorithms or artificial intelligence approaches could enable automated decision-making processes and adaptive learning systems capable of dynamically adjusting to changing environmental conditions or stakeholder preferences. Additionally, integrating FWZIC with multi-criteria decision analysis methods could enable a more comprehensive evaluation of

complex decision problems by considering multiple conflicting objectives and criteria simultaneously.

Moreover, future research could focus on empirically validating the proposed FWZIC-FDOSM integration through case studies or real-world applications in the construction and waste management industry (Hafezalkotob et al., 2019). Conducting comparative analyses with existing decision-making frameworks or methodologies would allow for a thorough assessment of the performance and advantages of the FWZIC-FDOSM approach. Additionally, soliciting feedback and insights from industry practitioners, policymakers, and other stakeholders through surveys or interviews could provide valuable validation and refinement of the integrated approach based on practical considerations and real-world constraints.

3.2.3 *MULTIMOORA Method*

Nonetheless, a more resilient approach for Multiple Attribute Decision Making (MADM) is the Multiplicative Multiple Objective Optimization by Ratio Analysis (MULTIMOORA) (Brauers et al., 2012). This method offers simplicity in comprehension, ease of implementation, and greater stability compared to TOPSIS and VIKOR (Brauers et al., 2012). Furthermore, MULTIMOORA is highly efficient, demanding the least processing time and mathematical operations (Brauers et al., 2012). Moreover, it excels at accurate modelling with comprehensive measurements, streamlining the decision-making process (Brauers et al., 2011). As a result, this study acknowledges the merits of the MULTIMOORA method and proposes an FDOSM-based MULTIMOORA approach for modelling CDW management strategies.

Nevertheless, a more robust MADM modelling method is the Multiplicative Multiple Objective Optimization by Ratio Analysis (MULTIMOORA) (Brauers et al., 2012). This method is easier to comprehend, simpler to implement, and more stable compared to TOPSIS and VIKOR. Moreover, MULTIMOORA demands the least processing time and mathematical operations. Furthermore, it offers accurate modelling with comprehensive measurement, streamlining the decision-making process. Consequently, this study recognizes the advantages of the MULTIMOORA method and proposes an FDOSM-based MULTIMOORA approach for modelling CDW management strategies.

Recognizing the superior attributes of q-rung orthopair fuzzy sets (q-ROFSs) compared to previous fuzzy sets, reference (Liu et al., 2019) introduced the notion of q-rung orthopair hesitant fuzzy sets (q-ROHFS) along with its operational principles. Building upon this, reference (Attaullah et al., 2022) enhanced q-ROHFS by incorporating probability considerations, giving rise to q-rung orthopair probabilistic hesitant fuzzy sets (q-ROPHFS).

This study aims to advance the field by formulating and developing both FWZIC and FDOSM methodologies using q-ROPHFS. Notably, the integration of q-ROPHFS with FWZIC and FDOSM within the MULTIMOORA framework has not been previously applied in any case study, as far as the authors are aware.

The newly proposed q-ROPHFS-FWZIC method serves the purpose of prioritizing barrier attributes in CDW management strategies based on their respective importance levels. Additionally, the innovative q-ROPHFS-FDOSM-based MULTIMOORA approach is designed to model CDW management strategies while addressing two specific research concerns, namely, the presence of multiple barrier attributes and data variability.

Expanding on the advancements made in MADM methodologies and the integration of fuzzy sets, this study contributes to the ongoing evolution of decision-making frameworks in the realm of sustainable CDW management. By incorporating q-rung orthopair probabilistic hesitant fuzzy sets (q-ROPHFS) (Attaullah et al., 2022) into established methodologies like FWZIC and FDOSM (Liu et al., 2019), the research expands the toolkit available to decision-makers, offering more nuanced and robust approaches to evaluating CDW management strategies.

Furthermore, the exploration of additional operators and aggregation methods, as well as the consideration of decision-makers' experience levels, opens avenues for further refinement and customization of MADM frameworks. This could lead to tailored decision-making processes that better reflect the unique contexts and priorities of stakeholders involved in CDW management, ultimately enhancing the effectiveness and acceptance of sustainable practices.

Moreover, the proposed framework's potential for benchmarking innovative systems within the CDW industry underscores its relevance beyond individual decision-making contexts. By establishing a standardized approach for evaluating and comparing different strategies, the framework facilitates knowledge sharing and collaboration within the industry, driving continuous improvement and innovation in sustainable CDW management practices.

In future research, exploring the application of the proposed framework across diverse geographical contexts and construction sectors could provide valuable insights into its scalability and adaptability. Additionally, conducting longitudinal studies to assess the long-term impacts of implementing sustainable CDW management strategies evaluated using the framework would further validate its effectiveness and utility in real-world scenarios.

3.3 Fuzzy Set (q-ROPHFS)

Fuzzy sets play a significant role in MADM by providing a flexible and robust framework for handling imprecise and uncertain information. MADM is a branch of decision theory that deals with the process of selecting the best alternative from a set of options based on multiple criteria or attributes. Traditional MADM techniques assume that the attributes are precisely defined and that there is no ambiguity in the decision-making process. However, in real-world scenarios, decision-makers often face situations where the criteria are subjective, vague, or imprecise. This is where fuzzy sets come into play.

Fuzzy sets were introduced by (L.A. Zadeh, 1965) to represent and manipulate uncertain or vague information. Unlike classical sets, where an element either belongs or does not belong to the set, fuzzy sets allow elements to have degrees of membership in the set, ranging from 0 (not a member) to 1 (fully a member). This degree of membership captures the imprecision and uncertainty inherent in many decision problems.

In the realm of MADM, fuzzy sets offer versatile applications:

Fuzzy Membership Functions play a crucial role by employing membership functions to articulate the extent to which an element belongs to a specific set. In MADM, these functions represent how well an alternative satisfies a particular criterion, utilizing shapes like triangular, trapezoidal, Gaussian, or other forms based on the criterion's nature. Linguistic Variables introduce a linguistic dimension, enabling decision-makers to describe criteria using terms like "high," "medium," and "low" rather than exact numerical values, providing a qualitative expression of an alternative's adherence to a criterion. Fuzzy Aggregation methods, such as weighted average or weighted sum, amalgamate multiple criteria to rank alternatives.

These methods consider the uncertainty in assessing each criterion, with Pedrycz's extensive work contributing to the development and application of fuzzy aggregation operators in MADM and group decision-making. Fuzzy Decision-Making and Aggregation propose operators like the ordered weighted averaging (OWA) operator for MADM, providing a comprehensive framework for handling uncertainties. Fuzzy Ranking generates nuanced fuzzy rankings for alternatives, offering a more detailed view of preferences or superiority between alternatives compared to rigid rankings. Fuzzy TOPSIS, an extension of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), incorporates fuzzy sets to accommodate imprecise data and criteria in MADM applications.

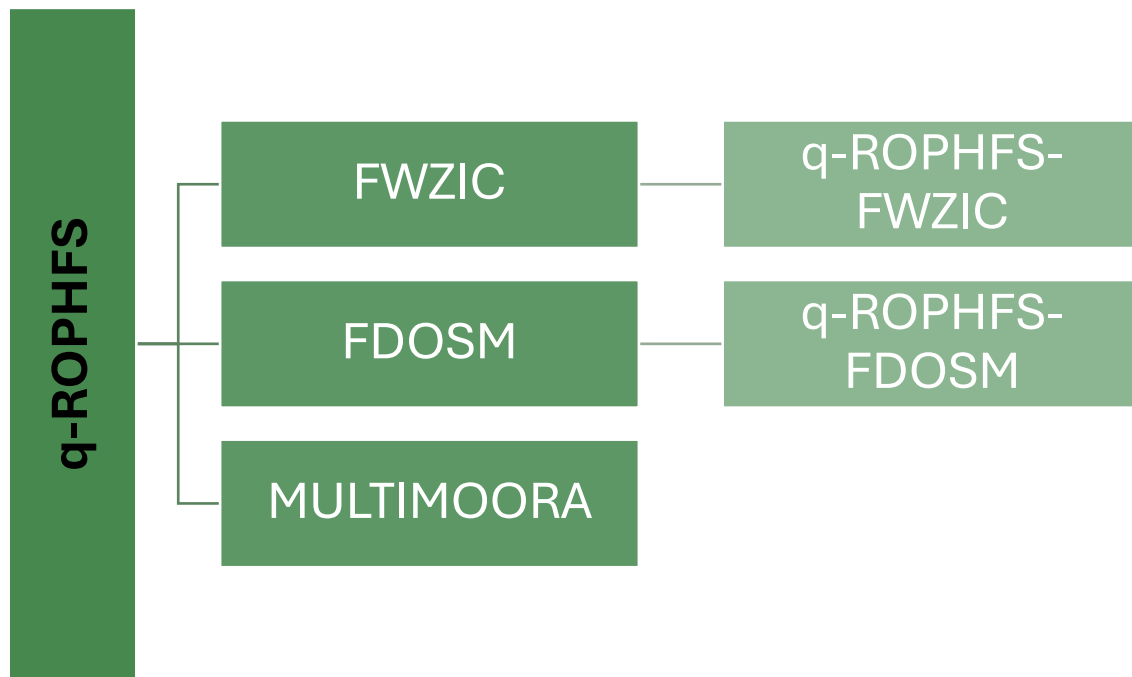
In summary, the integration of fuzzy sets in MADM equips decision-makers with a potent tool to address uncertainty and vagueness in decision-making. This approach allows for realistic and flexible modelling, leading to more robust and informed decisions, especially in complex and ambiguous environments where precise data and clear criteria are scarce.

Considering the superior performance of q -ROPHFS when compared to earlier FSs, in reference (Liu et al., 2019) and as explained in section 3.5, the notion of q -rung orthopair hesitant FS (q -ROHFS) along with its operational laws was introduced. Furthermore, reference (Attaullah et al., 2022) enhanced the q -ROHFS by incorporating probability and introduced the concept of q -rung orthopair probabilistic hesitant FS (q -ROPHFS). As a result, the primary objectives of this study are to construct and advance FWZIC and FDOSM utilizing q -ROPHFS. As far as the authors are aware, the amalgamation of the q -ROPHFS–FWZIC and q -ROPHFS–FDOSM-based MULTIMOORA techniques has not been employed in any previous case study. The innovative q -ROPHFS–FWZIC approach can effectively

prioritize the critical attributes of CDW management strategies based on their level of significance. Figure 10 Displays the New Version of Q-ROPHFS Across Various Fuzzy Sets.

Figure 10

New Version of Q-ROPHFS Under Different Fuzzy Sets



Expanding on the role of fuzzy sets in MADM, it's important to note their ability to capture the inherent uncertainty and subjectivity present in decision-making processes. Traditional decision-making models often struggle to accommodate these factors adequately, leading to potentially suboptimal or biased outcomes. Fuzzy sets offer a more nuanced approach by allowing decision-makers to express their preferences and judgments in a flexible and intuitive manner. This flexibility is particularly valuable in domains where precise quantification is challenging or impractical, such as in the evaluation of qualitative attributes or in situations with limited data availability.

Moreover, the application of fuzzy sets in MADM extends beyond decision-making to encompass a wide range of problem-solving tasks. For instance, fuzzy clustering techniques can be used to group alternatives based on their similarity in terms of multiple criteria, enabling decision-makers to identify distinct patterns or clusters within complex datasets. Similarly, fuzzy rule-based systems can provide interpretable models for mapping input variables to output decisions, offering valuable insights into the underlying decision logic.

In addition, the integration of fuzzy sets with other computational intelligence techniques, such as genetic algorithms, neural networks, and swarm intelligence, opens up new avenues for addressing complex decision-making problems. These hybrid approaches leverage the complementary strengths of different methods to overcome the limitations of individual techniques, resulting in more robust and effective decision support systems.

Overall, the adoption of fuzzy sets in MADM represents a paradigm shift towards more adaptive and human-centric decision-making approaches. By embracing uncertainty and ambiguity as inherent features of real-world decision problems, fuzzy sets empower decision-makers to make more informed and resilient choices in complex and uncertain environments. As research in this field continues to evolve, we can expect further advancements in both theoretical foundations and practical applications, ultimately leading to more sustainable and equitable decision outcomes across various domains.

3.4 Point of View for Data Set Generation in Different Case Studies

The lack of real data hinders the advancement of knowledge in various scientific and industrial fields. In response, many researchers have proposed various methods to generate their datasets.

Dataset generation encompasses the concepts and processes used by researchers to generate data from sampled sources such as participants, articles, and organizations. To validate and apply the proposed methods, it is necessary to test the dataset generation methods in different case studies. In the existing literature, two potential approaches stand out: using synthetic (or augmented) data (Güleç & Kabak, 2022; Radovanović, 2021) or using original articles (Alamoodi et al., 2022; Albahri et al., 2020; Krishnan et al., 2021). If no infrastructure is available for the case study application, aggregated data will be used. For example, researchers often exploit aggregated data to simulate scenarios to test compliance with environmental and safety regulations in CDW management (Ferreira et al., 2015; Klang et al., 2003; Coelho et al., 2012). In addition, some researchers choose the stem article method (Alamoodi, Mohammed et al., 2022; Albahri, A.S. et al., 2020; Krishnan et al., 2021), where original articles are influential or primary articles that serve as primary sources or references providing important information.

This method leverages existing, peer-reviewed research to create robust datasets that reflect real-world conditions and outcomes. Utilizing stem articles ensures that the data generation process is grounded in established research, enhancing the reliability and validity of the findings.

Furthermore, the use of synthetic data has gained prominence due to its flexibility and scalability. Synthetic data generation allows researchers to create large, varied datasets that can mimic the statistical properties of real data without the privacy concerns associated with using real-world data (Güleç & Kabak, 2022). This approach is particularly useful in scenarios where access to real data is restricted or where the cost of data collection is prohibitive. By generating synthetic datasets, researchers can conduct extensive testing and validation of their

models, ensuring robustness and generalizability.

Moreover, integrating both synthetic and stem article-based datasets can provide a more holistic approach to dataset generation. Combining these methods can capitalize on the strengths of each, offering comprehensive datasets that are both theoretically sound and empirically valid. This integrative approach can facilitate more rigorous testing and validation of CDW management strategies, leading to more effective and sustainable practices in the field.

Overall, the strategic use of synthetic data, stem articles, and aggregated data in generating datasets for case studies ensures a robust framework for advancing research in various domains, including sustainable CDW management. By leveraging these methodologies, researchers can overcome the limitations posed by the lack of real data, paving the way for innovative solutions and informed decision-making. This comprehensive strategy not only advances academic understanding but also offers practical benefits, such as enhanced policy formulation and more effective implementation of sustainability initiatives in the construction industry.

Table 5

Showcases Prior Studies Utilizing the Root Article Method

References	Case study	The root article	Number of prior studies/alternatives	Number of categories	Number of development factors	Data type	Data size (partial or full)
(Qahtan, Yatim, et al., 2023)	Healthcare industry 4.0 application based blockchain	(Hussien et al., 2021)	52	2	6,7	Binary based	Full
(Alamoodi, Albahri, et al., 2022)	Sign language recognition system	(Al-Samarray et al., 2022)	30	2	11	Categorical based	Full
(Ghailani, Zaidan et al., 2023)	Developing Sustainable Management Strategies in CDW based Decision Modelling Approach	(Hussien et al., 2021)	51	6	20	Binary based	Full

Based on the mentioned information in the Table 5, the study of (Qahtan, Yatim et al., 2023) used the basic research of (Hussien et al., 2021), to evaluate blockchain based on its

application in the healthcare sector. Additionally, focusing on industry using multi-criteria decision making (MCDM). The authors collected data points from a comprehensive binary data set, as detailed in the original article. The authors included 52 health systems, split into two categories, and assessed based on six and seven criteria. While (Alamoodi, Albahri, et al., 2022) used data from the root article by (Al-Samarraay et al., 2022a) to estimate 30 sign language recognition systems, assorted into two sets and evaluated based on 11 attributes. Finally, (Ghailani, Zaidan et al., 2023) employed the essential article by (Hussien et al., 2021) to benchmark and evaluate 51 CDW management strategies with data from 20 alternate within six main attributes.

Overall, the generation of datasets based on master theses has been used in several case studies, and the number of alternatives, categories, and development attributes varies from study to study. Furthermore, the type and scope of data (partial or complete) varies on a case-by-case basis, indicating the importance of contextualizing data collection methods to suit the unique requirements of each study. This flexibility in data set generation methods allows researchers to adapt to the specific needs of their investigations, ensuring relevant and accurate results. Additionally, the integration of comprehensive datasets in these studies demonstrates a methodological rigor that enhances the credibility and reliability of the findings. By employing well-structured data sets, researchers can systematically address the complexities inherent in their specific areas of study, whether in healthcare, technology, or environmental management. The use of MCDM across these diverse fields showcases its broad applicability and effectiveness in tackling multi-faceted decision-making scenarios (Hussien et al., 2021; Al-Samarraay et al., 2022a).

In summary, the systematic approach to data set generation as evidenced by these

studies underscores the critical role of structured methodologies in advancing research across various domains. The tailored use of data sets, combined with robust evaluation criteria, enables a comprehensive analysis that can inform best practices, policy decisions, and future research directions. This highlights the ongoing need for meticulous data collection and methodological innovation to address emerging challenges in different sectors. Through continuous refinement and application of these methods, researchers can significantly contribute to the development of sustainable and efficient solutions across various industries.

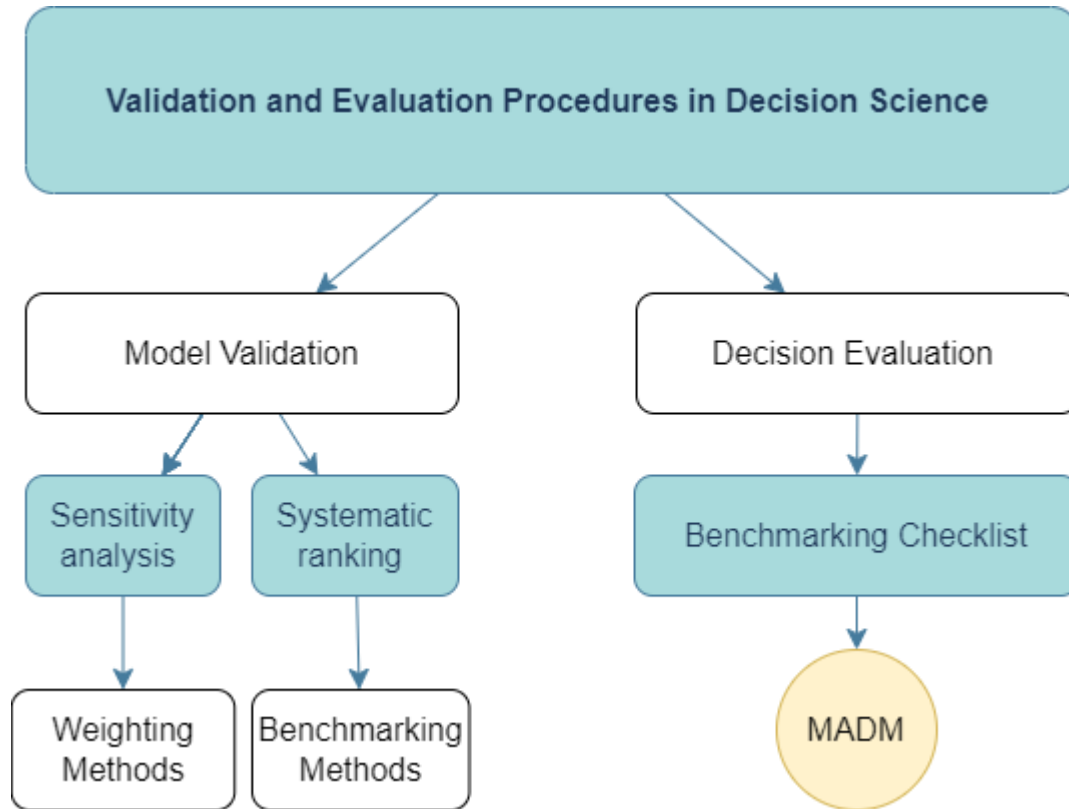
3.5 Overview for Validation and Evaluation Procedures in Decision Science

Validation and evaluation in MADM indicate the process of assessing the quality and performance of a decision-making model and the results produced by that model. Reference to (Alsalem et al., 2021b, 2022; Albahri, Zaidan, et al., 2022a), different steps used to validate and evaluate methods in decision science. As shown in Figure 12, this process can be divided into two main steps: model validation and decision evaluation. **Model validation** entails ensuring the model's consistency, completeness, accuracy, and capacity to deliver conclusions that align with the problem specification and data. During this phase, **sensitivity analysis** evaluates the model's robustness by analysing the impact of changes in input data and assumptions. Benchmarking compares the model's performance to other models or real-world data (Alamoodi, Albahri, et al., 2022; Anor et al., 2022) **Systematic ranking** is a strategy that ranks alternatives using specific criteria. The process comprises assigning a score or weight to each alternative for each criterion and combining them to determine the overall ranking (Qahtan et al., 2023), (Albahri et al., 2022a), and (Krishnan et al., 2021).

The second stage in this phase is to evaluate the quality of the model's decision outputs by comparing the performance of the selected alternative to the objectives and criteria. (Al-Samarraay et al., 2022b) suggest using a benchmarking checklist as part of this stage is recommended. This checklist helps ensure that all relevant aspects of the decision-making process are considered and that the outcomes are aligned with predefined goals and standards. Additionally, decision evaluation involves verifying the practicality and effectiveness of the recommended solutions in real-world applications, ensuring that theoretical benefits translate into actual improvements (Alsalem et al., 2021b).

Moreover, a comprehensive evaluation approach often includes a post-implementation review to gather feedback and identify areas for further refinement. This step is critical for continuous improvement and adaptation of the decision-making model to evolving challenges and contexts. Incorporating stakeholder feedback during this phase can also enhance the model's acceptability and effectiveness, as it ensures that diverse perspectives are considered and addressed (Albahri, Zaidan, et al., 2022a).

In conclusion, the validation and evaluation procedures in MADM are integral to ensuring that decision-making models are robust, reliable, and applicable to real-world scenarios. By systematically validating and evaluating these models, decision scientists can enhance the credibility and utility of their recommendations, ultimately contributing to more informed and effective decision-making processes across various domains. The continuous cycle of validation, evaluation, and refinement ensures that decision-making models remain relevant and effective in addressing complex and dynamic problems, thereby supporting better decision outcomes and strategic planning.

Figure 11*Validation and Evaluation Procedures***3.5.1 Sensitivity Analysis Procedure**

Sensitivity and correlation studies are performed to assess the robustness of the suggested MADM approaches (Alamleh et al., 2022; Qahtan et al., 2022) for selecting the most and least sustainable CDW management strategies. In sensitivity analysis, the weight values of the primary barrier features of reuse distribution are varied per Kirkwood and Kahraman's suggestions (Klein et al., 1998; Kahraman et al., 2002; Albahri et al., 2022), and the modelling order of each CDW management technique is investigated. The Table 6 below presents various case studies employs sensitivity analysis.

Table 6 illustrates that multiple case studies examined the same sensitivity type, under different circumstances and criteria. (Qahtan, Yatim, et al., 2023) used five scenarios and seven criteria. The second study (Albahri, O. S., Zaidan, Albahri, et al., 2022) used the weighting method.

(PFWZIC) with fuzzy set PFS to benchmark nine scenarios with five criteria weight measures. Finally, (Anor et al., 2022) employ the same number of scenarios and criteria, namely two and nine. All analyses employed the elasticity coefficient (α) to compute the counterbalance of other strategic weights to the criterion with the highest significant influence. Furthermore, the Correlation Type of the three mentioned studies used Spearman's correlation coefficient (SCC), which was used to assess the relationship between the results of various scenarios and the proposed solution in all the case studies shown in the table. As mentioned above, different weighting methods are S-FWZIC, PFWZIC, and LDFRS-FWZIC are commonly employed with various fuzzy sets, including spherical FSs, PFS, and linear Diophantine fuzzy rough sets.

Additionally, the sensitivity analysis helps identify which criteria are the most critical in influencing the final decision. By systematically altering the weights assigned to different criteria and observing the changes in the rankings of CDW management strategies, the analysis provides insights into the stability and reliability of the decision-making model. This process ensures that the recommended strategies are robust and can withstand variations in the underlying assumptions and data inputs, thereby enhancing the credibility of the proposed solutions (Klein et al., 1998; Kahraman et al., 2002).

The use of correlation analysis, particularly with Spearman's correlation coefficient, adds another layer of validation by examining the consistency between different scenarios and

the proposed solutions. By analysing the correlation between the rankings generated under various conditions, researchers can ascertain the reliability of the model. High correlation values indicate that the model produces consistent results, even when subjected to different weighting schemes and scenario variations. This aspect is crucial for ensuring that the decision-making framework can be confidently applied in real-world settings, where input data and stakeholder preferences may vary (Albahri et al., 2022; Qahtan et al., 2023).

Moreover, the application of sensitivity analysis highlights the resilience of the decision-making process against changes in external factors and input parameters. This is particularly important in the context of CDW management, where environmental, economic, and social factors can fluctuate significantly. By demonstrating that the proposed MADM approaches can maintain their effectiveness under various scenarios, the study reinforces the adaptability and practical relevance of the decision-making framework.

The integration of sensitivity and correlation analyses not only validates the model but also provides a roadmap for future improvements. By understanding which criteria have the most significant impact on the decision-making process, future research can focus on refining these critical areas. This iterative process of evaluation and refinement ensures that the decision-making framework evolves to address emerging challenges and incorporates the latest advancements in sustainable CDW management.

The sensitivity and correlation analyses are vital components of the evaluation process, providing both robustness checks and validation of the proposed MADM approaches. These analyses contribute significantly to the overall reliability and applicability of the decision-making framework for sustainable CDW management. The thorough examination of various scenarios and criteria ensures that the proposed solutions are not only theoretically sound but

also practically viable, paving the way for their successful implementation in real-world settings.

Table 6

Literature of Sensitivity Analysis Assessment in Different Case Studies

References	Case study	Weighting method	Fuzzy set	Number of scenarios	Number of criteria	Sensitivity Type	Correlation Type
(Qahtan, Yati m, et al., 2023)	Healthcare industry 4.0 application based blockchain	S-FWZIC	Spherical FSs	5	7	elasticity coefficient($\alpha!$)	Spearman correlation coefficient (SCC)
(O. S. Albahri, Zaidan, Albahri, et al., 2022)	Prioritizing COVID-19 vaccine dose recipients	PFWZIC	PFS	9	5	αc	SCC
(Anor et al., 2022)	select the best international oil companies to build a sustainable transportation system	LDFRS-FWZIC	linear Diophantine fuzzy rough sets	9	2 criteria 9 sub-criteria	αc	SCC

Note. The table displays the sensitivity analysis assessment literature across various case studies.

Mostly, a sensitivity analysis mechanism should be used to confirm the criteria weight. The weighting mechanism, fuzzy set, number of scenarios, and criteria differed from case to case, and there is no standard. All studies used αc for sensitivity and correlation. Sensitivity

analysis is essential for understanding how variations in input parameters can influence the outcome of the decision-making process. By systematically altering the weights assigned to various criteria, researchers can identify which factors are most critical to the decision outcome and assess the robustness of their models. This approach helps in recognizing the stability of the proposed decision-making framework under different conditions and ensures that the results are not overly dependent on specific assumptions or parameter settings.

Furthermore, sensitivity analysis can uncover potential interactions between criteria that may not be evident in the initial model. For instance, in the context of CDW management, changes in economic conditions might significantly impact the prioritization of strategies when combined with environmental regulations. Understanding these interactions is crucial for developing more comprehensive and adaptive management strategies. This process also aids in identifying the most influential criteria, which can be the focus of future data collection efforts to improve model accuracy and reliability.

Implementing a robust sensitivity analysis involves creating multiple scenarios where the criteria weights are varied systematically. These scenarios can range from best-case to worst-case conditions, providing a spectrum of possible outcomes. This comprehensive approach ensures that the decision-making model is tested across a wide range of possibilities, enhancing its credibility and applicability in real-world situations. Additionally, sensitivity analysis can help in identifying the threshold values for criteria beyond which the preferred decision changes, thus offering deeper insights into the decision landscape.

3.5.2 Systematic Modelling Procedure

Expanding the systematic modelling procedure could involve integrating state-of-the-art data visualization techniques, such as interactive dashboards or geographic information system mapping, to provide stakeholders with intuitive and accessible insights into CDW management strategies. By transforming complex data into visually engaging representations, these tools can enhance understanding and decision-making capabilities, enabling stakeholders to identify spatial patterns, trends, and hotspots in CDW generation and management across different regions or construction sites.

Furthermore, researchers may explore the integration of decision support systems (DSS) within the systematic modelling framework to facilitate real-time decision-making and adaptive management strategies for CDW. By harnessing the power of DSS, stakeholders can access timely information, scenario analysis, and predictive modelling capabilities to respond effectively to dynamic changes and uncertainties in CDW management practices.

Additionally, DSS can enable collaborative decision-making processes by providing a platform for stakeholders to share data, insights, and feedback, fostering collective action towards sustainable CDW management goals.

Moreover, incorporating a sensitivity analysis component into the systematic modelling procedure could provide valuable insights into the robustness of the decision-making framework under different scenarios and parameter variations. By systematically varying input parameters and observing the corresponding changes in decision outcomes, researchers can assess the stability and reliability of the proposed method across a range of conditions. Additionally, sensitivity analysis can help identify critical factors that significantly

influence decision outcomes, guiding stakeholders in prioritizing resources and efforts towards addressing key challenges in CDW management.

In this study, a systematic rating approach is used to validate the benchmarking method by researchers (AlSereidi et al., 2022). Table 7 shows a common approach used by scholars and total number of alternatives, number of groups, number of alternatives per group, and matrix-based data (raw, normalized, or weighted):

Table 7

Literature of Systematic Ranking Procedure in Different Case Studies

References	Case study	Total number of alternatives	Number of groups	Number of alternatives per group	Matrix based on raw, normalized,
(Qahtan, Yatim, et al., 2023)	Healthcare systems – TMIS	11	3	4,4,3	Raw
	Healthcare systems – RPMSs	16	3	5,5,5	
	Healthcare systems – EHRs	16	3	5,5,6	
	Healthcare systems – EMRs	6	2	3,3	
	Healthcare systems – PHRs	4	2	2,2	

(Qahtan, Yatim, et al., 2023) conducted a systematic ranking method using a matrix with 52 possibilities grouped into five categories, each containing different numbers of alternatives spread across two or three subgroups. The research focused on TMIS systems,

dividing them into three subgroups with varying numbers of systems. The study identified three references dealing with the Covid-19 vaccination dose, employing similar matrix-based approaches, with (Albahri, Zaidan, et al., 2022a) and (Albahri, Albahri, et al., 2022b) having the same number of options and groups (300-6). In contrast, (Alsalem et al., 2021b) used 150 possibilities divided into six categories. Another study by (Krishnan et al., 2021) explored smart e-tourism, presenting a matrix with 65 options across five case studies. The matrix used raw and normalized data. Additionally, (Hamid, Albahri, Albahri, et al., 2021) studied Telemedicine, employing a matrix like Krishnan's, with 500 choices grouped into three categories and 166 alternatives in each group. The final reference, (Salih et al., 2021), focused on network congestion control, featuring six choices equally divided into two groups in the systematic ranking approach.

Additionally, exploring comparative analyses and integrating advanced computational techniques, future research could also focus on the development of decision support tools specifically tailored to aid stakeholders in the construction and demolition waste (CDW) management sector. These tools could encompass user-friendly interfaces that allow stakeholders to input project-specific parameters and preferences, generating customized recommendations for sustainable CDW management strategies. By incorporating interactive features and visualization capabilities, such tools could enhance stakeholders' understanding of the implications and trade-offs associated with different management approaches, facilitating more informed decision-making processes.

Furthermore, there is a need for studies to assess the long-term effectiveness and sustainability of implemented CDW management strategies. Whilst a lot of studies assess the immediate results of specific interventions, longitudinal research can provide worthy thoughts

into the strength and flexibility of these strategies over time. By monitoring key performance indicators, such as waste diversion rates, resource utilization efficiency, and environmental impacts, over extended periods, researchers can identify trends, challenges, and opportunities for refinement or adaptation of CDW management practices.

Furthermore, future research could explore the intersectionality between CDW management and broader sustainability goals, such as circular economy principles and climate change mitigation strategies. By examining how CDW management strategies contribute to larger sustainability agendas and synergize with other initiatives, researchers can identify opportunities for holistic and integrated approaches to sustainable development. This could involve interdisciplinary collaborations between researchers from diverse fields, including environmental science, economics, engineering, and policy studies, to develop comprehensive frameworks and strategies that address interconnected sustainability challenges effectively.

3.5.3 Comparative Study Based on Benchmarking Checklist Procedure

To validate the benchmarking framework, conduct comparative research using benchmarking checklist techniques. Table 8 shows a few studies that used comparative studies for this goal.

Table 8

A Comparative Study of Benchmarking Checklist Procedures in Various Case Studies

References	Case study	Challenges and issues listed	Score points followed	Theory- or application- based	Number of benchmarking points
(Qahtan, Yatim, et al., 2023)	The Implementation of Blockchain Technology in Healthcare Industry 4.0	A Benchmarking Analysis of Blockchain Technology in Healthcare Industry 4.0: Multiple-Evaluation criteria Importance of Criteria Variations in data	N/A	Theory	17
(Ibrahim et al., 2023)	The Implementation of Sustainable Practices in the Palm Oil Industry	A Benchmarking Analysis of the Most Sustainable Practices in the Palm Oil Industry: Multiple evaluation criteria Criteria importance Criteria confliction.	Applied	Theory/ Application	16

(Qahtan, Alsattar, Zaidan, Pamucar, & Deveci, 2022).	Sustainable Transportation	Benchmarking and selecting the Integrated Sustainable Transportation Modelling Approaches for Electronic Passenger Vehicle multiple evaluation criteria, data variation, importance criteria	Applied	Theory/ Application	17
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Note. Procedures Across Different Case Studies.

The table above presents three current case studies for the comparative study. Two studies are based on theory and application (Qahtan, Alsattar, Zaidan, Pamucar, & Deveci, 2022; Ibrahim et al., 2023), while the first is based solely on theory (Qahtan, Yatim et al., 2023). (Ibrahim et al., 2023; Qahtan, Alsattar, Zaidan, Pamucar, & Deveci, 2022) used score points exclusively, as shown in the table. The key concerns shared by all studies include multiple evaluation criteria, data variance, and the significance of criteria. The number of benchmarking points was 17, 16, and 17 for (Qahtan, Yatim, et al., 2023; Ibrahim et al., 2023; Qahtan et al., 2022).

(Qahtan, Yatim, et al., 2023) indicated that many researchers use a benchmarking checklist to assess their decisions. The study by (Ibrahim et al., 2023) and that of (Qahtan, H.A.Alsattar, et al., 2022), both theoretical and applied, addressed similar issues concerning the value of criteria, multiple evaluation criteria, and the usage of score points. Comprehensive, the obstacles associated with linked topics vary from case study to case study, as does the comparative research basis (theory or application) and the number of benchmarking points.

Additionally, exploring the impact of different weighting schemes on decision outcomes could provide further insights into the relative importance of evaluation criteria in sustainable CDW management strategies (Albahri et al., 2022; Alamleh et al., 2022). By systematically varying the weights assigned to each criterion and analysing their effects on decision rankings, researchers can gain a deeper understanding of the trade-offs involved in CDW management decision-making. Moreover, investigating the applicability of emerging decision-making methodologies, such as artificial intelligence algorithms or machine learning techniques, could offer novel approaches for evaluating and optimizing sustainable CDW management strategies (Alsalem et al., 2019; Shahri et al., 2021). These advanced techniques have the potential to analyse complex datasets, identify patterns, and generate optimized solutions, thereby enhancing the efficiency and effectiveness of decision-making processes in the construction industry.

3.6 Research Gap

In the field of Construction and Demolition Waste (CDW) management, existing research lacks a comprehensive assessment of all barrier attributes in strategies. Despite efforts by researchers to address specific attributes, none have simultaneously covered all aspects of reuse distribution barriers. This creates a notable research gap. To address this, three assessment concerns must be tackled. First, multiple barrier attributes of reuse distribution need consideration (Alnoor et al., 2022; Zaidan et al., 2020). Second, prioritizing these attributes based on importance is crucial (Mahmoud et al., 2022; Jumaah et al., 2018). Third, accounting for data variance is necessary when assessing CDW management strategies (Albahri et al., 2022; Alamleh et al., 2022). While various Multiple Attribute Decision-

Making (MADM) methodologies exist for CDW, none specifically focuses on CDW strategies, highlighting a research gap. Despite researchers addressing six attributes related to barrier development, a void remains in applying these to comprehensively assess and compare diverse CDW management strategies. Figure 2.3 outlines three key assessment concerns: considering multiple barrier attributes, prioritizing them based on importance, and accounting for data variance (Alnoor et al., 2022; Zaidan et al., 2020; Mahmoud et al., 2022; Jumaah et al., 2018; Albahri et al., 2022; Alamleh et al., 2022).

Further exploration in this field could focus on creating and applying all-encompassing frameworks that merge these assessment considerations into an approach for evaluating strategies related to managing construction and demolition waste. For example, integrating data analytics methods like machine learning algorithms could improve the analysis of data variations. Offer more precise insights into the effectiveness of different strategies. Additionally investigating ways to engage stakeholders such as using decision making methods could assist in prioritizing barrier characteristics based on viewpoints and gaining stakeholder support for sustainable waste management endeavors.

Furthermore, conducting long term studies to monitor the implementation and results of waste management strategies over time could provide information about their lasting impact and identify areas where enhancements or optimizations are needed. By exploring these directions for research academics can help bridge existing gaps and advance knowledge in waste management. Besides, interdisciplinary research that combines science, engineering and social sciences could lead to a comprehensive understanding of the challenges and opportunities in waste management practices. This holistic approach would facilitate the

development of more adaptable strategies ultimately improving the sustainability and efficiency of construction and demolition waste management operations.

3.7 Chapter Summary

Chapter 3 discussed the sections 3.1.1, 3.2, and 3.5 also provide a theoretical framework for multi-attribute analysis in MADM approaches. Currently, no research has integrated the (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the (q-ROPHFS) for evaluating and benchmarking CDW management strategies. This would bridge the research gap and address identified challenges. According to the literature, different case studies have used the "root article" to build data sets when real data is unavailable; more information is provided in section 3.1.4. Section 3.5 discusses the validation and assessment techniques for MADM approaches, such as the systematic ranking procedure, the sensitivity analysis procedure, and the comparative research based on the benchmarking checklist.

Chapter 4: Research Methodology

4.1 Introduction

This chapter outlines the research methodology used to fulfil the study's objectives, focusing on developing a multi-attribute decision analysis-based benchmarking framework for the optimal selection of CDW strategies management, the primary aim of this study. A comprehensive plan comprising all necessary steps was devised for this purpose.

The methodology is structure around four key phases, with each phase dedicated to achieving one or more of the research objectives. The initial phase, referred to as the 'Investigation Phase,' is responsible for identifying and defining the research problem, including the identification of research and theory gaps, and proposing a solution using Multiple Attribute Decision Making (MADM) methods (Section 4.2). This phase involves a thorough literature review to uncover existing challenges in CDW management and establish a theoretical foundation for the proposed solution. By identifying these gaps, the study ensures that the subsequent phases are grounded in a well-defined research context, addressing both practical and theoretical needs.

The proposed benchmarking framework for CDW strategies management is realize through the second and third phases (Section 4.3). The 'Decision Matrices Identification Phase' (the second phase) involves formulating decision matrices based on identified CDW strategies management and CDW attributes (Section 4.4.1). This phase includes a detailed analysis of various CDW management strategies, categorizing them based on their attributes such as cost, environmental impact, and feasibility. By mapping these attributes to specific strategies, the

study creates a structured decision-making tool that facilitates the evaluation of different CDW management approaches.

In contrast, the 'Formulation and Development Phase' (the third phase) focuses on developing a benchmarking framework for CDW strategies management, integrating the FWZIC method and FDOSM-based multiplicative MULTIMOORA with q-rung orthopair probabilistic hesitant fuzzy sets (q-ROPHFS) (Section 4.4.2). This phase represents the core methodological development of the study, where advanced decision-making techniques are combined to handle the inherent uncertainties and complexities in CDW management. The integration of these methods aims to enhance the robustness and reliability of the benchmarking framework, ensuring that it can accommodate various scenarios and provide accurate evaluations.

The fourth phase, termed the 'Validation and Evaluation Phase,' validates and assesses the proposed framework, as detailed in Section 4.5. This phase involves rigorous testing of the framework through sensitivity analysis, correlation assessment, and comparative analysis with existing methods. By validating the framework, the study demonstrates its practical applicability and effectiveness in real-world settings, providing stakeholders with a reliable tool for CDW management decision-making. The validation process not only confirms the framework's utility but also identifies potential areas for further refinement and improvement.

Section 4.6 provides a summary of this chapter, reiterating the key methodological steps and their contributions to the study's overall objectives. This summary serves as a concise reference for the reader, highlighting the structured approach and systematic progression of the research methodology. By clearly outlining each phase and its corresponding activities, the chapter ensures transparency and coherence in the research

process, facilitating a comprehensive understanding of the study's methodological foundation.

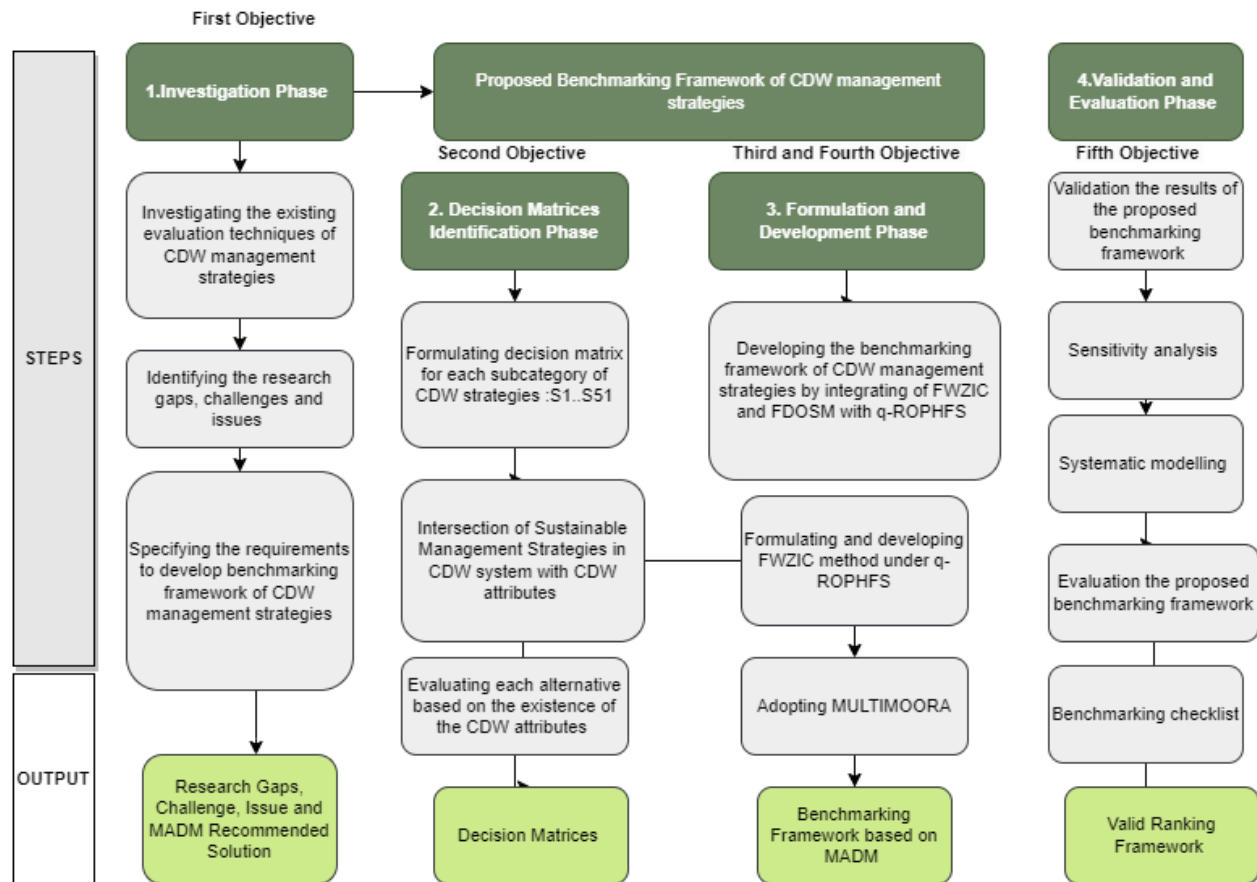
These phases' iterative design enables the framework to be continuously improved,

guaranteeing that it satisfies the high standards necessary for efficient CDW management.

Figure 12 illustrate all the above.

Figure 12

Research Methodology Phases



4.2 Investigation Phase

To accomplish the initial objective, which is to examine the existing evaluation techniques of sustainable management of CDW strategies and to underscore their limitations, it is necessary to undertake an initial study (H.A.Alsattar et al., 2022). This study involves the analysis of the current evaluation methods utilized in the sustainable management of CDW strategies, with the primary aim of identifying their deficiencies. During this phase, the literature pertaining to the development of CDW employing decision methodologies for sustainable management strategies, specifically focusing on attributes like reuse and distribution, is reviewed and organized into categories (Alnoor et al., 2022; Zaidan et al., 2020). Subsequently, a thorough assessment is carried out to identify any gaps in research, challenges, and issues concerning the evaluation and benchmarking of CDW strategies management systems. Alnoor et al. (2022) argue that the absence of comprehensive metrics hampers the effectiveness of evaluation processes, leading to inaccurate assessments of CDW management strategies. Additionally, Zaidan et al. (2020) highlight the need for integrating diverse stakeholder perspectives into the evaluation framework to ensure its inclusivity and relevance to various CDW management contexts. Furthermore, an exploration of (MADM) methods is conducted to pinpoint any gaps in existing theories and propose potential solutions for the assessment and benchmarking of CDW strategy management systems (Albahri et al., 2021; Jumaah et al., 2018; Qahtan et al., 2023). These methods offer a systematic approach to decision-making by considering multiple criteria simultaneously, which is essential for evaluating the complex trade-offs involved in CDW management strategies. However, as noted by Albahri et al. (2021), the applicability of MADM methods in the context of CDW

management requires further investigation, particularly regarding their ability to accommodate diverse stakeholder preferences and uncertainties inherent in CDW management decision-making processes. Moreover, in this stage, we utilize it to outline additional prerequisites for constructing a benchmarking framework for the management of CDW strategies (O.S.Albahri et al., 2021). These requirements encompass activities like creating the dataset and establishing the procedures for assessing and validating (MADM) methods. The information gathered during the preliminary study is integrated into the broader literature review, which is elaborated upon in Chapters 1,2 and 3.

4.3 Decision-maker Analysis and Engagement

Decision-Makers: Identifying and Capturing Their Input

In the context of this thesis on Construction and Demolition Waste (CDW) management, three expert decision-makers were carefully selected to provide specialized input based on their extensive experience and knowledge in the field. These experts were chosen for their:

1. Relevant Industry Experience: Each expert has considerable experience in managing CDW, particularly in the implementation of sustainable practices.
2. Specialized Knowledge: They are knowledgeable about the regulatory frameworks, environmental considerations, and innovative strategies in waste management.
3. Influence in Policy and Practice: The experts hold positions that enable them to impact decision-making processes within the industry.

Capturing Input:

The input from these decision-makers was captured using a structured approach that involved both surveys and a decision matrix (Appendix A: Survey, Appendix B: matrix).

1. *Surveys*: A detailed survey was designed and distributed to the experts, gathering their assessments of various CDW management strategies based on key criteria. The survey included rating scales to capture quantitative data. The full survey is provided in Appendix A.

2. *Decision Matrix*: The data from the surveys were systematically organized into a decision matrix, which allowed for a detailed analysis of the strategies based on the experts' input. The matrix facilitated a comparison of the sustainability of different CDW management approaches. The decision matrix and its detailed analysis are presented in Appendix B, specifically in sections B.2, B.3, and B.4.

Integration into the Thesis:

The insights from these expert decision-makers were critical to shaping the decision-modelling approach developed in this thesis. Their input, as captured in the survey and decision matrix, directly informed the weighting of criteria and the evaluation process. By embedding this expert knowledge into the decision-making framework, the thesis ensures that the proposed strategies are not only theoretically sound but also practically relevant and actionable. This approach underscores the importance of expert input in the development of sustainable CDW management strategies, providing a robust foundation for the thesis' findings and recommendations.

4.4 Benchmarking Framework for Sustainable CDW Management

The suggested benchmarking framework for sustainable CDW management strategies is accomplished through two distinct phases: the Decision Matrices Identification Phase which outlines the constructing decision matrices of CDW management strategies and the

Formulation and Development Phase, as outlined in the subsequent sections. Decision Matrices Identification Phase.

In the study, two fuzzy set-based techniques are employed: the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS) with the FWZIC method and the FDOSM based multiplicative MULTIMOORA method. Thus, the purpose of the q-ROPHFS and FWZIC methods is to be the most important in improving the evaluation of the CDW management strategies because it reflects the uncertainty and multiple criteria. The q-ROPHFS method generalizes fuzzy sets for probabilistic and hesitant information which is advantageous when working with the uncertain data and this is usually found in real world problems. This flexibility corresponds with the FWZIC method used to determine weights of various attributes, which represent the degrees of the importance of the related attributes in the decision-making process. Therefore, the FWZIC method proves most effective where there are many factors that must be considered in a problem. Likewise, the MULTIMOORA method based on the FDOSM of the above-stated various criteria is incorporated into the evaluation model using the multiplicative approach. This method is particularly useful in managing the multiple attributes at one time and is relatively easy to expand to large data set with different criteria and hence can be used to compare CDW strategies against sustainability indicators. In total, the proposed methods provide a set of efficient strategies to make accurate and sensitive decisions for the CDW management.

In this phase, we outline the process of constructing decision matrices for the categories of CDW management strategies, aligning with the second objective of this study: "To formulate the decision matrices based on the intersection of Sustainable Management Strategies in CDW systems with the CDW attributes." In every field of research and industry,

the absence of authentic data poses a hindrance to the advancement and expansion of knowledge. Consequently, decision science researchers have addressed this challenge by creating their own datasets. This has been achieved using synthetic data, as exemplified in studies by Güleç and Kabak (2022) and Radovanović (2021), or by referencing a seminal article, as seen in the works of Al-Samarraay et al. (2022), Alamoodi, Mohammed, et al. (2022), Albahri et al. (2020), and Krishnan et al. (2021). More details can be found in Chapter 3, Section 3.1.2.

Building upon the findings from the Investigation Phase (Chapter 2), we formulate the decision matrices. The assessment of the alternatives is rooted in the article authored by Hussien et al. (2021), which outlines the advancement of CDW strategies utilizing various attributes related to development barriers. It is worth noting that previous studies regarded these barrier attributes as development indicators. In contrast, we have chosen to treat these attributes as evaluation criteria for benchmarking the management of CDW strategies. Hence, Chapter 4 introduces the creation of decision matrices by intersecting the identified alternatives within the CDW categories (Strategy1, Strategy51) and the associated barriers (CDW attributes). Subsequently, Chapter 5 encompasses the presentation of the outcomes derived from these decision matrices.

4.4.1 Formulation and Development Phase

In the study, two fuzzy set-based techniques are employed: the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS) with the FWZIC method and the FDOSM based multiplicative MULTIMOORA method. Thus, the purpose of the q-ROPHFS and FWZIC methods is to be the most important in improving the evaluation of the CDW management

strategies because it reflects the uncertainty and multiple criteria. The q-ROPHFS method generalizes fuzzy sets for probabilistic and hesitant information which is advantageous when working with the uncertain data and this is usually found in real world problems. This flexibility corresponds with the FWZIC method used to determine weights of various attributes, which represent the degrees of the importance of the related attributes in the decision-making process. Therefore, the FWZIC method proves most effective where there are many factors that must be considered in a problem. Likewise, the MULTIMOORA method based on the FDOSM of the above-stated various criteria is incorporated into the evaluation model using the multiplicative approach. This method is particularly useful in managing the multiple attributes at one time and is relatively easy to expand to large data set with different criteria and hence can be used to compare CDW strategies against sustainability indicators. In total, the proposed methods provide a set of efficient strategies to make accurate and sensitive decisions for the CDW management.

This phase is dedicated to accomplishing the third and fourth research objectives, namely, "To formulate and develop an extension of FWZIC method under an integration of (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS). And "To develop decision-modelling approach for Sustainable Management Strategies in CDW using the formulated decision matrices and the integration of (FWZIC) method and (FDOSM)-based multiplicative (MULTIMOORA) with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS)". Drawing from the findings of the Investigation Phase (Chapter 2), we outline our proposed objectives as below:

Initially, Chapter 5 highlights the creation and establishment of the q-ROPHFS–FWZIC method, which assigns priorities and weights to the primary and secondary attributes associated with reusing and distributing CDW management strategies. Subsequently, in the same chapter, the q-ROPHFS–FDOSM, once developed, is employed to assess the CDW management strategies. Following this, in the same chapter, the MULTIMOORA method is employed to model all 51 CDW management strategies to identify the most optimal one. This process is built upon the Decision Matrices Identification Phase, where decision matrices encompassing various CDW strategy management categories are integrated into the proposed framework.

In conclusion, the incorporation of the q-ROPHFS–FWZIC and q-ROPHFS–FDOSM-based MULTIMOORA methods, in relation to the decision matrices, forms the basis of the benchmarking framework for evaluating the barrier attributes of CDW management strategies (refer to Chapter 5). The comprehensive results of the introduced MADM approaches have been detailed in Chapter 6.

4.5 Validation and Evaluation Phase

This phase outlines the methods employed to accomplish the fifth objective in this study, which involves “validating the outcomes of the suggested decision modelling approach for Sustainable Management Strategies in CDW using Sensitivity and Correlation Analysis, Systematic modelling, and comparative analysis”. The subsequent three subsections elaborate on the specific procedures utilized to meet this goal.

4.5.1 *Validation Based on Sensitivity Analysis and Correlation Analysis*

This section focuses on conducting sensitivity and correlation analysis to assess the

reliability of the proposed Multiple Attribute Decision Making (MADM) methods (Alamleh et al., 2022; Qahtan et al., 2022) in the identification of the most and least sustainable strategies for managing CDW. In the sensitivity analysis, adjustments are made to the weight values associated with key barrier attributes related to the distribution and reuse of CDW, following the recommendations of Kirkwood and Kahraman (Klein et al., 1998; Kahraman et al., 2002). This process also involves examining the modelling order of each CDW management strategy. As a result, new sets of weight values (WSs) for the primary barrier attributes related to reuse distribution can be determined using Equation (20) and the q-ROPHFS–FWZIC method from Algorithm 1 Table listed in page (113).

The first step in the sensitivity and correlation analysis is identifying the attribute that has the most significant impact on reuse distribution, as established by the q-ROPHFS–FWZIC method. Following this, the influence of the newly calculated weight sets (WSs) for the key barrier attributes related to reuse distribution is measured using Equation (20). The elasticity weight coefficient and Δx indicate the extent of adjustments made to the attribute weight values. It's important to highlight that, in this analysis, the initial weight values, set when $q=4$, serve as a baseline for validation.

Equations (21) and (22) are employed to calculate the α_c values for each attribute, and Equation (22) is used to determine the range of modifications denoted by Δx . After these calculations, the new WSs for each strategy are computed, and the revised modelling of CDW management strategies is estimated. Subsequently, this new modelling is compared with the initial model.

Equation (20): Weight Adjustment for Reuse Distribution:

$$w_c = (1 - w_s) \times (w_c^0 / W_c^0) = w_c^0 - \alpha_c \times \Delta x,$$

w_s refers to the weight of the most influential attribute.

w_c^0 refers to the initial weight of the main barrier attributes of reuse distribution determined by the q-ROPHFS–FWZIC method.

W_c^0 refers to the summation of attributes' initial weight values.

α_c refers to the elasticity weight coefficient.

Δx refers to the modification range of the attributes' weight value.

Spearman's rho correlation “Equation 23” assesses sensitivity analysis results, quantifying correlation intensity and direction (negative or positive) between initial and new models.

Equation (21): Elasticity Weight Coefficient (α_c)

$$\alpha_c = \frac{\partial w_c}{\partial w_s}$$

Equation (22): Modification Range (Δx)

$$\Delta x = \frac{w_s - w_c \wedge 0}{\alpha_c}$$

Equation (23): Spearman's Rho Correlation

$$R = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)},$$

d represents the model difference at position i

n represents the model number

The comprehensive findings from the sensitivity and correlation analyses are outlined in Chapter 6, specifically in Section 6.3.1.

4.5.2 *Validation Based on Systematic Ranking*

Academics employ systematic modelling as an additional assessment for validating their MADM approaches, ensuring that CDW management strategies are modelled systematically. As outlined in reference (AlSereidi et al., 2022), this involves an objective evaluation to validate the ranking results of CDW management strategies within each subcategory. The subsequent four steps outline the process for validating the benchmarking outcomes of the CDW strategies management system:

Step 1: Aggregating the values of the scoring matrix using an arithmetic mean to produce a final value for each CDW management strategy.

Step 2: Sorting the resulting values and their corresponding CDW management strategies smallest to the largest based on the modelling results at $q = 4$. Q -values at 4 uses to ensure that the CDW management strategies are sorted according to a parameter setting that will correspond to the goals or needs of the analysis. In q -rung orthopair fuzzy sets (q -ROFS), the q -value determines the flexibility in representing uncertainty by defining the relationship between membership and non-membership degrees. Higher q -values allow for a broader range of valid combinations, making it possible to capture more complex and significance scenarios of uncertainty. Starting with $q = 4$ is often advantageous because it offers significantly more flexibility than lower q -values. This flexibility is important in modelling complex decision-making situations where the constraints of lower q -values, such as 1 or 2, may be too limited. By utilizing $q = 4$, a more comprehensive and precise representation of uncertainty and hesitation can be achieved, which is essential for addressing complex problems in the research domain.

Step 3: Splitting the CDW management strategies into five groups. The validation procedure

is unaffected by the number of groups or alternatives within each group. The five subcategories for splitting CDW management strategies will satisfy the criterion of being detailed enough while at the same time being comparable and easy to interpret while at the same time ensuring that the validation process is strict no matter the number of groups or options within the groups. In addition, the validity of the results is established by comparing the mean values of the initial group to those of the subsequent groups. The expectation is that the mean of the first group will be the highest, followed by a progressive decrease in the mean values of the second, third, fourth, and subsequent groups. If the data conforms to these expected patterns, the results are considered valid.

Step 4: Calculating the mean values for each group to ensure that the CDW management strategies with the greatest mean value are the most desired.

Step 5: By comparing the mean values within each subcategory, we establish the basis for validation. The group with the highest mean value is considered the most preferable, as it signifies superior alternatives, while a lower value suggests fewer desirable alternatives.

Hence, the validity of the result is confirmed by comparing the meaning of the initial group to those of the subsequent groups. It is expected that the first group's mean will be the highest, while the second group's mean should exceed those of the third, fourth, fifth, and so on. If the assessments align with these expectations, the results are considered valid. The comprehensive outcomes of the systematic ranking are detailed in Chapter 5, specifically in Section 5.3.2.

4.5.3 Evaluation Based on Benchmarking Checklist Procedure

The proposed benchmarking framework is assessed through a comparative study using a benchmarking checklist procedure. Several benchmarking techniques were considered for the assessment of CDW management strategies but were considered unsuitable for the following reasons. Additionally, it is one of the most frequently applied methods, Classical AHP has some limitations when it comes to addressing the uncertainties that are characteristic for the attributes of CDW. The problem is that AHP's framework does not allow for proper quantification of these attributes' probability, which is essential for the multifaceted assessment of CDW strategies. However, AHP has issues with the handling of hesitant information, the use of which is incorporated in CDW assessments since decision makers may have different levels of confidence or lack some information. Another approach that was looked at was TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) but the application of this method is somewhat disputable due to the fact that it has the capacity to handle uncertainty. TOPSIS is more appropriate to order the alternatives based on the distance from the ideal solution; however, it is less effective than the methods based on fuzzy sets for handling the uncertainty and the fuzzy information. This limitation is of great importance in the case of CDW management because uncertainty and imprecise data are usual and should be managed correctly.

Likewise, VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) is also associated with the identification of the compromise solution by attempting to make the criteria to reach the best solution. The major weakness of VIKOR is that it is not as efficient as other methods whenever it is necessary to rank the attributes with high accuracy, but it is efficient in compromise cases. Concerning the CDW management, where it is required to

prioritize the strategies based on multiple attributes, the application of VIKOR might not meet the need for precise and comprehensive ranking. Hence, the selected methods, namely q-ROPHFS, FWZIC, and MULTIMOORA based on FDOSM, have been considered preferable due to their better performance in terms of uncertainty management and hesitancy information integration.

The benchmark study (Albahri et al., 2021) involved modelling active queue management methods with FDOSM using both TOPSIS and VIKOR. Their results indicated that FDOSM based on VIKOR is the optimal decision-making approach. Therefore, the q-ROPHFS–FWZIC and q-ROPHFS–FDOSM based on MULTIMOORA methods are compared with FDOSM based on VIKOR (Albahri et al., 2021), with a focus on theoretical aspects (weighting and modelling methods). Additionally, the ability of these methods to address MADM challenges in the application/case study is a key consideration in the comparison.

We conduct a comparison based on two dimensions: theoretical and application. This involves assessing our proposed method against the benchmark study in terms of theoretical considerations, specifically weighing and modelling methods. Regarding weighing, q-ROPHFS–FWZIC is evaluated against the benchmark study's weighting methods, both of which utilize FDOSM capable of assigning implicit weights to attributes. Conversely, the application aspect comparison focuses on MADM challenges specific to each case. The following points provide a summary of the comparison. Table 9 presents these comparison points, drawn from various references including (Qahtan et al., 2023; Qahtan et al., 2022), to align with the current investigation. Further, it provides information on how effectively the

weighting and modelling procedures have been performed to handle issues such as incompatibility, interdependency, and informational uncertainty of the attributes.

Table 9

Comparison Points: Definition

Comparison points	
In terms of application	Did the case study consider multiple assessment attributes?
	Had the relative importance of the assessment attributes been taken into consideration?
Weighting method	Was the data variation concern addressed in the case study?
	Was the inconsistency issue handled in the weighing method?
	Was the dependency issue amongst the attributes handled in the weighing method?
	Did the gathering of expert feedback prove to be simple?
	Did the weighting method solve the issues of informational vagueness and uncertainty as well as experts' hesitation?
	Did the combination of the fuzzy set and the weighting method enable DMs to generalise other fuzzy set extensions?
	Did the combination of the fuzzy set and the weighting method provide wide space to the experts to express their preferences?
	Did the weighting method assign explicit weights to the attributes?
In terms of theory	Did the modelling method assign implicit weights to the attributes?

Modelling method	Are the calculations of the modelling method straightforward and comprehensible? Did the modelling method solve the issue of informational ambiguity and uncertainty? Did the combination of the fuzzy set and the modelling method enable DMs to generalise other fuzzy set extensions? Did the combination of the fuzzy set and the modelling method provide wide space to the experts to express their preferences?
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4.6 Chapter Summary

This chapter outlines the research methodology applied to fulfil the study's objectives, which are organized into four distinct phases, each aligning with one or more research goals. First is the 'Investigation' phase, corresponding to the initial objective. This phase identifies the research gap, challenges, and issues in the evaluation and benchmarking of CDW strategy management. Furthermore, it investigates Multiple Attribute Decision Making (MADM) methods to address theory gaps and recommend solutions for evaluating and benchmarking CDW strategy management. The second phase, 'Decision Matrix Identification,' is related to the second objective. It achieves this objective by developing decision matrices for CDW strategy management across various categories. The third and fourth objectives are fulfilled through the 'Formulation and Development' phase. Here, an extension of the FWZIC method known as the q-rung orthopair probabilistic hesitant–FWZIC (q-ROPHFS–FWZIC) method is formulated and developed. Additionally, the integration of the FWZIC method and FDOSM-based multiplicative MULTIMOORA, using q-rung orthopair probabilistic hesitant fuzzy sets

(q-ROPHFS), is developed with respect to the formulated decision matrices, ultimately proposing a benchmarking framework for CDW strategy management. In the final phase, 'Validation and Evaluation,' the fifth objective is accomplished by validating the benchmarking and weighting methods through sensitivity analysis and systematic modelling. To evaluate the proposed method, a comparative study, employing a benchmarking checklist, is conducted to assess the study theoretically and practically in relation to another research. The following chapter will provide a detailed presentation of the proposed benchmarking framework for CDW strategy management.

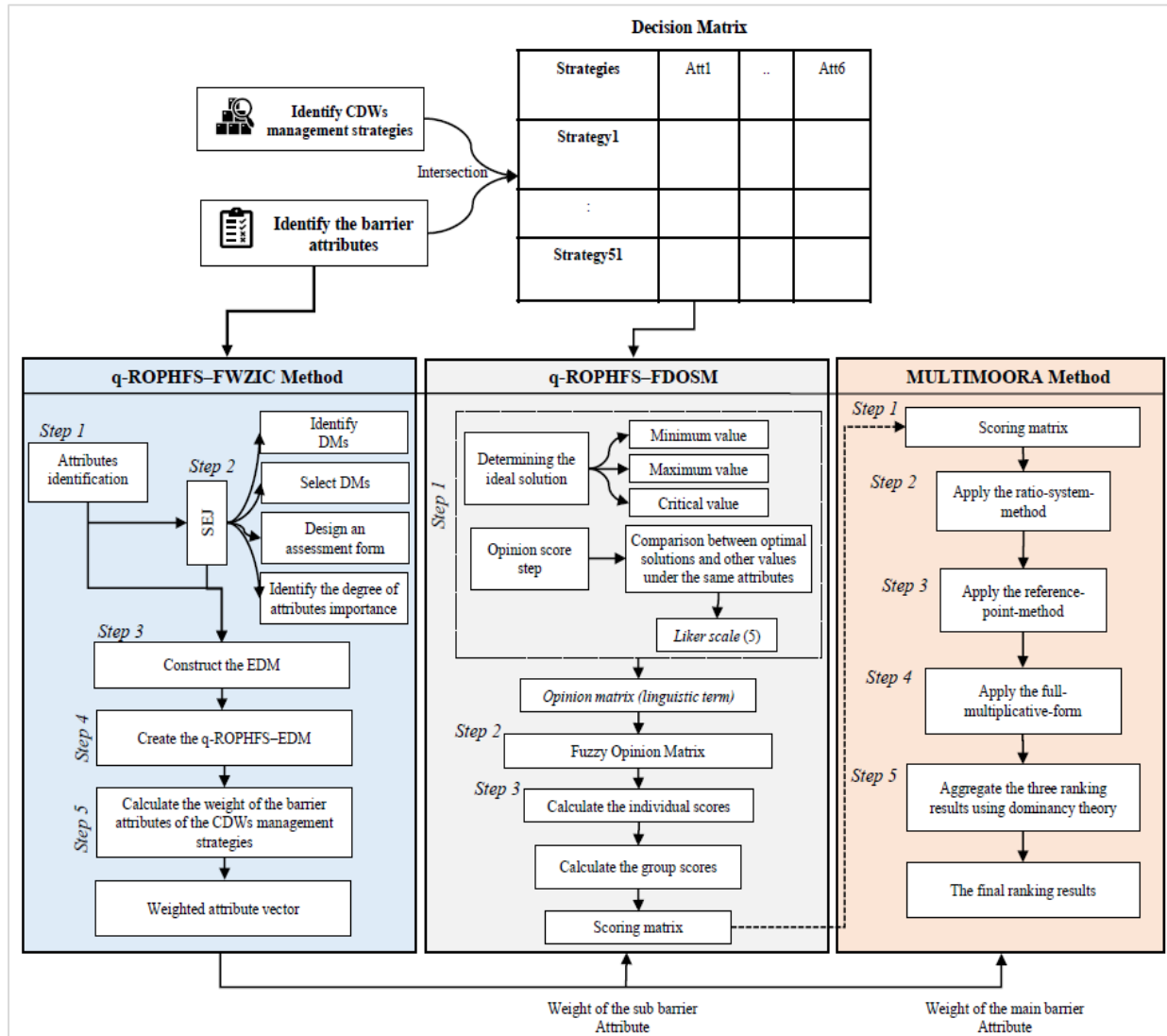
Chapter 5: Benchmarking Framework

5.1 Introduction

In this chapter, we delve into the proposed benchmarking framework for managing CDW strategies. The framework is divided into two main sections: the identification phase of the decision matrix and the formulation and development phase. The first section focuses on creating decision matrices using the identified CDW strategies management system and the evaluation attributes and comprehensive analysis specific to CDW strategies management system (detailed in Section 5.2). These decision matrices are then utilized in the second section, acting as a dataset for the study. The latter section comprises three subsections: the q-ROPHFS-FWZIC method, q-ROPHFS-FDOSM method, and MULTIMOORA method which develop the methodologies and frameworks to benchmark CDW strategies management. In Section 5.3 and 5.4, we investigate into the process of assigning weights to the evaluation attributes of CDW management. This is accomplished by developing and formulating FWZIC with the q-ROPHFS method. Moreover, FWIC and q-ROPHFS method combines fuzzy set theory with the q-ROPHFS technique to assign weights to evaluation attributes. This approach accounts for the inherent suspicion and subjectivity in CDW management decision-making, allowing for a more strong and flexible weighting process. Following that, in Section 5.5, the FDOSM method is created and formulated to benchmark CDW strategies management based on the constructed decision matrices and the attribute weights. Figure 13 provides a visual representation of the CDW strategies management benchmarking framework. Identify CDW's management strategies and barrier attributes by uses decision matrix assesses 51 strategies and six main attributes.

Figure 13

Representation of Benchmarking Framework of CDW Strategies Management



5.2 Decision Matrices Identification Phase

The decision matrix of the CDW management strategies is constructed in this section. According to reference (S.Qahtan et al., 2022), the decision matrix can be constructed based on the root article. Considering this, reference (K.Rakhshan et al., 2020) is regarded as the root

article in this study. The matrix construction is summarised in the following steps:

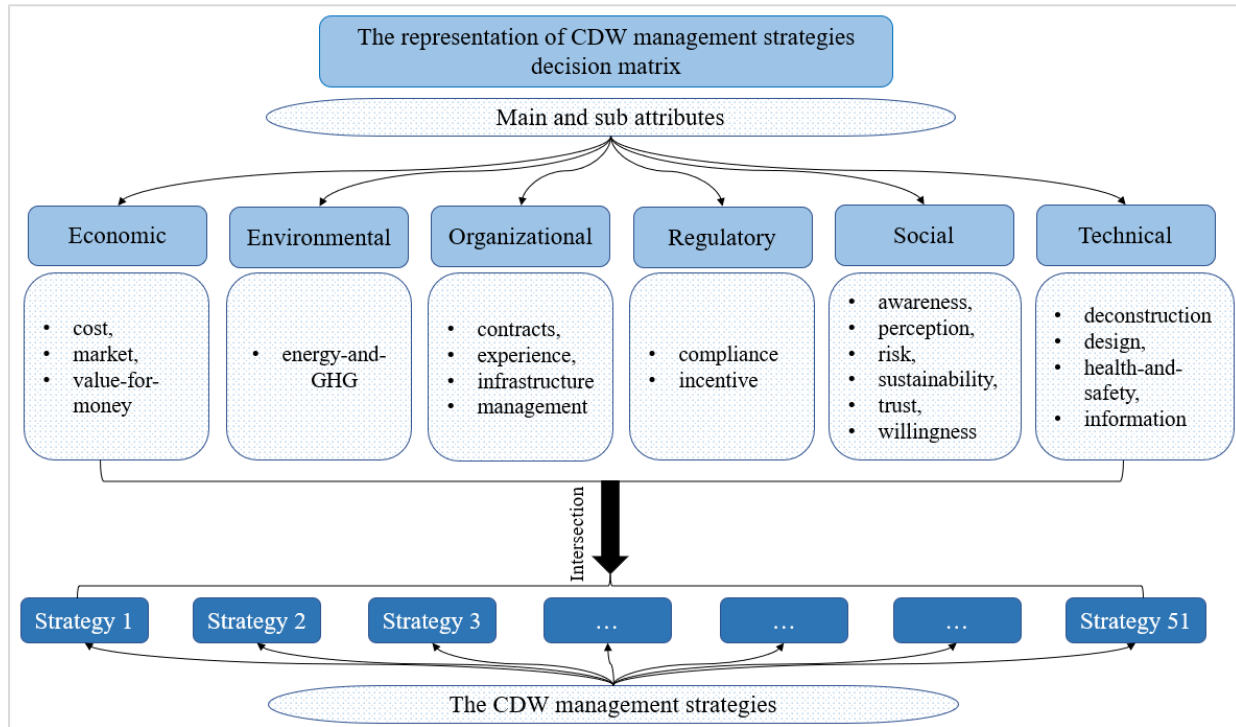
Step 1: The CDW management strategies are examined and identified. The systematic review undertaken by reference (K.Rakhshan et al., 2020) identified 51 CDW management strategies for reuse. In this study, these strategies (alternatives) are modelled in order from the most sustainable to the least sustainable.

Step 2: The barrier attributes of reuse distribution in the CDW management strategies are analysed and identified. According to reference (K.Rakhshan et al., 2020), six main barrier attributes of reuse distribution (i.e. economic, environmental, organisational, regulatory, social, and technical aspects) are selected to evaluate the CDW management strategies for reuse. The economic attribute has three sub-attributes: cost, market, and value-for-money. The environmental attribute has only one sub-attribute: energy-and-GHG (Greenhouse Gases). The organisational attribute has four sub-attributes: contracts, experience, infrastructure, and management. The regulatory attribute has two sub-attributes: compliance and incentive. The social attribute has six sub-attributes: awareness, perception, risk, sustainability, trust, and willingness. The technical attribute has four sub-attributes: deconstruction, design, health and safety and information. The definitions and further details of the main and sub-attributes can be found in reference (Rakhshan et al., 2020).

Step 3: The decision matrix of the CDW management strategies is formulated by intersecting the CDW management strategies (Step 1) with their main and sub-barrier attributes of reuse distribution (Step 2). Figure 14 shows the representation of the CDW management strategy decision matrix.

Figure 14

Representation of the CDW Management Strategy Decision Matrix



The succeeding sections describe the weighting scheme of the barrier attributes of reuse distribution in CDW management strategies via the q-ROPHFS–FWZIC method. Then, the weights are fed into the q-ROPHFS–MULTIMOORA method to benchmark the CDW management strategies, and the most and least sustainable strategies are selected.

5.2.1 Barriers Attributes Identification

In the context of attributes refer to the specific criteria, characteristics, or factors used to evaluate and compare different alternatives (e.g. CDW strategies management). Based on the proposed taxonomy (Figure 2-Chapter 2), CDW strategies, specifically St1 to St51, were designed using six primary aspects, which are economic, environmental, organizational, regulatory, social, and technical. Within these aspects, each has its respective sub-attributes.

For the economic aspect, the three development sub-attributes are cost, market, and value-for-money. The environmental aspect has one sub-attribute, which is energy-and-GHG. Within the organizational aspect, there are four development sub-attributes: contracts, experience, infrastructure, and management. The regulatory aspect comprises two development sub-attributes: compliance and incentive. The social aspect encompasses six development sub-attributes: awareness, perception, risk, sustainability, trust, and willingness. Finally, the technical aspect includes four development sub-attributes: deconstruction, design, health and safety, and information. In this study, the provided development attributes served as criteria for assessing and comparing the management of CDW strategies. The subsequent points outline the description of each attribute:

5.2.1.1 Economic Attributes. The economic attribute refers to a financial or cost-related factor used to evaluate alternatives. Examples include cost, Market, Value of Money. Economic attributes help decision-makers consider financial aspects when ranking alternatives (L.Jaillon et al., 2014).

Cost: is a sub-attribute under the main attribute "economic" refers to the financial expenses associated with a decision, which refers to the disposal costs, material costs and construction costs. It helps assess the financial efficiency of each alternative (N.Dantata et al., 2005).

Market: The second sub-attribute market which is under the economic attribute assesses the project's alignment with market conditions, including demand, competition, and pricing. It helps determine the project's economic viability and competitiveness in the market (A.Mahpour, 2018).

Value for Money: Based on the Economic attribute, the final sub-attribute value of money assesses how well an investment balances costs with benefits, focusing on cost-effectiveness and efficiency (C.F.Dunant et al., 2018). Additionally, this primary sub-attributes, other factors may also contribute to the economic assessment of alternatives. These could include considerations such as long-term financial sustainability, risk management strategies, and potential return on investment. Each of these elements plays a crucial role in shaping the overall economic evaluation and influencing decision-making processes. Long-term financial sustainability involves analyzing the potential financial impacts of alternatives over an extended period. This assessment considers factors such as recurring costs, revenue streams, and the ability of the project to generate sustained economic benefits over time (C.F.Dunant et al., 2018).

Decision-makers must balance the benefits and long-term implications of a course of action to ensure the financial viability of their choices. Risk management strategies play a dynamic role in the cost of economic decisions, minimizing potential financial losses and maximizing opportunities. Evaluating the risks associated with all options allows decision-makers to take appropriate measures to reduce financial uncertainty and counter adverse consequences. By integrating risk management into the economic assessment. Overall, economic attributes encompasses a range of factors and sub-attributes that collectively influence decision-making processes. By considering cost, market dynamics, value for money, and additional factors such as long-term sustainability, risk management can conduct comprehensive economic assessments that inform strategic options and lead to successful results.

5.2.1.2 Environmental Attribute. *Energy and GHG:* As a result, the first sub-attribute in the second attribute Environmental is Energy and GHG, assesses energy use and greenhouse gas emissions associated with a process or project, providing insights into environmental impact and sustainability.

In the area of consideration, energy assessment and GHG emissions are important. This aspect measures energy consumption models and gas emissions on the impact of a process or people associated with a project. By examining these factors, analysts can better understand the impact and sustainability aspects of the enterprise. Understanding the dynamic energy and emissions profile will help create strategies to reduce impact and promote related practices. In addition, energy and GHG efficiency assessment includes the analysis of resource use and carbon production. Describing energy consumption trends, the parties present can identify inefficiencies. Introduction of adaptation measures. Similarly, examining gas emissions has the effect of clarifying the project's role in climate change. Orient efforts towards attenuation. Through assessment and strategic actions, organizations can improve their responsibility and align to sustainable development objectives.

Furthermore, energy and GHG assessment has evolved from simple quantitative analysis to include qualitative considerations. In addition to numerical measures, it includes qualitative aspects, including the use of renewable energy, emission reduction initiatives, and respect for environmental regulation. With qualitative information, analysts can evaluate the project's alignment to the best environmental feasibility and regular compliance criteria. This holistic approach guarantees understanding the nuances of environmental impacts and eases decision-making. Essentially, energy and GHG assessment, based on environmental properties, constitutes a key part of sustainable development efforts. Examining dynamic energy and

emission profiles, the parties present can orient themselves towards respectful behaviour of the environment and minimize negative impacts on the ecosystem. Due to the blend of quantitative analysis and qualitative information, organizations can promote a culture of environmental management and contribute to a more sustainable opportunity.

5.2.1.3 Organizational Attribute. *Contracts*: The first sub-attribute "Contracts" under the third main attribute "Organizational" typically refers to the terms and agreements related to construction and waste management contracts, including specifications, responsibilities, and legal aspects. Contracts sub attributes refer to the waste management agreements between parties involved in constructions process, waste and demolition process must organize and minimize risks.

Experience: The second sub-attribute "Experience" under the third main attribute "Organizational" typically refers to the organization's prior knowledge and expertise in effectively handling CDW, recycling, waste reduction, and sustainable practices. It evaluates the organization's past experiences and performance in managing construction and demolition waste. Moreover, in this field, qualified experts are needed to manage all the Construction and Demolition Waste and recycling by following security and safety procedures and imposing and acknowledging the practice of Construction and Demolition Waste sustainable. To evaluate the experience a consideration to implement sustainable practices of construction and demolition waste is necessary, which involves the successful implementation of recycling programs and minimizing construction waste, adherence to sustainability practices, and environmental regulations. The ability to handle construction and demolition waste CDW to

reduce the environmental impact of construction waste should be a proven organizational strength.

Infrastructure: The third sub-attribute "Infrastructure" under the third main attribute "Organizational" in CDW management attributes refers to the physical facilities and resources necessary for effective construction and demolition waste management operations. This includes facilities like recycling centres, waste processing plants, transportation networks, and equipment. Furthermore, physical facilities and resources needed to maintain the sustainability practices of construction and demolition waste, organization must consider all required facilities to decrease the disadvantages cause from CDW. Advanced technologies may develop recycling centres, waste, and recycling operations secured transportations.

Management: The fourth sub-attribute "Management" under the third main attribute "Organizational" in CDW management refers to the strategies and practices related to the effective control and supervision of waste management activities within an organization. This includes planning, coordination, and oversight of CDW handling, disposal, and recycling efforts (K.Kabirifar et al., 2020). Effective management leads to improved social communication protocols, saving resources, and enhancing improvement mechanisms to improve the performance of the CDW management process. Moreover, it is an idea to move towards justice through personal project groups managed by the organizers, i.e. environmental protection standards that improve nature. By prioritizing effective management techniques, an organization can led to effective operations, leading to their improvement. Newer communications and cultures in communications thrive through CDW management.

5.2.1.4 Social Attribute. *Awareness*: The sub-attribute "Awareness" under the main attribute "Social" in CDW management attributes refers to the level of knowledge and consciousness within the community or stakeholders regarding waste management practices and their associated social implications.

***Perception*:** The sub-attribute "Perception" under the main attribute "Social" in CDW management attributes typically refers to the way people or stakeholders perceive and understand the sustainability and impact of CDW management practices, considering their subjective views, attitudes, and opinions.

***Risk*:** The sub-attribute "Risk" under the main attribute "Social" in CDW management attributes typically refers to the assessment of potential adverse impacts or uncertainties associated with social aspects, such as safety hazards, community concerns, or reputational risks during construction and waste management processes.

***Sustainability*:** The sub-attribute "Sustainability" under the main attribute "Social" in CDW management attributes typically refers to the consideration of long-term environmental, social, and economic impact in construction projects to ensure responsible and eco-friendly practices. It encompasses the effort to minimize resource depletion and promote responsible resource use throughout a building's life cycle.

***Trust*:** In the context of CDW management attributes, the sub-attribute "Trust" under the main attribute "Social" typically refers to the level of confidence, reliability, and credibility that stakeholders have in the process and decisions related to construction and demolition waste management. Trust can involve the belief that the management practices are transparent, ethical, and accountable, which contributes to positive social perceptions and cooperation in waste management efforts.

Willingness: In the context of CDW management attributes, the sub-attribute "Willingness" under the main attribute "Social" refers to the readiness or eagerness of stakeholders, communities, or individuals to actively participate or support sustainable waste management practices and initiatives. It reflects the degree of cooperation and engagement from a social perspective.

Besides, referring to social attributes in construction and demolition management are sensitive to encouraging engagement and collaboration by the community. Considering the different sub-attributes like awareness, perception, risk, sustainability, trust, and willingness, stakeholders will develop and increase a solid and green environment. Enhancing the waste management system and practice will be effective in engaging the community and stakeholders to make a reasonable decision that ensures their concerns and perspectives are considered and maximizes sustainable outcomes. However, activate participation to collect a significant enhancement in construction and demolition waste CDW management and achieve the objective of sustainable improvement.

5.2.1.5 Regulatory Attribute. *Compliance:* In the context of CDW management attributes, the first sub-attribute "Compliance" under the fourth main attribute "Regulatory" refers to the extent to which a construction and demolition waste (CDW) strategy adheres to relevant laws, regulations, and standards. It assesses how well the strategy aligns with legal requirements and compliance obligations.

Incentive: The second sub-attribute "Incentive" under the fourth main attribute "Regulatory" in CDW management attributes refers to the measures or policies that encourage

or motivate compliance with waste management regulations. It typically involves rewards or benefits to promote better adherence to waste disposal guidelines.

In addition, effective routines are essential to foster a culture of employee conformity and encourage sustainable behaviours in CDW management. Solid rules are established not only according to clear criteria for daytime management but also for monitoring and application mechanisms. Accompanied by game motivation programs, these rules can lead to significant improvements in conformity stress and environmental performance. Provocations show that fiscal charges, grants, or reconnaissance programs can motivate organizations to meet routine baseline requirements, as well as support innovation and best practice measures in the way CDW is managed. With routine measures on positive motivations, political decision-makers can create a dynamic environment where compliance and sustainability go hand in hand and more sustainability, which ultimately leads to the practice of managing daylight and more responsibility.

5.2.1.6 Technical Attribute. *Deconstruction*: The first sub-attribute "Deconstruction" under the sixth main attribute "Technical" in CDW management attributes refers to the process of systematically dismantling or taking apart existing structures or buildings as part of a renovation or demolition project. It focuses on the techniques and methods used to disassemble and recover materials from the existing structure efficiently.

***Design*:** The second sub-attribute "Design" under the sixth main attribute "Technical" in CDW management attributes typically refers to the planning and architectural aspects of a project, focusing on how well the design optimizes resource use, waste reduction, and construction efficiency.

Health and Safety: In the context of CDW management attributes, the third sub-attribute "Health and Safety" under the sixth main attribute "Technical" pertains to the measures and practices in place to ensure the well-being and protection of workers and the public during construction and demolition activities, focusing on health and safety considerations.

Information: The fourth sub-attribute "Information" under the sixth main attribute "Technical" pertains to data and knowledge related to the construction and demolition processes, techniques, and materials, which can be used to enhance efficiency and decision-making in waste management.

In general, the various technical aspects work together to create a strategy, for managing construction and demolition waste (CDW). Effective deconstruction methods do not help recover materials. Also contribute insights for material reuse and resource optimization in the design process. Safety protocols ensure that both deconstruction and design activities are conducted safely prioritizing the wellbeing of workers and the public. The continuous exchange of information supports decision making at all stages promotes innovation and identifies practices in waste management techniques. These different components highlight the importance of an integrated approach, to handling construction and demolition waste.

5.3 CDW Strategies Management Identification

Through a comprehensive examination of the literature (Chapter 2, Sections 2.2 and 2.3), fifty-one CDW strategies were discerned. The six key barrier attributes (economic, environmental, organizational, regulatory, social, and technical) are chosen to assess CDW management strategies for reuse. These attributes have specific sub-categories:

- i. **Economics**: cost, market, and value-for-money.
- ii. **Environmental**: energy-and-GHG.
- iii. **Organizational**: contracts, experience, infrastructure, and management.
- iv. **Regulatory**: compliance and incentive.
- v. **Social**: awareness, perception, risk, sustainability, trust, and willingness.
- vi. **Technical**: deconstruction, design, health and safety, and information.

The number of strategies identified within the cost sub-attribute is 31 among all the attributes. The market sub-attribute, the second in the economic category, is associated with 21 CDW management strategies, while the value-for-money sub-attribute is utilized by 7 strategies. In the environmental main attribute, "Energy and GHG" is applied in three strategies.

The organizational attribute contains four sub-attributes. "Contract" is assessed by only one strategy, the second sub-attribute is used in ten strategies, the third sub-attribute is assessed by 12 strategies, and the fourth sub-attribute is evaluated by seven CDW management strategies. Within the regulatory attribute, the first sub-attribute, "Compliance," is assessed by 21 strategies, while the second sub-attribute, "Incentive," is used in 7 strategies.

The social attribute comprises six different sub-attributes. "Awareness" is evaluated by six CDW management strategies, "Perception" by 14 strategies, "Risk" by 12 strategies, "Sustainability" by two strategies, "Trust" by two strategies, and "Willingness" by nine strategies. The technical attribute has four sub-attributes. "Deconstruction" is valued by 19 strategies, "Design" is evaluated by 18 CDW management strategies, the third sub-attribute is

set by 11 strategies, and the "Information" sub-attribute is determined by six CDW management strategies. It's important to highlight that the proposed method remains unaffected by the increase in the number of identified systems, as they are primarily employed as proof of concept in this study. Furthermore, the benchmarking framework can be applied to other scenarios involving different management strategies for CDW.

5.4 Decision Matrices Formulation Phase

Within the proposed framework, the central element is the decision matrices. There are five decision matrices developed to assess the management of CDW strategies. The first and second decision matrices are created by combining six CDW Attributes (namely economic, environmental, organizational, regulatory, social, and technical) with the sub-attributes categorized under main attributes. The presentation of these decision matrices can be found in Table 10.

Table 10 presents the combination of primary and secondary attributes across 51 strategies to create the decision matrices, as shows in Table 9. Six primary attributes intersect with each secondary attribute. For instance, secondary attribute 1 (cost) aligns with primary attribute 1 (economic) and intersects with strategy 1 (A1SA1/S1.. etc).

Table 10*Decision Matrices of Main/Sub-Attributes*

Strategies/Attri butes	A1			A2			A3		
	SA1	SA2	SA3	SA1	SA1	SA2	SA3	SA4	
S1	A1SA1/	A1SA2/	A1SA3/	A2SA1/	A3SA1/	A3SA2/	A3SA3/	A3SA4/	
	S1	S1	S1	S1	S1	S1	S1	S1	
S2	A1SA1/	A1SA2/	A1SA3/	A2SA1/	A3SA1/	A3SA2/	A3SA3/	A3SA4/	
	S2	S2	S2	S2	S2	S2	S2	S2	
S3	A1SA1/	A1SA2/	A1SA3/	A2SA1/	A3SA1/	A3SA2/	A3SA3/	A3SA4/	
	S3	S3	S3	S3	S3	S3	S3	S3	
S4	A1SA1/	A1SA2/	A1SA3/	A2SA1/	A3SA1/	A3SA2/	A3SA3/	A3SA4/	
	S4	S4	S4	S4	S4	S4	S4	S4	
....					...			...	
S51	A1SA1/	A1SA2/	A1SA3/	A2SA1/	A3SA1/	A3SA2/	A3SA3/	A3SA4/	
	S51	S51	S51	S51	S51	S51	S51	S51	

Strategie s/Attribut es	A4				A5				A6			
	SA1	SA2	SA1	SA2	SA3	SA4	SA5	SA6	SA1	SA2	SA3	SA4
S1	A4S A1/S 1	A4S A2/S 1	A5S A1/S 1	A5S A2/S 1	A5S A3/S 1	A5S A4/S 1	A5S A5/S 1	A5S A6/S 1	A6S A1/S 1	A6S A2/S 1	A6S A3/S 1	A6S A4/S 1
S2	A4S A1/S 2	A4S A2/S 2	A5S A1/S 2	A5S A2/S 2	A5S A3/S 2	A5S A4/S 2	A5S A5/S 2	A5S A6/S 2	A6S A1/S 2	A6S A2/S 2	A6S A3/S 2	A6S A4/S 2
S3	A4S A1/S 3	A4S A2/S 3	A5S A1/S 3	A5S A2/S 3	A5S A3/S 3	A5S A4/S 3	A5S A5/S 3	A5S A6/S 3	A6S A1/S 3	A6S A2/S 3	A6S A3/S 3	A6S A4/S 3
S4	A4S A1/S 4	A4S A2/S 4	A5S A1/S 4	A5S A2/S 4	A5S A3/S 4	A5S A4/S 4	A5S A5/S 4	A5S A6/S 4	A6S A1/S 4	A6S A2/S 4	A6S A3/S 4	A6S A4/S 4

....	...						...					
S51	A4S	A4S	A5S	A5S	A5S	A5S	A5S	A5S	A6S	A6S	A6S	A6S
	A1/S	A2/S	A1/S	A2/S	A3/S	A4/S	A5/S	A6/S	A1/S	A2/S	A3/S	A4/S
	51	51	51	51	51	51	51	51	51	51	51	51

A1 =	A2 =	A3 =	A4=	A5 =	A6 =
Economic	Environmental	Organizational	Regulatory	Social	Technical

SA1	SA2	SA3	SA1	SA1	SA2	SA3	SA4	SA1	SA2
Cost	Market	Value-For-Money	Energy-and-GHG	Contract	Experience	Infrastructure	Management	Compliance	Incentive
SA1	SA2	SA3	SA4	SA5	SA6	SA1	SA2	SA3	SA4
Awareness	Perception	Risk	Sustainability	Trust	Willingness	Deconstruction	Design	Health-and-safety	Information

Note. The Table Displays Decision Matrices for Main and Sub-Attributes.

The third, fourth, and fifth decision matrices are created through the integration of CDW strategies management and are assessed using an objective approach. The assessment involves the use of "yes" and "no" to indicate the presence or absence of specific attributes. The findings from this section will be presented and discussed in Chapter 6. Once the decision matrices are established, three key challenges, namely, dealing with multiple evaluation attributes, assessing attribute importance, and addressing data variations, are explored as outlined in Chapter 1. To address these challenges, a decision-making solution needs to be developed. The proposed solution involves determining the significance of each attribute and establishing benchmarks for the CDW strategies management system, as will be detailed in the upcoming section.

5.5 Formulation and Development Phase

In this phase, the primary focus is on achieving the third and fourth research objectives. These objectives involve formulating and extending the FWZIC method through the integration of the FWZIC method and the FDOSM-based multiplicative MULTIMOORA method with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS). Additionally, the aim is to develop a decision-modelling approach for Sustainable Management Strategies in CDW using the derived decision matrices and the integration of the FWZIC method and the FDOSM-based multiplicative MULTIMOORA method with the q-rung orthopair probabilistic hesitant fuzzy set (q-ROPHFS). This information can be found in Chapter 3, Section 3.5.3. To provide context, a benchmarking framework is established based on the thorough analysis of the strengths and weaknesses of MADM methods, as detailed in Chapter Three, Section 3.1. The comprehensive outcomes of this phase are discussed and documented in Chapter 4. The subsequent sub-sections present the specific steps taken during the implementation of this phase.

5.5.1 Formulation of the Q-ROPHFS–FWZIC Method

Information uncertainty may hinder the precise weighting of the attributes. Real-world MADM applications must account for informational vagueness and uncertainty. FWZIC is an outstanding method for estimating the weight of attributes with no inconsistency. In addition, the vagueness and uncertainty issues and the hesitation of experts can be adequately addressed by extending FWZIC to the q-ROPHFS environment. The following steps are required to weigh the barrier attributes of reuse distribution in CDW management strategies by using the proposed q-ROPHFS–FWZIC method:

Step 1: The preidentified barrier attributes of reuse distribution in CDW management strategies are explored.

Step 2: At least three DMs with prior experience in CDW management are identified and selected to construct a structured expert judgment (SEJ).

In addition, an assessment form is designed and endorsed by the DMs. The assessment form used in this study is provided in Appendix A. The preferences on the attributes of the DMs are represented by five linguistic scales, as presented in Table 10, and gathered using the designed form.

Table 11

Linguistic and Numerical Scales and Their Corresponding q-ROPHFNs

Linguistic expressions			q-ROPHFNs							
For q-ROPHFS–FWZIC	For q-ROPHFS–FDOSM	Numeric scale	M1	P1	M2	P2	V1	P1	V2	P2
Very important (VI)	No difference (ND)	1	0.9	0.4	0.95	0.6	0.15	0.2	0.1	0.8
Important (I)	Slight difference (SD)	2	0.7	0.5	0.75	0.5	0.35	0.3	0.3	0.7
Average (Av)	Difference (D)	3	0.5	0.3	0.55	0.7	0.55	0.5	0.5	0.5
Low important (LI)	Big difference (BD)	4	0.4	0.8	0.5	0.2	0.55	0.4	0.6	0.6
Very low important (VLI)	Huge difference (HD)	5	0.2	0.7	0.25	0.3	0.8	0.35	0.9	0.65

Step 3: The barrier attributes of reuse distribution in CDW management strategies are crossed with the three pre-selected DMs to construct the expert decision matrix (EDM). This intersection is represented by using “Equation 1”. The linguistic terms gathered by using the assessment form in the preceding step are replaced with a numerical scale for further analysis.

$$EDM = \begin{matrix} & A_1 & \dots & A_n \\ \begin{matrix} DM_1 \\ \vdots \\ DM_{f3} \end{matrix} & \begin{bmatrix} A_{11}/DM_{11} & \dots & A_{1n}/DM_{1n} \\ \vdots & \ddots & \vdots \\ A_{f1}/DM_{f1} & \dots & A_{fn}/DM_{fn} \end{bmatrix} \end{matrix}. \quad (1)$$

Step 4: The q-ROPHFS–EDM is created by applying the q-ROPHFS on the EDM. In this step, the crisp numbers (numerical scale) are swapped with q-ROPHF numbers (q-ROPHFNs), as shown in Table 2. According to reference (Attaullah et al., 2022), q-ROPHFS and q-ROPHFNs can be defined as follows:

Definition (1) (Attaullah et al., 2022). In a universal set denoted by Ω , a q-ROPHFS $\mathfrak{F}$ can be described as follows:

$$\mathfrak{F} = \left\{ \left\langle x, \frac{\beta_{\mathfrak{F}}(x)}{\delta_x}, \frac{\psi_{\mathfrak{F}}(x)}{\partial_x} \right\rangle \mid x \in \Omega \right\},$$

where $\beta_{\mathfrak{F}}(x)/\delta_x$ and $\psi_{\mathfrak{F}}(x)/\partial_x$ are sets of values in $[0,1]$, which represent the positive and negative degrees, respectively. In addition, δ_x and ∂_x refer to the possibilities of the positive and negative degrees with the following property: $0 \leq \delta_{\mathfrak{F}_t}$ and $\partial_{\mathfrak{F}_t} \leq 1$ with $\bigoplus_{i=1}^p \delta_{\mathfrak{F}_t} \leq 1$ and $\bigoplus_{i=1}^p \partial_{\mathfrak{F}_t} \leq 1$, where p is the total elements in the q-ROPHFS, and it must satisfy the following properties: $\forall x \in \Omega$, $\forall \omega_{\mathfrak{F}}(x) \in \beta_{\mathfrak{F}}(x)$, and $\forall v_{\mathfrak{F}}(x) \in \psi_{\mathfrak{F}}(x)$ with

$$\left(\max(\beta_{\mathfrak{N}_3}(x))\right)^q + \left(\min(\psi_{\mathfrak{N}_3}(x))\right)^q \leq 1^3 \text{ and } \left(\min(\beta_{\mathfrak{N}_3}(x))\right)^q + \left(\max(\psi_{\mathfrak{N}_3}(x))\right)^q \leq 1.$$

Meanwhile, q-ROPHFN is represented by the pair $\mathfrak{F} = (\beta_{\mathfrak{N}_3}/\partial_x, \psi_{\mathfrak{N}_3}/\partial_x)$ for ease of presentation.

Step 5: The weight of the barrier attributes of reuse distribution in CDW management strategies is calculated by referring to the q-ROPHFS–EDM constructed in the preceding step. Initially, the q-ROPHF arithmetic mean (q-ROPHFAM) operator “Equation 2”) is used to aggregate the q-ROPHFNs for each attribute across the q-ROPHFS–EDM of the three DMs.

$$\text{q-ROPHFAM } (\mathfrak{N}_1, \mathfrak{N}_2, \dots, \mathfrak{N}_r) = \left(\begin{array}{c} \bigcup_{\mathfrak{h}_{\mathfrak{N}_j} \in \beta_{\mathfrak{N}_j}, \mathfrak{d}_{\mathfrak{N}_j} \in \partial_{\mathfrak{N}_j}} \sqrt[q]{1 - \prod_{j=1}^r \left(1 - (\mathfrak{h}_{\mathfrak{N}_j})^q\right)^{1lr}} / \prod_{j=1}^r \mathfrak{d}_{\mathfrak{N}_j} \\ \bigcup_{\mathfrak{q}_{\mathfrak{N}_j} \in \psi_{\mathfrak{N}_j}, \partial_{\mathfrak{N}_j} \in \partial_{\mathfrak{N}_j}} \prod_{j=1}^r (\mathfrak{q}_{\mathfrak{N}_j})^{1lr} / \prod_{j=1}^r \partial_{\mathfrak{N}_j} \end{array} \right) \quad (2)$$

Then, the calculated weights are fuzzy values that must be DE fuzzified by using the q-ROPHFS score function and converted to crisp weights according to “Equation 3”.

$$s(\mathfrak{N}) = \left(\frac{1}{M_{\mathfrak{N}}} \sum_{\mathfrak{h}_{\mathfrak{N}_j} \in \beta_{\mathfrak{N}_j}, \mathfrak{d}_{\mathfrak{N}_j} \in \partial_{\mathfrak{N}_j}} (\mathfrak{h}_i \cdot \mathfrak{d}_i) \right)^q - \left(\frac{1}{N_{\mathfrak{N}}} \sum_{\mathfrak{q}_{\mathfrak{N}_j} \in \psi_{\mathfrak{N}_j}, \partial_{\mathfrak{N}_j} \in \partial_{\mathfrak{N}_j}} (\mathfrak{q}_i \cdot \partial_i) \right)^q. \quad (3)$$

Finally, the total weights of the attributes must be equal to one. If this condition is not met, then “Equation 4” is applied to rescale the weights.

$$w_j = s(\mathfrak{N}) / \sum_{j=1}^J s(\mathfrak{N}), \quad (4)$$

where $s(\mathfrak{N})$ represents the weight for each attribute.

The pseudocode of the q-ROPHFS–FWZIC method is provided in Algorithm 1.

Algorithm 1: q-ROPHFS–FWZIC method

1: Step 1: Define the barrier attribute reuse distribution in the CDW management

strategies

- 2: Identify $C[i]$
 - 3: **Step 2: SEJ**
 - 4: Define $E[i]$
 - 5: Define AF, NS
 - 6: $m \leftarrow \text{length}(E)$
 - 7: **For** $i = 1:m$ **do**
 - 8: **if** $E(i)$ is true **then**
 - 9: $E(i) \leftarrow AF(i)$
 - 10: **end if**
 - 11: **End for**
 - 12: **Step 3: Construct EDM**
 - 13: Initialise $EDM[i, j] \leftarrow E \cup C$
 - 14: $J \leftarrow \text{length}(C)$
 - 15: $m \leftarrow \text{length}(E)$
 - 16: **For** $j = 1:J$ **do**
 - 17: **For** $i = 1:m$ **do**
 - 18: $EDM[i, j] \leftarrow NS(E_{ij}/C_{ij})$
 - 19: **End for**
 - 20: **End for**
 - 21: **Step 4: Apply q-ROPHFS**
 - 22: **For** $j = 1:J$ **do**
-

```

23:   For  $i = 1:m$  do
24:       |    $EDM[i, j] \leftarrow EDM[i, j]$ 
25:   End for
26: End for

27: Step 5: Compute the final weight of the main and sub-attributes

28: Step 5.1: Aggregate the fuzzy values of the main and sub-attributes

29: For  $j = 1:J$  do
30:     |    $\tilde{C}_j \leftarrow \sum_{i=1}^m NS(\tilde{E}_{ij} / \tilde{C}_{ij})$ 
31: End for

32: Step 5.2: Find the score values

33: For  $j = 1:J$  do
34:     |    $s(\mathfrak{X}) \leftarrow \left( \frac{1}{M_{\mathfrak{X}}} \sum_{\mathfrak{h}_{\mathfrak{X}_j} \in \beta_{\mathfrak{X}_j}, \delta_{\mathfrak{X}_j} \in \delta_{\mathfrak{X}_j}} (\mathfrak{h}_i \cdot \delta_i) \right)^q - \left( \frac{1}{N_{\mathfrak{X}}} \sum_{\mathfrak{q}_{\mathfrak{X}_j} \in \psi_{\mathfrak{X}_j}, \partial_{\mathfrak{X}_j} \in \partial_{\mathfrak{X}_j}} (\mathfrak{q}_i \cdot \partial_i) \right)^q$ 
35: End for

36: Step 5.3: Rescale the final weights

37: For  $j = 1:J$  do
38:     |    $w_j = s_j / \sum_{j=1}^J s_j$ 
39: End for

```

5.5.2 Q-ROPHFS–FDOSM Method Development

In this section, the decision matrix of the CDW management strategies (Section 5.2) and the weight of the barrier attributes of reuse distribution (Section 5.2.1) are fed to the

proposed q-ROPHFS–FDOSM to score the CDW management strategies, as shown in the following steps (M.M.Salih et al., 2020):

Step 1: In the first step of FDOSM, the decision matrix of the CDW management strategies (Section 5.2) is converted into the CDW management strategy opinion matrix according to reference (M.M.Salih et al., 2020). **First**, the optimal solution of each attribute in the decision matrix of the CDW management strategies is selected. The selection of optimal solutions was based on the preferences of specialists (i.e. the DMs). At least three DMs in the management of CDWs should be hired for this purpose. The optimal solution is expressed in “Equation 5”.

$$A^* = \left\{ \left[\left(\max_i v_{ij} \mid j \in J \right), \left(\min_i v_{ij} \mid j \in J \right), (Op_{ij} \in I.J) \mid i = 1.2.3. \dots m \right] \right\},$$

(5)

where max is the benefit attribute, min is the non-benefit attribute, and Op_{ij} is a critical value that lies between the max and the min values. Op_{ij} is derived based on expert judgment. No critical value is identified for CDW management strategy modelling.

Second, the optimal solution of each attribute is compared with the values of all alternatives in terms of differences. Five linguistic scales are used in the comparison (Table 2).

“Equation 6” expresses the comparisons conducted in this step.

$$Op_{Lang} = \left\{ \left((v_{ij} \geq A_j^* \mid j \in J). \mid i = 1.2.3. \dots m \right) \right\},$$

(6)

where $\geq$ represents the conducted comparison. This step yields three opinion matrices for each DM, as represented in “Equation 7”.

$$Op_Lang = \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} op_{11} & \cdots & op_{1n} \\ \vdots & \ddots & \vdots \\ op_{m1} & \cdots & op_{mn} \end{bmatrix}.$$

(7)

Step 2: The opinion matrices are converted into fuzzy opinion matrices. The linguistic expressions within the opinion matrices are swapped with q-ROPHFNs, as shown in Table 2.

Step 3: The individual and group scores are calculated. **First**, the q-ROPHFNs of each alternative within the fuzzy opinion matrix of the three experts are aggregated using the q-ROPHF Einstein arithmetic mean (q-ROPHFEAM) operator, as expressed in “Equation 8”.

$$q\text{-RPHFEAM} (\aleph_1, \aleph_2, \dots, \aleph_r) = \left(\begin{array}{l} \bigcup_{h_{\aleph_j} \in \beta_{\aleph_j}, \delta_{\aleph_j} \in \delta_{\aleph_j}} \left[\frac{\sqrt[q]{\prod_{j=1}^r \left(1 + (h_{\aleph_j})^q\right)^{w_i} - \prod_{j=1}^r \left(1 - (h_{\aleph_j})^q\right)^{w_i}}}{\sqrt[q]{\prod_{j=1}^r \left(1 + (h_{\aleph_j})^q\right)^{w_i} + \prod_{j=1}^r \left(1 - (h_{\aleph_j})^q\right)^{w_i}}} \right] / \prod_{j=1}^r \tilde{p}_{\aleph_j}, \\ \bigcup_{\varrho_{\aleph_j} \in \psi_{\aleph_j}, \partial_{\aleph_j} \in \partial_{\aleph_j}} \left[\frac{\sqrt[q]{2 \prod_{j=1}^r \left((\varrho_{\aleph_j})^q\right)^{w_i}}}{\sqrt[q]{\prod_{j=1}^r \left(2 - (\varrho_{\aleph_j})^q\right)^{w_i} + \prod_{j=1}^r \left((\varrho_{\aleph_j})^q\right)^{w_i}}} \right] / \prod_{j=1}^r b_{\aleph_j}. \end{array} \right). \quad (8)$$

Then, the aggregated fuzzy values are DE fuzzified by using the q-ROPHFS score function and converted to crisp values according to “Equation 3”. The crisp values represent the score of each alternative per expert. **Finally**, group scoring is performed to unify the scoring results of the three recruited experts. Thus, the scores of the CDW management strategies of the three experts are aggregated using the arithmetic mean presented in “Equation 9”.

$$Group\ scoring = \oplus R^*, \quad (9)$$

where $\oplus$ represents the arithmetic mean, and R^* denotes the final score for each

expert.

The pseudocode of the q-ROPHFS–FDOSM is illustrated in Algorithm 2.

Algorithm 2: Scoring CDW management strategies using q-ROPHFS–FDOSM

1: Step 1: Formulate the CDW management strategy decision matrix

2: identify $C[i]$

3: identify $As[j]$

4: $DM[i, j] \leftarrow \textit{intersect}(C, Ps)$

5: Step 2: Formulate the q-ROPHFS–FDOSM

6: $DM[i, j] \leftarrow \text{Dataset} //$ (evaluation procedure)

7: Initialise $OM[i, j]$

8: Step 3: Optimal solution selection, comparison and transformation

9: $J \leftarrow \text{length}(C)$

10: $m \leftarrow \text{length}(As)$

11: For $j = 1:J$ **do**

12: **For** $i = 1:m$ **do**

13: $A^*[j] \leftarrow \max\{C[i, j]\} \mid \min\{C[i, j]\}$

14: $OM[i, j] \leftarrow A^*[j] \otimes C[i, j]$

15: $\widetilde{OM}[i, j] \leftarrow OM[i, j]$

16: **End for**

17: End for

18: Step 4: Calculate the individual and group scores

19: $J \leftarrow \text{length}(C)$

```

20:  $m \leftarrow \text{length} (As)$ 

21:  $n \leftarrow \text{Number of DMs}$ 

22: For  $j = 1:J$  do

23:   For  $x = 1:n$  do

24:     For  $i = 1:m$  do

25:        $\widetilde{IND}^x_j [\beta_i, \delta_i, \psi_i, \partial_i] \leftarrow q\text{-RPHFEAM}$ 

26:     End for

27:      $S^x[j] \leftarrow \left( \frac{1}{M_N} \sum_{h_{Nj} \in \beta_{Nj}, \delta_{Nj} \in \partial_{Nj}} (h_i \cdot \delta_i) \right)^q - \left( \frac{1}{N_N} \sum_{q_{Nj} \in \psi_{Nj}, \partial_{Nj} \in \partial_{Nj}} (q_i \cdot \partial_i) \right)^q$ 

28:   End for

29:    $GS[j] \leftarrow \oplus S^x[j]$ 

30: End for

```

5.5.3 MULTIMOORA Method Adaptation

In this section, the resulting scores of each CDW management strategy (Section 3.3) are fed to MULTIMOORA to model the CDW management strategies and determine the most and the least sustainable strategies, as shown in the following steps (A.Hafezalkotob et al., 2019):

Step 1: The scoring matrix resulting from q-ROPHFS–FDOSM represents the input data for MULTIMOORA. This matrix is used in the following steps to find the final model of each alternative.

Step 2: The ratio-system method is applied on the scoring matrix to calculate the modelling value (Y_i) of the CDW management strategies with respect to all the predefined attributes by using “Equation 10”.

$$Y_i = \sum_{j=1}^g w_j x_{ij}^* - \sum_{j=g+1}^n w_j x_{ij}^*, \quad (10)$$

where g and $n - g$ are the number of benefit and non-benefit attributes, respectively.

The higher Y_i is, the superior the associated alternative. Hence, the model of alternatives can be determined by ordering their respective values from highest to lowest, as shown in “Equation 11”.

$$R_{RSM} = \{A_{i|maxy_i} > \dots > A_{i|miny_i}\}. \quad (11)$$

Step 3: The reference-point method is applied to the scoring matrix to calculate the modelling value (Z_i) of the CDW management strategies with respect to all the predefined attributes. Initially, the maximal objective reference point (MORP) vector is defined as follows:

$$R_j = \{max_i x_{ij}^*, j \leq g; min_i x_{ij}^*, j > g\}. \quad (12)$$

Then, the distance between the weighted value of each MORP vector member and the weighted alternative rating is determined by “Equation 13”.

$$d_{ij} = |w_j r_j - w_j x_{ij}^*|. \quad (13)$$

The utility of the reference-point method is gained by maximising the distance given in “Equation 14” as follows:

$$Z_i = \max_j d_{ij}. \quad (14)$$

The lower Z_i is, the superior the associated alternative. Therefore, the model of alternatives can be determined by ordering their respective values from lowest to highest, as shown in “Equation 15”.

$$\mathbf{R}_{RPM} = \{A_{i| \min_i Z_i} > \dots > A_{i| \max_i Z_i}\}. \quad (15)$$

Step 4: The full multiplicative form is applied to the scoring matrix to calculate the modelling value (U_i) of the CDW management strategies with respect to all the predefined attributes by using “Equation 16”.

$$U_i = \prod_{j=1}^g (x_{ij}^*)^{w_j} / \prod_{j=g+1}^n (x_{ij}^*)^{w_j}. \quad (16)$$

The higher U_i is, the superior the associated alternative. Thus, the model of alternatives can be determined by ordering their respective values from highest to lowest, as shown in “Equation 17”.

$$\mathbf{R}_{FMF} = \{A_{i| \max_i U_i} > \dots > A_{i| \min_i U_i}\}. \quad (17)$$

Step 5: The final modelling of the CDW management strategies is determined using dominance theory, which aggregates the three modelling results to determine the final modelling result, as presented in “Equation 18”.

$$\begin{aligned} \mathbf{R}^i &= \{\mathbf{R}_{RSM}^i, \mathbf{R}_{RPM}^i, \mathbf{R}_{FMF}^i\}, \\ \text{dom}^{i,j} &= \begin{cases} 1 & \mathbf{R}^i \leq \mathbf{R}^j \\ 0 & \text{otherwise} \end{cases}, \\ S_i &= \sum_{j=1}^n \text{dom}^{i,j}. \end{aligned} \quad (18)$$

The higher S_i is, the superior the associated alternative. Hence, the model of alternatives can be determined by ordering their respective values from highest to lowest, as shown in “Equation 19”.

$$R_{dom} = \{A_{i|max S_i} > \dots > A_{i|min S_i}^i\}. \quad (19)$$

The pseudocode of the MULTIMOORA method is presented in Algorithm 3.

Algorithm 3: Modelling CDW management strategies using MULTIMOORA

- 1. Step 1: Scoring matrix resulting from q-ROPHFS–FDOSM**
 2. Identify EA[i]
 3. Identify BN[i]
 4. $J \leftarrow \text{length}(D)$
 5. $m \leftarrow \text{length}(BN)$
 - 6. Step 2: Compute the subordinate utilities: RS, RPA and FMF**
 7. **For** $j = 1:J$ **do**
 8. **For** $i = 1:m$ **do**
 9. $Y_i = \sum_{j=1}^g w_j x_{ij}^* - \sum_{j=g+1}^n w_j x_{ij}^*$
 10. $r_j = \{ \max_i x_{ij}^*, \quad j \leq g; \min_i x_{ij}^*, \quad j > g \}$
 11. $d_{ij} = [w_j r_j - w_j x_{ij}^*]$
 12. $z_i = \max_j d_{ij}$
 13. $u_i = \pi_{j=1}^g (x_{ij}^*)^{w_j} / \pi_{j=g+1}^n (x_{ij}^*)^{w_j}$
 14. **End for**
-

15. End for

16. Step 3: Generate the subordinate modelling: RS, RPA and FMF

17. For $j = 1:J$ do

18. For $i = 1:m$ do

19. $\mathbf{R}_{\text{RSM}}^i = \{ A_{i|\max_i y_i} > \dots > A_{i|\min_i y_i} \}$

20. $\mathbf{R}_{\text{RPM}}^i = \{ A_{i|\min_i z_i} > \dots > A_{i|\max_i z_i} \}$

21. $\mathbf{R}_{\text{FMF}}^i = \{ A_{i|\max_i u_i} > \dots > A_{i|\min_i u_i} \}$

22. $\mathbf{R}_j = \{ \mathbf{R}_{\text{RSM}}^i, \mathbf{R}_{\text{RPM}}^i, \mathbf{R}_{\text{FMF}}^i \}$

23. End for

24. End for

25. Step 4: Generate the final modelling

26. For $i = 1:m$ do

27. For $i = 1:m$ do

28. If $\mathbf{R}_i$ dominated $\mathbf{R}_{ii}$

29. $dom^{i,j} = 1$

30. Else

31. $dom^{i,j} = 0$

32. End if

33. End for

34. End for

35. Step 5: Modelling the alternatives according to the value of dominance method.

The best alternative has the highest $\mathbf{R}_{\text{dom}}$.

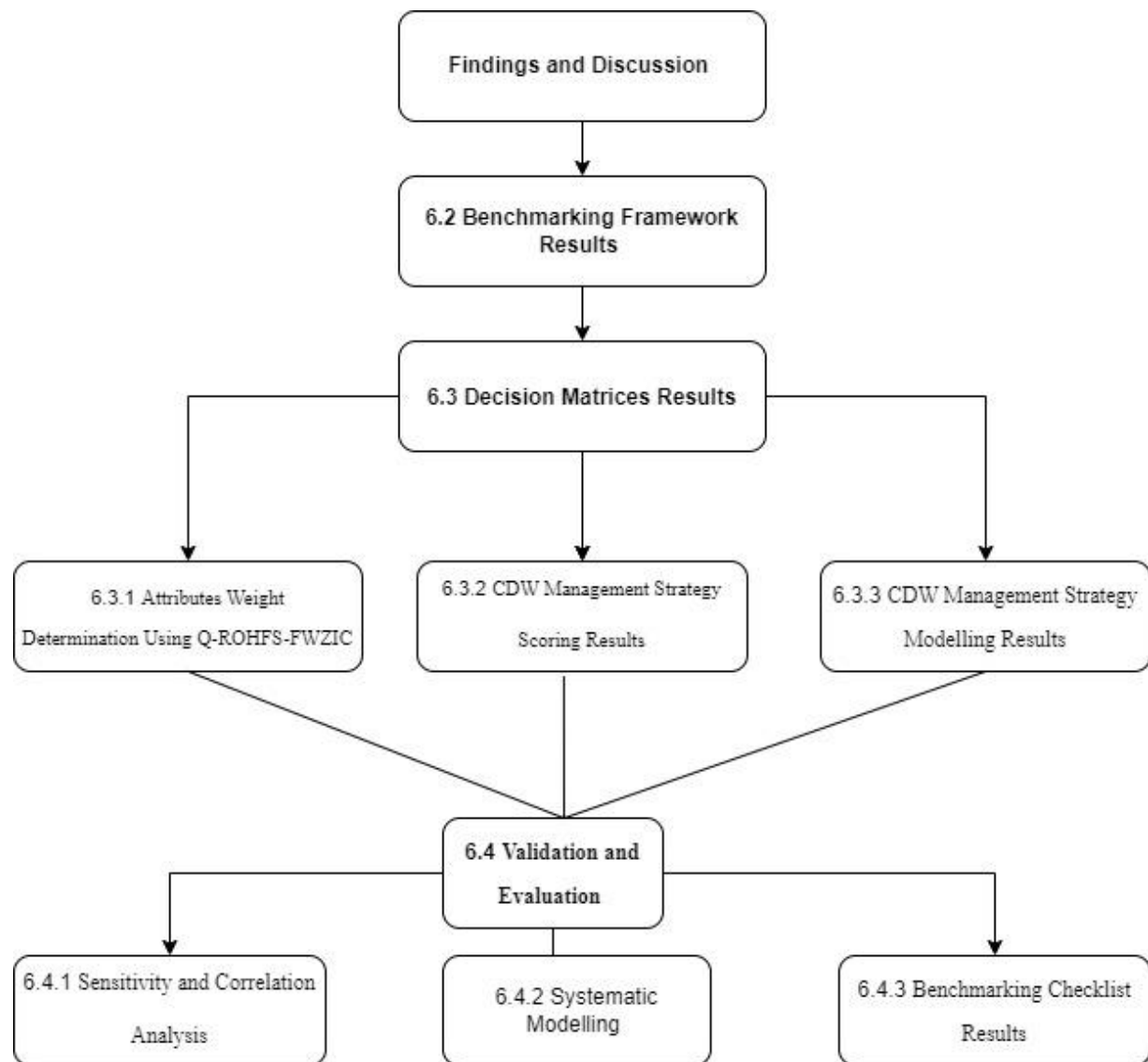
5.6 Chapter Summary

This chapter is dedicated to outlining the framework for benchmarking the management of (CDW) strategies to meet the study's objectives. The framework encompasses two primary phases: the identification of decision matrices and the subsequent formulation and development phase. In the first phase, decision matrices are constructed for the management of CDW strategies across various categories (i.e., CDW strategies) to fulfil the study's second objective. The second phase involves the creation and refinement of the q-ROPHFS–FWZIC method, which prioritizes the barrier attributes associated with the distribution of reused materials in CDW management strategies and calculates their respective weight values. Additionally, the q-ROPHFS–FDOSM method is devised and perfected to assess CDW management strategies. Finally, the q-ROPHFS–FDOSM-based MULTIMOORA method is integrated with the q-ROPHFS–FWZIC method to model CDW management strategies and determine the most and least sustainable approaches. This enables the benchmarking of CDW strategies management across different categories, thereby accomplishing the third and fourth objectives of this study. The subsequent chapter will provide a comprehensive presentation and discussion of the overall research results.

Chapter 6: Findings and Discussion

6.1 Introduction

This chapter presents the outcomes of the proposed benchmarking framework for managing CDW strategies. The results of this benchmarking framework for CDW strategy management are detailed in three distinct subsections. In Section 6.3, we provide the decision matrices for the two categories of CDW strategy management. Section 6.3.1 outlines the outcomes of the q-ROHFS-FWZIC method, which reflects the weights assigned to CDW attributes. Section 6.3.2 focuses on presenting the score values for each CDW management strategy, considering the preferences of the decision-makers regarding sub-barrier attributes such as reuse distribution and employing the MULTIMOORA method for modelling CDW management strategies. We evaluated and modelled a total of fifty-one strategies, considering the importance of the primary attributes. In Section 6.4, we delve into the results of the validation and evaluation methods, including Sensitivity and Correlation Analysis (Section 6.4.1), an evaluation based on systematic modelling (Section 6.4.2), and validation using a benchmarking checklist (Section 6.4.3). To conclude, the chapter's summary is presented in Section 6.5. Figure 15 offers an overview of the outcomes of the benchmarking framework for CDW management strategies.

Figure 15*Benchmarking Framework Results*

6.2 Benchmarking Framework Results

The findings from the decision matrices for sub-attributes of CDW management strategies can be found in Section 6.3.1. Additionally, Section 6.3.2 provides an overview of the results obtained using the q-ROHFS-FWZIC method, which highlights the assigned weights to CDW attributes. Section 6.3.3 is dedicated to showcasing the score values for individual CDW management strategies. This section also considers the decision-makers' preferences regarding sub-barrier attributes like reuse distribution, employing the MULTIMOORA method for modelling CDW management strategies.

6.3 Decision Matrices Results

This section reports the proposed decision matrix that is used to model CDW management strategies formulated in Chapter 5-Section 5.2. The absence of attributes from the management strategies of CDWs is indicated by '0,' whilst their presence is represented by a scale from one to nine. The scale numbers in the table 11 represent the number of barriers categorised by (K.Rakhshan et al., 2020) under each sub-attribute. Reference (K.Rakhshan et al., 2020) assigned three to Strategy₄₅ under the cost sub-attribute, which refers to the disposal costs, material costs and construction costs. The constructed matrix is fed to q-ROPHFS-FDOSM to score CDW management strategies. The following section reports the weighting findings of the barrier attributes of reuse distribution derived using the q-ROPHFS-FWZIC method and as shown in Table B.2 in Appendix B.

Strategy ₃₂	9	2	0	0	0	0	0	0	5	0	2	1	2	0	0	4	0	0	2	0
Strategy ₃₃	0	2	0	0	0	2	1	0	3	2	3	0	0	0	0	1	1	0	0	0
Strategy ₃₄	4	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₃₅	4	1	1	0	0	0	0	0	2	1	0	1	1	0	0	0	0	0	1	0
Strategy ₃₆	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0
Strategy ₃₇	5	2	0	0	0	1	1	0	6	0	0	2	1	0	1	0	1	0	0	0
Strategy ₃₈	9	3	1	0	1	0	0	0	6	2	1	2	1	0	0	2	3	1	3	1
Strategy ₃₉	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Strategy ₄₀	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	3	0	0
Strategy ₄₁	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₄₂	1	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Strategy ₄₃	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Strategy ₄₄	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₄₅	3	4	1	0	0	0	1	2	1	1	0	1	0	0	0	1	1	0	0	1
Strategy ₄₆	9	1	1	0	0	1	1	1	0	0	0	0	2	0	1	0	0	0	0	0
Strategy ₄₇	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Strategy ₄₈	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Strategy ₄₉	1	3	0	1	0	0	1	1	2	1	0	0	0	0	0	1	0	0	0	0
Strategy ₅₀	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Strategy ₅₁	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0

Table 12 presents the decision matrices proposed for use as the basis for benchmarking CDW management strategies. In this table, the absence of attributes in CDW management strategies is denoted by '0,' whereas their presence is indicated on a scale ranging from one to nine, as explained in Chapter 2, Section 2.4. Following the establishment of these decision matrices, this chapter delves into the examination of three crucial aspects: multiple evaluation attributes, attributes' importance, and data variation. To point these issues, an MADM solution was developed, as detailed in Chapter 5, and the comprehensive results are documented and discussed in this chapter.

6.3.1 Attributes Weight Determination Using Q-ROHFS-FWZIC

This section presents the weights of the main and sub-barrier attributes of reuse distribution in CDW management strategies are reported in this section. As discussed in

Chapter 5-Section 5.5.1 the q-ROPHFS–FWZIC method was used to prioritise the preidentified attributes according to their importance level. The consistency of the provided weighted attributes is the major benefit of the q-ROPHFS-FWZIC method. At the beginning, the three DMs provided their preference for each attribute using the predesigned and endorsed assessment form and five linguistic scales that measured the importance level of the attributes. Reported in Table 13 Table B.2 in Appendix B reports the SEJ, which represents the preferences of the DMs in linguistic terms. First, the terms converted into a numeric scale to construct the EDM, as presented in Table 14 Table B.3 in Appendix B. Secondly, the numeric scales were converted into q-ROPHFNs to construct the q-ROPHFS–EDM. Finally, the q-ROPHFS-FWZIC method, the q-ROPHFNs within the q-ROPHFS–EDM of each DM were aggregated using the q-ROPHFAM operator to generate a fuzzy weight for each attribute. Then, the fuzzy weights were DE fuzzified using the q-ROPHFS score and rescaled to produce the final crisp weight of each attribute. Tables 14 and 15 report the final weight value of the main and sub-barrier attributes of reuse distribution in the CDW management strategies.

Table 13

Preferences of the DMs in Linguistic Terms (SEJ)

Main attributes/DMs	DM1	DM2	DM3	Sub-attributes/DMs	DM1	DM2	DM3
Economic	I	I	VI	Cost	VI	I	VI
				Market	Av	Av	LI
				Value-for-money	I	Av	I
Environmental	Av	I	Av	Energy-and-GHG	Av	I	Av
				Contracts	Av	Av	I
Organisational	VLI	LI	LI	Experience	I	VI	VI
				Infrastructure	VLI	LI	Av
				Management	I	I	I

Regulatory	Av	I	I	Compliance	VI	VI	I
				Incentive	I	I	Av
				Awareness	Av	Av	Av
				Perception	Av	Av	4
Social	I	VI	VI	Risk	VI	I	VI
				Sustainability	I	I	I
				Trust	I	VI	I
				Willingness	LI	LI	VLI
Technical	Av	Av	LI	Deconstruction	I	Av	Av
				Design	I	I	VI
				Health-and-safety	VI	VI	VI
				Information	LI	LI	VLI

Table 14

Preferences of the DMs in the numeric scale (EDM)

Main attributes/DMs	DM1	DM2	DM3	Sub-attributes/DMs	DM1	DM2	DM3
Economic	2	2	1	Cost	1	2	1
				Market	3	3	4
				Value-for-money	2	3	2
Environmental	3	2	3	Energy-and-GHG	3	2	3
				Contracts	3	3	2
				Experience	2	1	1
Organisational	5	4	4	Infrastructure	5	4	3
				Management	2	2	2
				Compliance	1	1	2
Regulatory	3	2	2	Incentive	2	2	3
				Awareness	3	3	3
				Perception	3	3	4
				Risk	1	2	1
Social	2	1	1	Sustainability	2	2	2
				Trust	2	1	2
				Willingness	4	4	5
				Deconstruction	2	3	3
Technical	3	3	4	Design	2	2	1

Health-and-safety	1	1	1
Information	4	4	5

Table 15

Weight Value of the Main Barrier Attributes of Reuse Distribution in the CDW Management Strategies

Main attributes/weights per q value	$q = 4$	$q = 5$	$q = 6$	$q = 7$	$q = 8$	$q = 9$	$q = 10$
Economic	0.2918	0.3202	0.3416	0.3563	0.3658	0.3712	0.3737
Environmental	0.1314	0.1073	0.0854	0.067	0.0522	0.0404	0.0313
Organisational	0.0194	0.0101	0.0051	0.0025	0.0012	0.0006	0.0003
Regulatory	0.1749	0.1551	0.1326	0.1105	0.0904	0.073	0.0584
Social	0.3205	0.3679	0.411	0.4489	0.4817	0.5096	0.5333
Technical	0.0621	0.0394	0.0243	0.0147	0.0087	0.0051	0.0030

Amongst the main attributes, the social attribute was the most influential (Table 14). The weight value of this attribute exhibited a gradual increase from 0.3205 to 0.5333 with an increase in the q value, ranging from $q = 4$ to $q = 10$. The social attribute is succeeded by the economic attribute, with the corresponding weight values of 0.2918, 0.3202, 0.3416, 0.3563, 0.3658, 0.3712 and 0.3737 for q values of 4, 5, 6, 7, 8, 9 and 10, respectively. In terms of the influential degree, the regulatory, environmental, and technical attributes took third, fourth, and fifth place. The weight values of these attributes exhibited a gradual decrease with an increase in the q value. Amongst the main attributes, the organisational attribute exhibited the lowest influential degree. The weight values of organisational attribute exhibited a gradual decrease from 0.0194 to 0.0003 with an increase in the q value, ranging from $q = 4$ to $q = 10$.

Table 16

Weight Value of The Sub-Barrier Attributes of Reuse Distribution in the CDW Management Strategies

Main attributes	Sub-attributes/weights per q value	$q = 4$	$q = 5$	$q = 6$	$q = 7$	$q = 8$	$q = 9$	$q = 10$
Economic	Cost	0.5749	0.6541	0.7237	0.782	0.8293	0.867	0.8967
	Market	0.1113	0.0701	0.0428	0.0255	0.015	0.0088	0.0051
	Value-for-money	0.3138	0.2757	0.2335	0.1925	0.1557	0.1242	0.0982
Environmental	Energy-and-GHG	0.1314	0.1073	0.0854	0.067	0.0522	0.0404	0.0313
Organisational	Contracts	0.1884	0.1549	0.1249	0.0995	0.0785	0.0616	0.0481
	Experience	0.4594	0.5311	0.6011	0.6663	0.7249	0.7761	0.8196
	Infrastructure	0.0525	0.0324	0.0197	0.0118	0.007	0.0041	0.0024
	Management	0.2998	0.2816	0.2543	0.2225	0.1896	0.1583	0.1299
Regulatory	Compliance	0.6469	0.7035	0.756	0.8025	0.8419	0.8747	0.9013
	Incentive	0.3531	0.2965	0.244	0.1975	0.1581	0.1253	0.0987
Social	Awareness	0.0779	0.0513	0.0324	0.02	0.0121	0.0072	0.0043
	Perception	0.0634	0.0401	0.0246	0.0148	0.0088	0.0052	0.0030
	Risk	0.3273	0.3742	0.416	0.4525	0.4839	0.5108	0.5338
	Sustainability	0.2136	0.1984	0.176	0.1511	0.1266	0.1042	0.0846
	Trust	0.2980	0.3257	0.3457	0.3591	0.3675	0.3721	0.3740
	Willingness	0.0198	0.0103	0.0052	0.0025	0.0012	0.0006	0.0003
Technical	Deconstruction	0.1700	0.1303	0.098	0.0732	0.0547	0.0408	0.0306

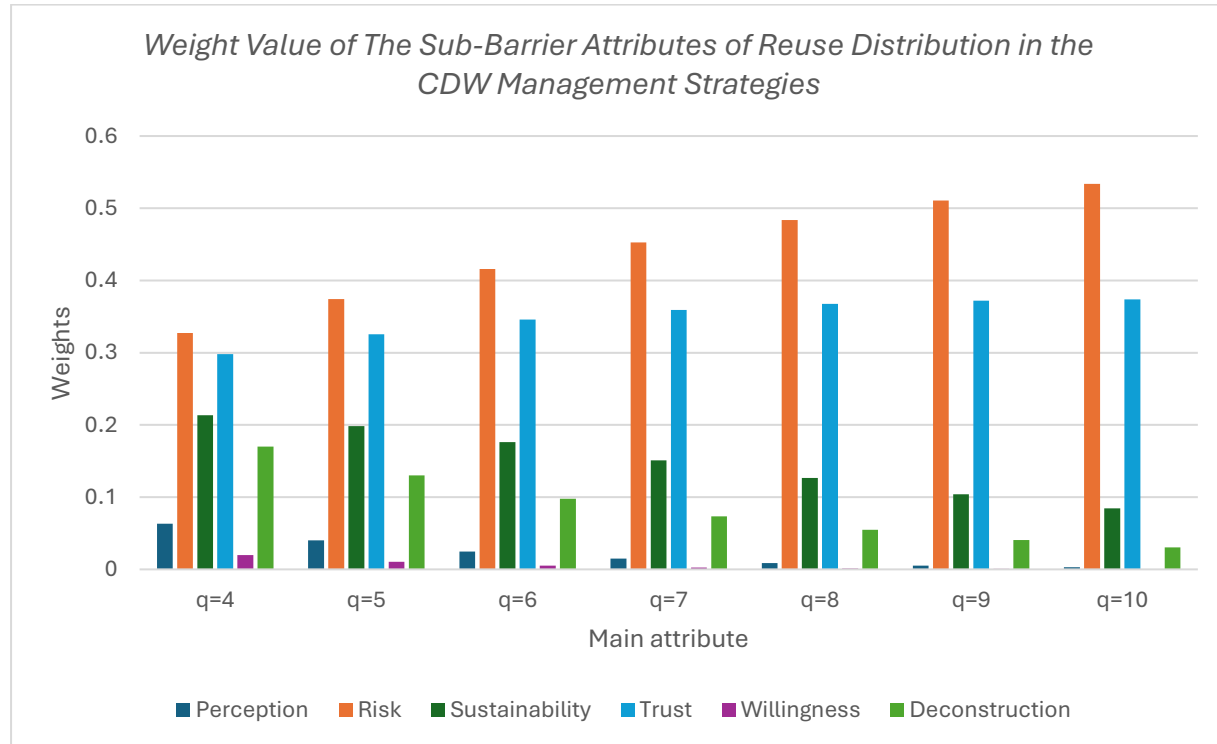
	Design	0.3775	0.389	0.3921	0.3894	0.3832	0.3749	0.3657
	Health-and-safety	0.4274	0.4685	0.5040	0.5346	0.5609	0.5836	0.6034
	Information	0.0251	0.0123	0.0059	0.0028	0.0013	0.0006	0.0003

Amongst the sub-attributes, the compliance attribute was the most influential (Table 14).

The weight value of this attribute exhibited a gradual increase from 0.6469 to 0.9013 with an increase in the q value, ranging from $q = 4$ to $q = 10$. Meanwhile, the willingness attribute exhibited the lowest influential degree. The weight values of organisational attribute exhibited a gradual decrease from 0.0198 to 0.0003 with an increase in the q value, ranging from $q = 4$ to $q = 10$. The weights of the remaining sub-attributes were distributed between the most and the least influential attributes. The cost attribute was the most influential under the economic attribute, followed by the value-for-money and market attributes. Only one sub-attribute, namely, energy-and-GHG, exists under the environmental attribute. The experience attribute was the most influential under the organisational attribute, followed by management, contracts and infrastructure attributes. The compliance attribute was the most influential under the regulatory attribute, followed by the incentive attribute. The risk attribute was the most influential under the social attribute, followed by the trust, sustainability, awareness, perception, and willingness attributes. Finally, the health-and-safety attribute was the most influential under the technical attribute, followed by the design, deconstruction, and information attributes.

Figure 16

Weight Value of The Sub-Barrier Attributes of Reuse Distribution in the CDW Management Strategies

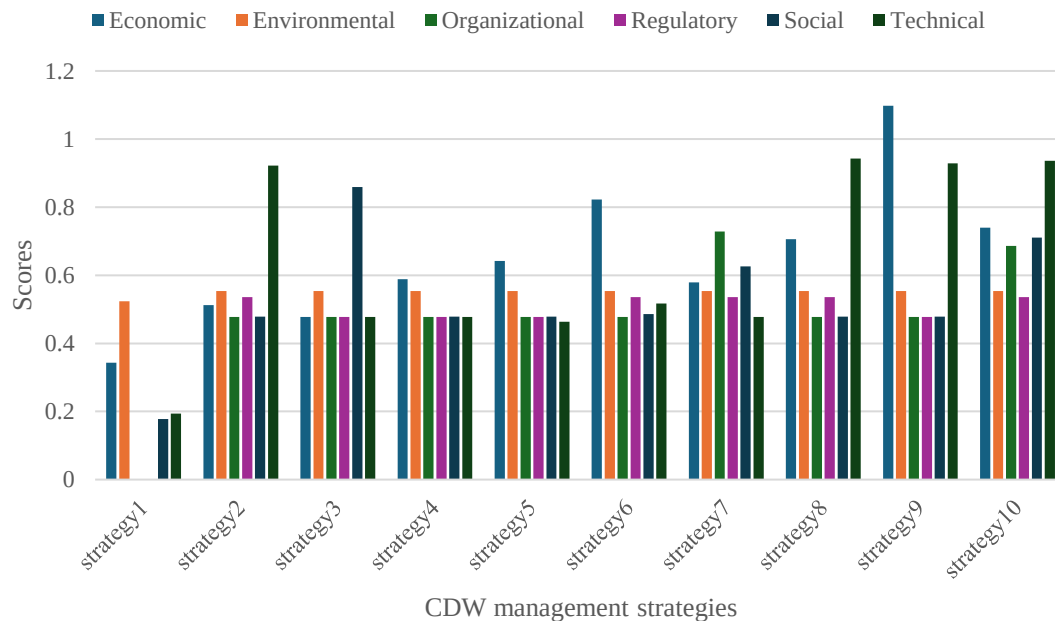


The weight value of the sub-barrier attributes of reuse distribution was fed to q-ROPHFS–FDOSM to score the CDW management strategies. Meanwhile, the weight value of the main barrier attributes of reuse distribution was fed to MULTIMOORA to find the final model of each.

6.3.2 CDW Management Strategy Scoring Results

This section presents the score value of each CDW management strategy based on the preferences of the DMs about the sub-barrier attributes of reuse distribution. The resulting decision matrix of CDW management strategies (Section 5.1) was fed to q-ROPHFS–

FDOSM. Three DMs selected the optimal solution of each attribute in the decision matrix. Then, the optimal solution of each attribute was compared with the values of all alternatives in terms of differences. The result of the first step was an opinion matrix of the CDW management strategies from each DM, as reported in Table B.4 in Appendix B. Thereafter, these opinion matrices were converted into fuzzy opinion matrices by replacing the linguistic expressions with q -ROPHFNs. Then, the individual scores for each CDW management strategy were aggregated with respect to the weight of the sub-barrier attributes of reuse distribution and DE fuzzified using the q -ROPHFEAM operator and q -ROPHFS score function. Finally, the group scores for all CDW management strategies were calculated using the arithmetic mean. Figure 17 presents an example of the group scoring results of the 10 strategies (Strategy₁–Strategy₁₀) at $q = 4$. Table B.5 in Appendix B reports the overall group scoring results of the CDW management strategies per seven q values (i.e. $q = 4, 5, 6, 7, 8, 9$ and 10).

Figure 17*Scoring Results*

These group scoring matrices were used as input data to calculate the final models of CDW management strategies via the MULTIMOORA method.

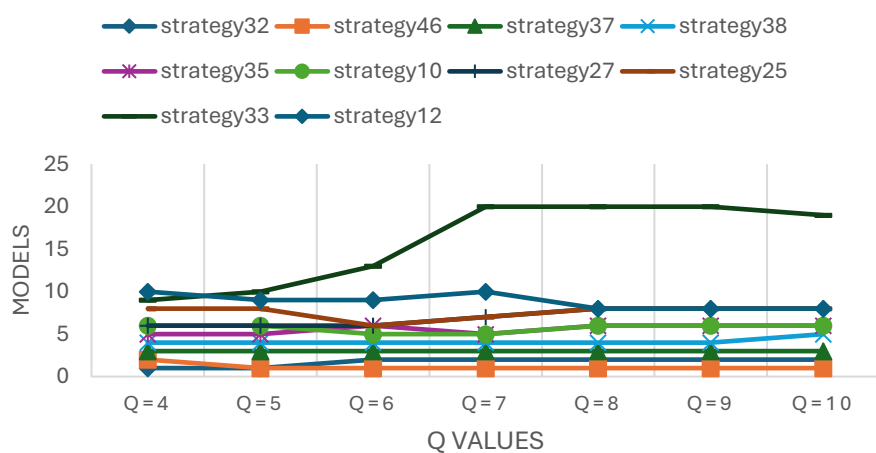
6.3.3 CDW Management Strategy Modelling Results

As previously mentioned, the scoring matrices (Section 5.5.2) were used as input data for the MULTIMOORA method for modelling CDW management strategies. Fifty-one strategies were evaluated and modelled with respect to the weight of the main attributes. The ratio-system method was utilised to compute the modelling value of CDW management strategies, followed by the reference-point method and full-multiplicative-form calculations. The resulting scores and models are aggregated using dominance theory to produce the final modelling results of the CDW management strategies. Table B.6 in Appendix B reports the

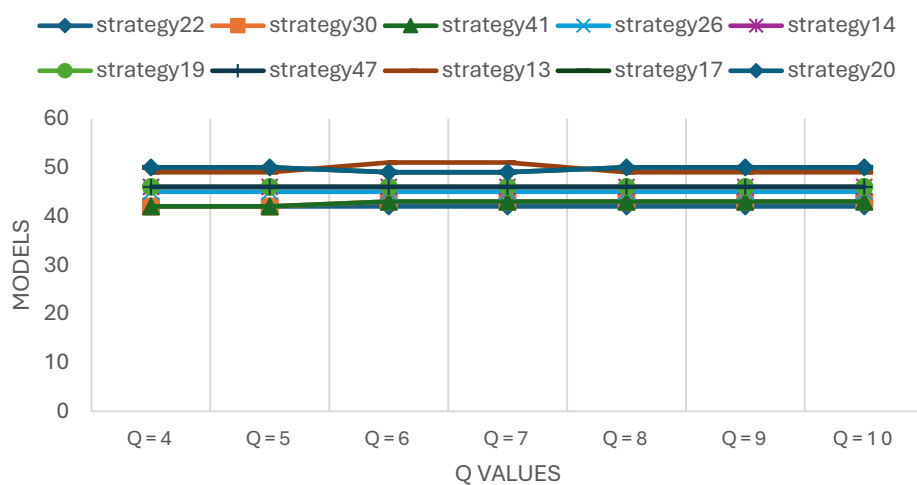
overall modelling results of CDW management strategies per seven q values (i.e. $q = 4, 5, 6, 7, 8, 9$ and 10). Figure 18 presents the modelling results of the 10 most sustainable strategies and the 10 least sustainable strategies.

Figure 18

Modelling Results



(a)



(b)

According to Figure 18 (a), the most sustainable strategy was Strategy₄₆, which modelled first throughout six q values ($q = 5 - q = 10$) but fell to second at $q = 4$. This strategy was followed by Strategy₃₂, which modelled first across two q values ($q = 4$ and $q = 5$) but fell to second at ($q = 6 - q = 10$). Strategy₃₇ modelled third across all q values. Strategy₃₈ modelled fourth amongst the five q values ($q = 4 - q = 9$) but fell to fifth at $q = 10$. Strategy₃₅ and Strategy₁₀ modelled fifth and sixth at $q = 4$ and $q = 5$, swapped models at $q = 6$ and modelled fifth and sixth at $q = 7$ and $q = 8 - q = 10$, respectively. Strategy₂₇ modelled sixth at $q = 4 - q = 6$, but it fell to the seventh and eighth models at $q = 7$ and $q = 8 - q = 10$, respectively. Strategy₂₅ modelled eighth at $q = 4, q = 5$ and $q = 8 - q = 9$, but it modelled sixth and seventh at $q = 6$ and $q = 7$, respectively. Strategy₃₃ received the ninth model at $q = 4$, but it fell to the 10th, 13th, 20th, and 19th models at $q = 5, q = 6, q = 7 - q = 9$ and $q = 10$, respectively. Strategy₁₂ modelled 10th at $q = 4$ and $q = 7$, but it modelled ninth and eighth at $q = 5 - q = 6$ and $q = 8 - q = 10$, respectively.

According to Figure 18 (b), the least sustainable strategies were Strategy₁₇ and Strategy₂₀, which modelled 50th throughout five q values ($q = 4, q = 5$ and $q = 8 - q = 10$) but rose to 49th at $q = 6$ and $q = 7$. The two strategies were followed by Strategy₁₃, which modelled 49th across the five q values ($q = 4, q = 5$ and $q = 8 - q = 10$) but fell to 51st at ($q = 6 - q = 10$). Strategy₄₇, Strategy₁₉ and Strategy₁₄ had the 46th model across all q values. Strategy₂₆ and Strategy₂₂ modelled 45th and 42nd across all q values. respectively. Finally, Strategy₃₀ and Strategy₄₁ received the 42nd model at $q = 4$ and $q = 5$, but they fell to the 43rd model at $q = 6 - q = 10$. The models of the remaining strategies were distributed between the most and the least models across all q values.

6.4 Validation and Evaluation

The Sensitivity and correlation analysis are presented in Section 6.1. The systematic modelling is provided in Section 6.2. The objective and subjective comparison analyses are discussed in Section 6.3.

6.4.1 Sensitivity and Correlation Analysis

In this section, sensitivity and correlation analyses are undertaken to test the robustness of the proposed MADM methods (Alamleh et al., 2022; Qahtan et al., 2022). for determining the most and the least sustainable CDW management strategies. In sensitivity analysis, the weight values of the main barrier attributes of reuse distribution are modified in accordance with Kirkwood and Kahraman's recommendations (J.H.Klein et al., 1998; Y.R.Kahraman, 2002), and the modelling order of each CDW management strategy is examined. Therefore, the new weight sets (WSs) of the main barrier attributes of reuse distribution can be determined according to "Equation 20".

$$w_c = (1 - w_s) \times (w_c^0 / W_c^0) = w_c^0 - \alpha_c \times \Delta x, \quad (20)$$

where w_s refers to the weight of the most influential attribute, w_c^0 refers to the initial weight of the main barrier attributes of reuse distribution determined by the q-ROPHFS–FWZIC method, W_c^0 refers to the summation of attributes' initial weight values, α_c refers to the elasticity weight coefficient, and Δx refers to the modification range of the attributes' weight value. For emphasis, the initial weight values considered in this test are the weights when $q = 4$, as proof of concept. "Equations 21" and (22) are used to obtain the α_c values of each attribute, and "Equation 22" can be utilised to determine the modification range values of Δx .

$$\alpha_c = w_c^o / W_c^0 \quad (21)$$

$$-w_s \leq \Delta x \leq 1 - w_s \quad (22)$$

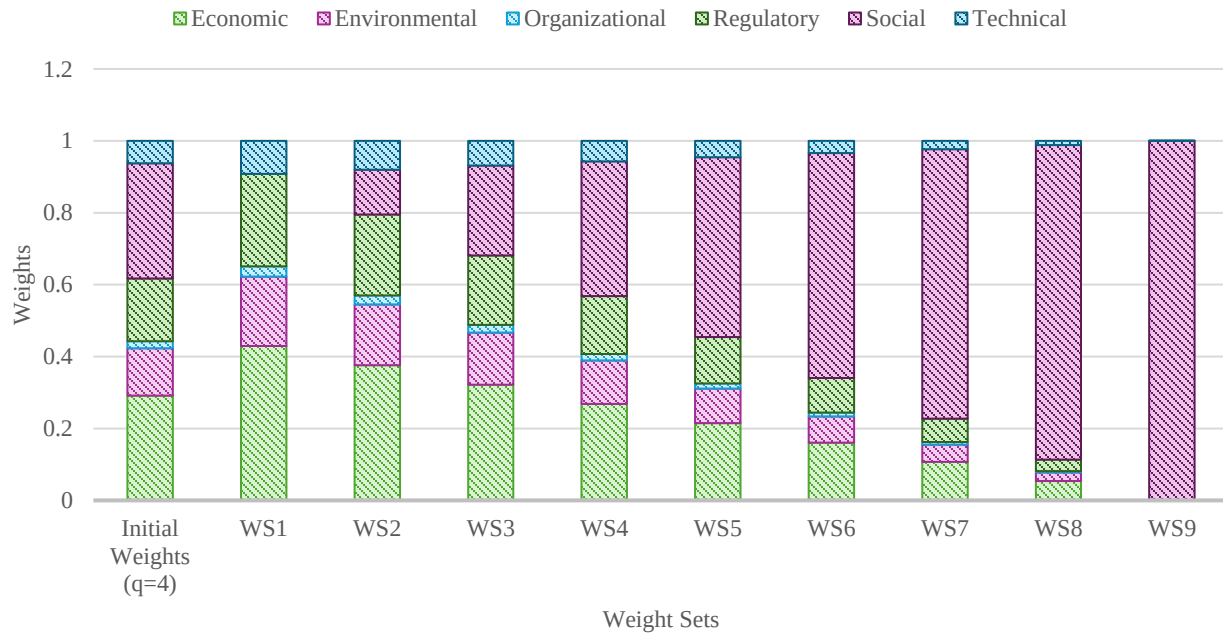
In Table 17, the social attribute was the most influential in this study because it had the highest weight value ($W_{Social}=0.3205$). The resulting α_c values of the main barrier attributes of reuse distribution are presented in Table 5.

Table 17

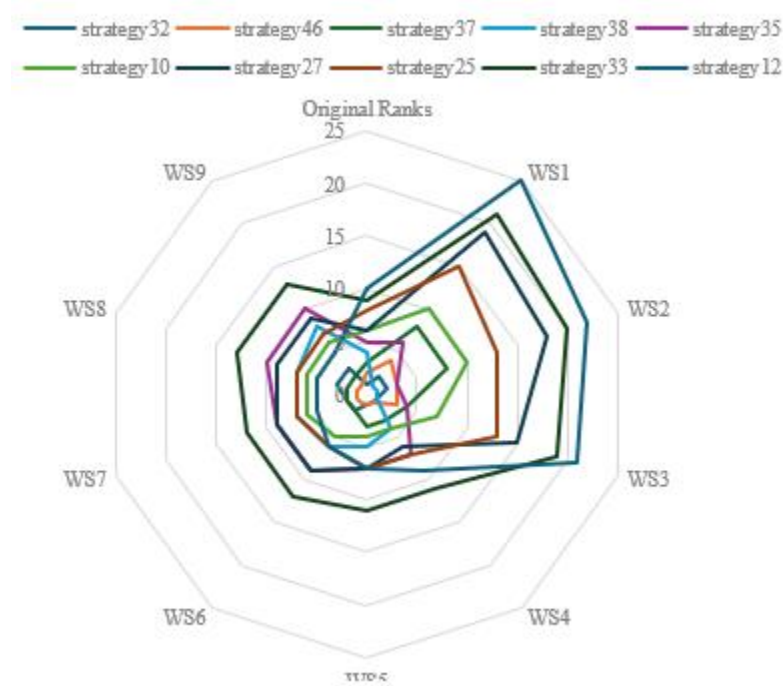
α_c Values of the Main Barrier Attributes of the Reuse Distribution

Main barrier attributes	Economic	Environmental	Organisational	Regulatory	Social	Technical
α_c	0.4294	0.1934	0.0286	0.2574	0.4716	0.0913

The calculated modification range values of Δx are $-0.3205 \leq \Delta x \leq 0.6795$. Finally, nine WSs (WS1, WS2, ..., WS9) of the main barrier attributes of reuse distribution for this test were determined, as shown in Figure 19 The total attribute weight across each WS must be equal to one ($\sum w_c = 1$).

Figure 19*WSs Analysis*

After the new WSs for each strategy have been calculated, the new modelling of the CDW management strategies is estimated. Figure 20 illustrates the influence of the new WSs on the modelling order of the 10 most sustainable CDW management strategies. Then, the new modelling is compared with the initial modelling. The main aim of the sensitivity analysis is to determine how sensitive the MADM methods are to alterations in the weights of the barrier attributes of reuse distribution. Strategy32 changed its initial model in six (WS1, WS2 and WS6–WS9) out of nine WSs. Strategy37 and Strategy10 altered their models in seven WSs (WS1–WS3 and WS6–WS9). Strategy38 and Strategy27 changed their initial models in all WSs except WS4. Strategy46, Strategy25, Strategy33 and Strategy12 changed their models across all WSs.

Figure 20*New Modelling Order*

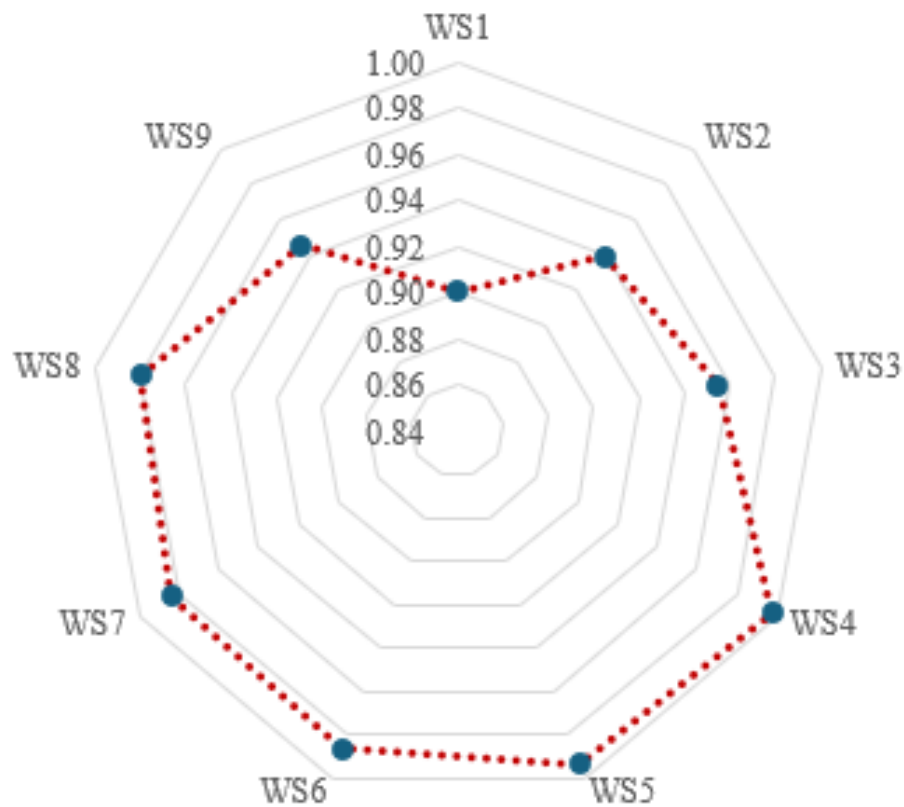
Spearman's rho correlation is estimated according to "Equation 23" to analyse the overall results of sensitivity analysis and quantify the intensity and direction (negative or positive) of the correlation between the initial and the new models.

$$R = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2-1)}, \quad (23)$$

where d represents the model difference at position i , and n represents the model number. Figure 21 shows Spearman's rho correlation of the CDW management strategies in the nine WSs.

Figure 21

Spearman's Rho Correlation of CDW



Spearman's rho correlation between the initial and the new models in nine WSs (WS₁–WS₉) ranged from 0.9 to 1.0, indicating a significant positive relationship (Figure 22). The mean Spearman rho correlation was 0.96, indicating a positive and strong association.

6.4.2 Systematic Modelling

Systematic modelling is another test used by academics to validate their MADM approaches. This test verifies that the CDW management strategies are modelled in a systematic manner. According to reference (A.AlSereidi et al., 2022), the following four steps must be taken for this test.

First, the values of the scoring matrix (Table B.5 in Appendix B) are aggregated using an arithmetic mean to produce a final value for each CDW management strategy. The scoring matrix is considered in this test when $q = 4$, as proof of concept.

Second, the resulting values and their corresponding CDW management strategies are sorted from the smallest to the largest based on the modelling results at $q = 4$ (Table B.6 in Appendix B).

Third, the CDW management strategies are divided into five groups, with the first, second, third and fourth groups comprising 10 strategies and the fifth group comprising 11 strategies. According to the modelling orders (Table B.5 in Appendix B), the CDW management strategies within each group are provided in Table 18. The validation procedure is unaffected by the number of groups or alternatives within each group.

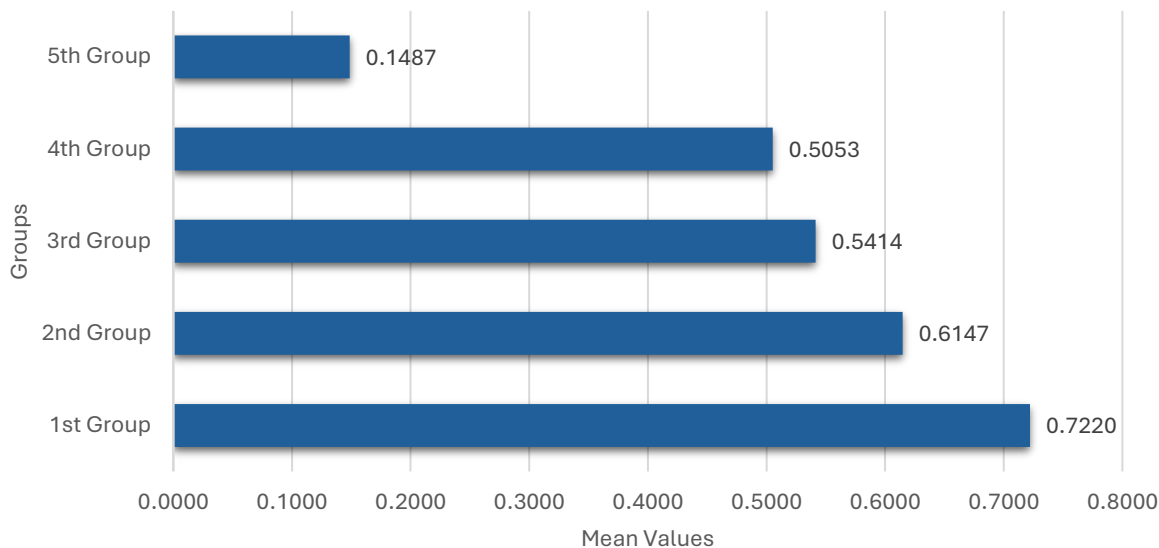
Table 18

CDW Management Strategies Within Each Group

Groups	CDW management strategies
1st group	Strategy ₃₂ , Strategy ₄₆ , Strategy ₃₇ , Strategy ₃₈ , Strategy ₃₅ , Strategy ₁₀ , Strategy ₂₇ , Strategy ₂₅ , Strategy ₃₃ and Strategy ₁₂
2nd group	Strategy ₄₅ , Strategy ₃ , Strategy ₂₉ , Strategy ₉ , Strategy ₆ , Strategy ₇ , Strategy ₁₅ , Strategy ₁₁ , Strategy ₄₈ and Strategy ₈
3rd group	Strategy ₄₉ , Strategy ₃₆ , Strategy ₃₄ , Strategy ₃₁ , Strategy ₂ , Strategy ₅ , Strategy ₄ , Strategy ₁₆ , Strategy ₄₂ and Strategy ₄₃

4th group	Strategy ₂₁ , Strategy ₄₀ , Strategy ₂₃ , Strategy ₁₈ , Strategy ₄₄ , Strategy ₃₉ , Strategy ₅₀ , Strategy ₂₄ , Strategy ₂₈ and Strategy ₅₁
5th group	Strategy ₁ , Strategy ₂₂ , Strategy ₃₀ , Strategy ₄₁ , Strategy ₂₆ , Strategy ₁₄ , Strategy ₁₉ , Strategy ₄₇ , Strategy ₁₃ , Strategy ₁₇ and Strategy ₂₀

Fourth, the mean value of each group is calculated. The CDW management strategies with the greatest mean value are the most desired because a higher score indicates a better alternative, and a lower score denotes a poorer alternative (Table B.5 in Appendix B). The validity of the result is then established by comparing the mean of the first group to the means of the subsequent groups, with the expectation that the mean of the first group will be the highest. Meanwhile, the mean of the second group is anticipated to be larger than the third, fourth, fifth, etc. If the evaluations confirm the anticipated outcomes, then the results are valid. Figure 22 presents the results of the systematic modelling test.

Figure 22*Results of the Systematic Modelling Test*

The first group had the greatest mean (0.7220) compared with the other four groups because its 10 strategies were modelled the highest. The second group had a higher mean (0.6147) than the third group (0.5414), the third group had a higher mean than the fourth group (0.5053), and the fourth group had a higher mean than the fifth group (0.1487). This test indicates that the provided modelling results for CDW management strategies are accurate and consistent.

6.4.3 Benchmarking Checklist Results

This section presents objective and subjective comparison analyses. The proposed method is subjected to an objective comparison analysis with the VIKOR ranking method. The weighting results of barrier attributes of reuse distribution determined by q-ROPHFS–FWZIC are fed into the VIKOR method. The group scorings of the CDW management strategies

determined by q-ROPHFS–FDOSM are transmitted into the VIKOR method and serves as the decision matrix. Subsequently, a comparison is made between the ranking outcomes of the VIKOR technique and the proposed approach. The summary of the comparison of ranking outcomes between the MULTIMOORA and VIKOR methods is presented in Table 19, whilst the overall modelling results are reported in Table B.7 in Appendix B. The q-ROPHFS–FWZIC method utilised seven distinct q values (i.e. 4 – 10) to derive the weighting outcomes, necessitating the execution of VIKOR based on these values.

Table 19

*Comparison of Q-ROPHFS–FDOSM (MULTIMOORA) and Q-ROPHFS–FDOSM (VIKOR)
Using Q-ROPHFS–FWZIC Results*

q values	Number of differences	Strategies with different modelling results	Percentage
4	43	Strategy ₂ –Strategy ₂₀ , Strategy ₂₂ –Strategy ₂₇ , Strategy ₂₉ , Strategy ₃₁ ,	84
		Strategy ₃₃ –Strategy ₄₂ and Strategy ₄₄ –Strategy ₅₀	%
5	39	Strategy ₃ –Strategy ₁₂ , Strategy ₁₄ , Strategy ₁₆ , Strategy ₁₈ , Strategy ₁₉ ,	76
		Strategy ₂₁ –Strategy ₂₅ , Strategy ₂₇ –Strategy ₂₉ , Strategy ₃₁ ,	%
		Strategy ₃₃ –Strategy ₄₆ , Strategy ₄₈ and Strategy ₅₀	
6	41	Strategy ₂ –Strategy ₇ , Strategy ₉ –Strategy ₁₄ , Strategy ₁₆ –Strategy ₂₃ ,	80
		Strategy ₂₅ , Strategy ₂₈ –Strategy ₃₁ , Strategy ₃₃ –Strategy ₄₅ and Strategy ₄₈ –Strategy ₅₀	%

		Strategy ₁ , Strategy ₂ , Strategy ₄ –Strategy ₆ , Strategy ₈ –Strategy ₁₄ ,	71
		Strategy ₁₇ , Strategy ₁₈ , Strategy ₂₀ –Strategy ₂₃ , Strategy ₂₅ ,	%
7	36	Strategy ₂₇ , Strategy ₂₈ , Strategy ₃₀ , Strategy ₃₁ , Strategy ₃₃ ,	
		Strategy ₃₄ , Strategy ₃₆ , Strategy ₃₉ –Strategy ₄₅ , Strategy ₄₇ , Strategy ₄₉	
		and Strategy ₅₀	
		Strategy ₁ , Strategy ₂ , Strategy ₄ –Strategy ₆ , Strategy ₈ –Strategy ₁₂ ,	71
		Strategy ₁₄ –Strategy ₁₆ , Strategy ₁₈ , Strategy ₂₁ , Strategy ₂₂ ,	%
8	36	Strategy ₂₄ , Strategy ₂₅ , Strategy ₂₇ , Strategy ₂₈ , Strategy ₃₀ ,	
		Strategy ₃₁ , Strategy ₃₃ –Strategy ₃₆ , Strategy ₃₉ , Strategy ₄₁ –Strategy ₄₅	
		and Strategy ₄₇ –Strategy ₅₀	
		Strategy ₁ –Strategy ₇ , Strategy ₉ –Strategy ₁₂ , Strategy ₁₄ –Strategy ₁₆ ,	71
		Strategy ₁₈ , Strategy ₂₁ –Strategy ₂₅ , Strategy ₂₇ , Strategy ₂₈ ,	%
9	36	Strategy ₃₀ , Strategy ₃₃ , Strategy ₃₅ , Strategy ₃₆ , Strategy ₃₉ –	
		Strategy ₄₂ , Strategy ₄₄ , Strategy ₄₅ and Strategy ₄₇ –Strategy ₅₀	
		Strategy ₁ –Strategy ₇ , Strategy ₉ –Strategy ₁₂ , Strategy ₁₄ –Strategy ₁₆ ,	75
1		Strategy ₁₈ , Strategy ₂₁ –Strategy ₂₅ , Strategy ₂₇ –Strategy ₃₀ ,	%
0	38	Strategy ₃₃ , Strategy ₃₅ , Strategy ₃₈ –Strategy ₄₅ and Strategy ₄₇ –	
		Strategy ₅₀	

When q was equal to 4, 43 strategies exhibited distinct ranking outcomes, accounting for 84% of the total. Only eight strategies (namely, Strategy₁, Strategy₂₁, Strategy₂₈, Strategy₃₀, Strategy₃₂, Strategy₄₃, Strategy₄₆ and Strategy₅₁) demonstrated identical ranks, which constituted 16% of the total. Approximately 76% of the total number of strategies

evaluated, or 39 strategies, exhibited varying ranking results for $q = 5$. Only 24% of the strategies, specifically, Strategy₁, Strategy₂, Strategy₁₃, Strategy₁₅, Strategy₁₇, Strategy₂₀, Strategy₂₆, Strategy₃₀, Strategy₃₂, Strategy₄₇, Strategy₄₉ and Strategy₅₁, had identical ranks for the same value of q . Forty-one of the total number of strategies showed different ranking outcomes, representing 80% of the total, when q was equal to six. By contrast, a mere ten strategies, specifically, Strategy₁, Strategy₈, Strategy₁₅, Strategy₂₄, Strategy₂₆, Strategy₂₇, Strategy₃₂, Strategy₄₆, Strategy₄₇ and Strategy₅₀, exhibited equivalent rankings, accounting for 20% of the overall results. The study found that when q was set to 7, 8 and 9, a total of 36 strategies displayed different ranking outcomes, which constituted 71% of the overall results. Meanwhile, a total of 29% was represented by fifteen strategies that exhibited equivalent ranks. The study revealed that 38 strategies demonstrated distinct ranking outcomes, which constituted 75% of the total, when q was equal to 10. A mere thirteen strategies, specifically, Strategy₈, Strategy₁₃, Strategy₁₇, Strategy₁₉, Strategy₂₀, Strategy₂₆, Strategy₃₁, Strategy₃₂, Strategy₃₄, Strategy₃₆, Strategy₃₇, Strategy₄₆ and Strategy₅₁, exhibited equivalent rankings, accounting for a quarter of the overall strategies.

Therefore, the study conducted a subjective comparison analysis to verify the validity of the proposed MADM methods, following an objective comparison analysis that revealed significant differences in the ranking outcomes between the compared methods. A benchmark study (O.S.Albahri et al., 2021) was used for this purpose. In the benchmark study, the authors modelled active queue management methods by using FDOSM based on TOPSIS and FDOSM based on VIKOR. According to their findings, the FDOSM based on VIKOR modelling is the best option for making decisions. Consequently, the proposed q-ROPHFS–FWZIC and q-ROPHFS–FDOSM based on MULTIMOORA are compared with the FDOSM

based on VIKOR (O.S.Albahri et al., 2021) in terms of theory (weighting and modelling method). Furthermore, the ability of the compared methods to solve MADM concerns in the application/case study is considered in the comparison. Table 20 presents three and 12 comparison points in terms of application and theory, respectively.

Table 20

Comparison Points Between the Proposed Study and the Benchmark Study

Comparison points		Proposed q-ROPHFS– FWZIC and q-ROPHFS– FDOSM based on MULTIMOORA	FDOSM based on VIKOR
In terms of applicatio n	Did the case study consider multiple assessment attributes?	Yes	Yes
	Had the relative importance of the assessment attributes been taken into consideration?	Yes	No
	Was the data variation concern addressed in the case study?	Yes	Yes
Weighting	Was the inconsistency issue handled in the weighing method?	Yes	—

In terms of theory	Was the dependency issue amongst the attributes handled in the weighing method?	Yes	—
	Did the gathering of expert feedback prove to be simple?	Yes	—
	Did the weighting method solve the issues of informational vagueness and uncertainty as well as experts' hesitation?	Yes	—
	Did the combination of the fuzzy set and the weighting method enable DMs to generalise other fuzzy set extensions?	Yes	—
	Did the combination of the fuzzy set and the weighting method provide wide space to the experts to express their preferences?	Yes	—
	Did the weighting method assign explicit weights to the attributes?	Yes	—
	Did the modelling method assign implicit weights to the attributes?	Yes	Yes
	Modelli		

Are the calculations of the modelling method straightforward and comprehensible?	Yes	Yes
Did the modelling method solve the issue of informational ambiguity and uncertainty?	Yes	No
Did the combination of the fuzzy set and the modelling method enable DMs to generalise other fuzzy set extensions?	Yes	No
Did the combination of the fuzzy set and the modelling method provide wide space to the experts to express their preferences?	Yes	No

In terms of application, the proposed study and the benchmark study had three modelling concerns: multiple assessment attributes, prioritising/weighting these attributes based on their importance level and variance in data. The benchmark study aimed to address the second concern, whilst the proposed study formulated the q-ROPHFS–FWZIC method for this purpose. Regarding theory (weighting method), the proposed q-ROPHFS–FWZIC method was developed and formulated to assign explicit weights to the attributes, whilst the benchmark study did not use any weighting method. Table 20 highlights the most essential aspects of the proposed weighting method and fuzzy set. Regarding theory (modelling

method), both studies used FDOSM, which can assign implicit weights to the attributes. The calculations were also straightforward and comprehensible. The benchmark study failed to address the remaining comparison points using a classical fuzzy set (triangular fuzzy numbers).

Overall, the proposed study achieved all 15 comparison points (100%). By contrast, reference (O.S.Albahri et al., 2021) met only four of 15 points (26.7%). These findings indicate that the proposed study has developed a robust method for modelling CDW management strategies and determining the most and least sustainable strategies based on the most important comparative points.

6.5 Chapter Summary

This chapter discloses the outcomes obtained from the second, third, and fourth stages of the methodology, focusing on (MADM) and (CDW) management strategies. The second phase presents the results of evaluating CDW management systems and unveils the final configuration of the decision matrix. Subsequently, the third phase encompasses the results of the decision-making method. The fourth phase reflects the findings from three distinct validation and evaluation procedures. In the specific context of CDW management strategies, the decision matrix, and barriers attributes weights, determined through the q-ROPHFS-FWZIC method, were incorporated into the q-ROHFS-FDOSM methodology, coupled with MULTIMOORA optimization. This amalgamation facilitated the benchmarking of CDW management strategies across its various sub-categories. To assess the research outcomes, an evaluation was conducted through sensitivity analysis and systematic modelling. Concurrently, the proposed framework underwent validation using a benchmark checklist.

Chapter 7: Conclusion and Future Study

7.1 Overview

This chapter presents a summary of the thesis, outlining key findings corresponding to each research objective. The theoretical contribution involves investigating existing evaluation techniques and proposing an enhanced decision-making framework for Sustainable Management Strategies in CDW management. This framework advances the understanding of how various strategies can be systematically assessed and optimized, offering a strong tool for researchers and practitioners. The practical implications of the research include the development of decision matrices that align strategies with specific CDW attributes, thereby providing a structured approach for evaluating and selecting the most sustainable practices. The validation of the proposed approach through sensitivity analysis and comparative assessment demonstrates its effectiveness and reliability in real-world scenarios. These practical contributions are expected to guide policymakers, industry stakeholders, and environmental managers in making informed decisions that promote sustainability in construction and demolition activities. Limitations are acknowledged, particularly regarding data availability and the complexity of integrating multiple decision-making methods. Data availability issues can constrain the comprehensiveness of the analysis and the generalizability of the findings. Moreover, the integration of various decision-making techniques presents methodological challenges that require careful consideration to ensure the robustness and accuracy of the results. These limitations highlight areas where further refinement and additional research are necessary.

Moreover, as mentioned above, a comprehensive overview of the thesis, summarizing its main findings and describing its theoretical and practical contributions. The theoretical contribution focuses on the study of existing assessment techniques and the proposal of an improved decision-making framework for sustainable management strategies in construction and demolition waste (CDW) management. By advancing the understanding of how different strategies can be systematically assessed and optimized, this framework provides a valuable tool for both researchers and practitioners in the field. It represents a step forward in the academic discourse on sustainable CDW management by providing a structured approach to decision-making.

In terms of practical implications, the research contributes to the development of a decision matrix that aligns strategies with specific CDW characteristics. This structured approach facilitates the evaluation and selection of the most sustainable practices, providing concrete benefits to policymakers, industry stakeholders, and environmental managers. Furthermore, the validation of the proposed approach through sensitivity analysis and comparative evaluation demonstrates its effectiveness and reliability in real-world scenarios, strengthening its practical applicability.

However, the section also acknowledges some limitations, particularly concerning data availability and the complexity of integrating multiple decision-making methods. These limitations may limit the comprehensiveness of the analysis and the generalizability of the results. Additionally, integrating different decision-making techniques creates methodological challenges that need to be carefully considered to ensure the robustness and accuracy of the results. In recognizing these limitations, the section highlights the need for further refinement

and additional research to address these challenges and strengthen the effectiveness of the framework.

Overall, this section provides a balanced assessment of the dissertation's contributions, highlighting its theoretical significance while recognizing practical challenges and avenues for future research. It provides a valuable foundation for advancing sustainable CDW waste management practices and guiding decision-making in the construction and demolition sector.

Future work focuses on refining the proposed framework by incorporating more comprehensive and diverse datasets to enhance its applicability, robustness, and reliability across different scenarios. Addressing identified limitations, such as improving data collection methods and simplifying the integration of decision-making techniques, will be critical in advancing the framework's effectiveness and ease of use. Additionally, exploring applications in other waste management contexts, such as industrial waste, electronic waste, and municipal solid waste, can significantly extend the utility of the framework beyond CDW management. This broader application will not only help to generalize the findings but also offer valuable insights into sustainable waste management practices across various sectors. By applying the framework to different types of waste, we can identify unique challenges and opportunities specific to each waste stream, thereby fostering a more holistic approach to waste management. Furthermore, future work will consider the incorporation of emerging technologies such as artificial intelligence and machine learning to improve predictive capabilities and decision-making efficiency. These advancements will contribute to the continuous improvement of sustainable waste management practices and support the transition towards a circular economy on a global scale.

Another important aspect of future research concerns the involvement and collaboration of the present parties. Without including industry experts, political decision-makers, and community members in the research process, we cannot guarantee that the work proposal is not only scientifically sound, but also relevant in practice and socially acceptable. This collaborative approach will help to adapt the work proposals to respond to the specific needs and constraints of the different present parties, thereby improving their impact and their adoption. In addition, pilot projects and case studies were made in different geographical contexts and regular observations and valuable information were collected to reassure the workers and validate their benefits. Finally, this iterative process of improvement and validation reinforces the role of the work proposals as essential to promote sustainable practices of labour management in different contexts.

In addition, the exploration of interdisciplinary collaborations with fields such as urbanism, architecture, and environmental sciences can enrich personnel with the integration of diverse perspectives and expertise. This interdisciplinary approach Favors innovation and holistic solutions to the complex problems of CDW management, providing results, effectiveness, and sustainability. In addition, collaboration with local communities and indigenous knowledge systems can provide valuable information on ways to manage day-to-day in a culturally sensitive and context-specific way, guaranteeing that strategies are inclusive and respectful of different cultural and socio-economic environments. Adopting a multi-disciplinary and inclusive approach, future research projects can contribute to the development and adaptation of complete personnel, accommodating the multi-faceted dimensions of sustainable management.

7.2 Key Findings

In the field of sustainable development, effective management of Construction and Demolition Waste (CDW) plays a pivotal and indispensable role in mitigating adverse environmental impact and fostering resource efficiency. However, the evaluation and judicious selection of appropriate Sustainable Management Strategies for CDW often encounter multifaceted challenges due to the intricate and dynamic interplay of various factors such as environmental considerations, economic feasibility, and social implications.

This research endeavour ambitiously aims to comprehensively address these challenges by meticulously investigating existing evaluation techniques, critically identifying their inherent weaknesses, and ingeniously proposing an enhanced decision-making framework for Sustainable Management Strategies in CDW. The overarching objectives of this study are multifaceted and multifarious, encompassing not only the formulation of decision matrices meticulously aligning diverse strategies with the intricate tapestry of CDW attributes but also the pioneering extension of existing decision-making methodologies to adeptly handle uncertainty and hesitation inherent in such complex domains. Moreover, the research ambitiously aims to pioneer the development of a robust and comprehensive decision-modelling approach that integrates disparate facets of CDW management, thereby providing a holistic perspective to decision-makers.

Furthermore, the proposed approach will undergo meticulous validation through a rigorous array of analytical techniques including sensitivity analysis, correlation assessment, systematic modelling, and comprehensive comparative analysis. Through these validation procedures, the proposed decision-modelling approach for Sustainable Management Strategies

in CDW will undergo thorough scrutiny, ensuring its robustness, reliability, and applicability in real-world scenarios.

Through this comprehensive research endeavour, we aim to meticulously unravel insights and methodologies that significantly contribute to the continual advancement of sustainable CDW management practices. Also, we aspire to not only foster informed decision-making but also actively promote the pivotal transition towards embracing a circular economy paradigm.

From the study findings, the benchmarking framework results provide a better perspective of the CDW management strategies than the literature on sustainability and waste management. The conclusions made of the research reveal that the strategies that relate to the economic, environmental, and technical factors including the Strategy4 and Strategy8 are in harmony with the literature that addresses cost concern and environmental impact. The study conducted by Rakhshan et al. (2020) and the study conducted by Huang et al. (2021) revealed that the cost and the environmental aspects should be minimized for the management of CDW. These strategies are in harmony with the literature that has transitioned to the acknowledgement of the double bottom-line of economic and environmental enhancement in the handling of wastes.

However, some of the strategies such as the Strategy21 and Strategy43 pay lesser attention to social aspect as compared to other literature that advocates for equal attention to social sustainability. Zhang et al. (2021) have noted that the social factors including community engagement and acceptance are crucial in waste management initiatives. This is an indication that although some of the strategies may not satisfy the social dimension of sustainability to

the optimum level, it shows an area that may be enhanced and made to be in par with the rest of the sustainability framework.

In the case of the q-ROPHFS-FWZIC and MULTIMOORA method analysis, the weight assigned to social attributes is also high and varies between 0.3205 and 0.5333, this is in concordance with other researchers who noted the social factors as relevant to waste management. This view is in tandem with Mishra, Rani, Pamucar, Hezam, & Saha (2022) who noted that community involvement and appreciation are paramount in WM intercessions. This agrees with the findings of this research whereby the management strategies of CDW are affected by risk and trust, which are social factors. The low values of organizational attributes (decreasing from 0.0194 to 0.0003) calculated in this research are significantly lower than the values presented in the literature that emphasizes the role of organizational structures. This is because of the regional or contextual variations which should be explored as to why the organizational factors are given a lesser priority in this study.

The complied weight is also high ranging from 0.6469 to 0.9013 pieces of literature that support the fact that regulation is a key driver of waste management. Barchiesi, Costa, & Di Pillo (2022) also found that compliance with environmental laws has a positive outcome in waste management. This is in line with the assertion and the findings of this study reveal that the level of compliance with regulations influences CDW management plans. The reduction of the willingness attribute from 0.0198 to 0.0003 is the reverse of literature that has identified willingness as a key attribute in waste management. S & AB (2017) stresses that the consumers' attitude and their willingness to engage in recycling activities is one of the factors. The lower weight in our study could mean regional differences or other variables that affect

the willingness differently and that is why we need to carry out more research to establish these differences.

The obtained rankings of strategies with Strategy46 being the most sustainable and Strategy17 being among the least sustainable, supports the findings of the literature that indicates that a set of social, economic and regulatory factors influences the sustainability rankings. However, the specific positioning of strategies may be shifted due to differences in the practices of the regions, policies and the participation of the stakeholders. This goes to show that geographical factors should be considered especially when comparing the waste management systems.

The sensitivity, correlation and systematic modelling analysis carried out to confirm the proposed MADM methods also confirm that they are credible and accurate. As supported by the sensitivity analysis by Afrasiabi, Tavana, & Di Caprio (2022), it can be seen that the alteration of the weights of the attributes influenced the modelling order of the CDW management strategies. Spearman's rho correlation of initial and new models varying from 0.9 to 1. The reliability of the results is supported by 0. The discrepancies with the VIKOR technique were the comparison of the ranking results, which proved the effectiveness of the developed q-ROPHFS–FWZIC in the multiple assessment attribute and the control of the informational fuzziness and ambiguity. The subjective comparison also gave the affirmation of the high level of the proposed method that met all 15 comparison points while the benchmark study only responded to 26. 7% of these points. These validation procedures are useful in establishing the reliability of the proposed framework in the ranking of sustainable CDW management strategies.

i. Investigation of existing evaluation techniques for Sustainable Management Strategies in Construction and Demolition Waste (CDW) and highlighting weaknesses:

In conducting an extensive and thorough review of existing evaluation techniques for Sustainable Management Strategies in CDW, several weaknesses and deficiencies have been identified. Firstly, it is evident that many of the existing techniques lack consideration for certain critical sustainability dimensions, encompassing social, economic, environmental, technical, and organizational aspects. This glaring oversight leads to an incomplete assessment of the overall sustainability impact of management strategies, undermining their effectiveness. Secondly, a pervasive issue revolves around the inadequate availability of data, particularly concerning CDW characteristics and management processes. This scarcity significantly hampers accurate evaluation and decision-making processes, hindering progress in sustainable CDW management initiatives. Thirdly, there exists a noticeable degree of subjectivity in the evaluation attributes employed within many techniques. This subjectivity introduces bias and undermines the reliability and objectivity of the assessment outcomes, thereby limiting their utility and applicability in practical settings. Addressing these identified weaknesses is not only crucial but imperative for enhancing the effectiveness, credibility, and robustness of evaluation techniques for Sustainable Management Strategies in CDW. From the findings, the study described the evaluation methods and mentioned major limitations of the existing approaches while conducting the research. It was pointed out that many techniques were inadequate for assessing some crucial sustainability dimensions, especially the social and organisational ones. Secondly, it was noted that there was insufficient information with regards to CDW attributes and management activities, which was cited as a major barrier to

assessment. The study also affirmed that subjectivity was prevalent especially in the attributes used in many of the techniques hence compromising the objectivity of the outcomes. These findings serve the objective of the paper by establishing the current gaps in the existing approaches and the consequent need to improve the evaluation of CDW management.

ii. Formulation of decision matrices based on the intersection of Sustainable Management Strategies in CDW systems with CDW attributes:

The formulation of decision matrices involves systematically categorizing Sustainable Management Strategies, encompassing methodologies like recycling, reuse, and waste-to-energy, based on their effectiveness in addressing specific CDW attributes. These attributes may encompass material type, volume, contamination level, and other pertinent factors relevant to CDW management. By meticulously mapping strategies against CDW attributes, decision matrices provide a structured framework for assessing the suitability of various management approaches in diverse contexts. This systematic and methodical approach facilitates informed decision-making and assists in identifying the most appropriate strategies for optimizing CDW management practices. This research effectively developed decision matrices that can classify different SMSs like recycling, reuse, waste to energy etc depending on the ability of the strategy to deal with certain attributes of CDW. This structured manner enables one to have a clear look at how various strategies fit into attributes such as type of material, volume and level of contamination. The decision matrices help in making the right decisions concerning the management of CDW by presenting a clear and structured approach to the decision-making process. This accomplishment is directly related to the goal of developing a systematic framework for evaluating management strategies.

iii. Formulation and extension of FWZIC method integrating with FDOSM-based

MULTIMOORA with q-ROPHFS:

To further enhance the evaluation process and bolster its effectiveness, the FWZIC (Fuzzy Weighted Z-Integral Compromise) method undergoes extension by seamlessly integrating it with the FDOSM (Fuzzy Delphi-based Ordered Weighted Similarity Measure) based MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form) approach. Moreover, the incorporation of q-ROPHFS (q-rung Orthopair Probabilistic Hesitant Fuzzy Set) significantly contributes to addressing uncertainty and hesitation inherent in decision-making scenarios. This comprehensive extension not only enables a more robust assessment of Sustainable Management Strategies in CDW but also allows for the consideration of multiple objectives while effectively handling fuzzy and hesitant information. The integration of these advanced methods markedly enhances the decision-making process, leading to more reliable and accurate evaluations of CDW management strategies. The research proposed therefore, the FDOSM based MULTIMOORA approach by integrating it with q-ROPHFS and FWZIC method. This extension reduces the vagueness and indecisiveness in decision making by enabling a proper and thorough analysis of Sustainable Management Strategies. The incorporation of these modern techniques enhances the efficiency of the assessment, which is a great achievement towards the goal of creating a better decision-making model.

iv. Development of decision-modelling approach for Sustainable Management Strategies in

CDW using formulated decision matrices and integrated methods:

Building upon the foundational decision matrices formulated earlier and leveraging the integrated FWZIC-FDOSM-MULTIMOORA with q-ROPHFS method, a sophisticated decision-modelling framework is meticulously crafted. This framework not only enables the thorough evaluation and prioritization of Sustainable Management Strategies in CDW but also ensures alignment with predefined criteria and objectives. By harnessing structured decision matrices and seamlessly integrating advanced methodologies, the framework empowers stakeholders to engage in systematic and transparent decision-making processes. It offers stakeholders a comprehensive understanding of the multifaceted implications and trade-offs associated with various management strategies, thereby facilitating the judicious selection of the most suitable approaches for advancing sustainability in CDW management. The research introduced a comprehensive decision-modelling approach that is founded on the decision matrices and incorporated methods, which include FWZIC-FDOSM-MULTIMOORA with q-ROPHFS. It enables one to evaluate and sort the Sustainable Management Strategies in CDW based on the set criteria and objectives. It is an analytical tool named after the fact that it is used to determine the costs and outcomes of the strategies that are used in a business decision. This development meets the intended objective of providing a sound decision-modelling framework for the sustainability of CDW management.

v. Validation of the proposed decision modelling approach for Sustainable Management Strategies in CDW using Sensitivity and Correlation Analysis, Systematic modelling, and comparison analysis:

To validate and confirm the reliability of the decision-modelling approach that has been proposed in this study, the research used Sensitivity and Correlation Analysis, Systematic

Strategy10	9	Moderate	Medium	Medium	Moderate	High	Medium	High
Strategy11	11	Moderate	Low	High	High	Medium	High	Medium
Strategy12	6	High	Medium	High	Moderate	High	Medium	High
Strategy13	13	Low	Low	Medium	Low	Low	Medium	Low
Strategy14	4	High	High	High	High	High	High	Medium
Strategy15	1	Very High	Very High	Very High	Very High	Very High	Very High	Very High

7.3 Theoretical Contributions

The primary contribution of this research lies in the creation of an advanced benchmarking framework specifically designed for the complex field of Construction and Demolition Waste (CDW) management strategies. This was achieved through the integration of the q-ROPHFS–FDOSM-based MULTIMOORA method with the innovative q-ROPHFS–FWZIC method. The result is a framework that effectively addresses the challenges of benchmarking CDW management strategies, providing stakeholders with a reliable tool for selecting secure and sustainable systems.

This research makes significant contributions in three key areas, ***Decision Matrix Development***: A robust decision matrix is developed, strategically positioned at the intersection of CDW management strategies and the various barrier attributes associated with reuse distribution. Multiple matrices are crafted to address the primary and sub-barrier attributes, providing a comprehensive evaluation that considers economic, environmental, organizational, regulatory, social, and technical factors. The barrier attributes are weighted using the q-ROPHFS–FWZIC method, and these weights are then applied in the q-ROPHFS–

MULTIMOORA method to benchmark the sustainability of different CDW management strategies.

Innovative Weighting Method: The introduction of the q-ROPHFS-FWZIC method represents a significant advancement in addressing the importance of attribute weighting. This method systematically prioritizes and assigns weights to the barrier attributes of reuse distribution in CDW management strategies, ensuring that the evaluation process is finely tuned to reflect the complexities of the field. These weights are then integrated into the scoring mechanism of the q-ROPHFS–FDOSM method, further refining the assessment of CDW management strategies.

Integrated Decision-Modelling Approach: The combination of the q-ROPHFS–FDOSM-based MULTIMOORA method with the q-ROPHFS–FWZIC method results in a comprehensive decision-modelling approach. This integrated framework models CDW management strategies to identify the most and least sustainable options by analysing decision matrices and computed scores, leveraging the advanced capabilities of the MULTIMOORA method. The resulting benchmarking framework is a testament to the meticulous research conducted, covering all aspects of CDW management strategy with exceptional precision.

This research not only advances the field of decision-making but also applies this knowledge to the practical and complex domain of CDW reuse distribution within management strategies. The development of this benchmarking framework represents a significant step toward more sustainable and resilient CDW management practices.

7.4 Practical Contributions

The results of this study would likely benefit a variety of stakeholders involved in the

construction industry, including construction companies, architects and engineers, policymakers, and members of the public. **First**, the study found that addressing social and economic concerns and ensuring compliance with regulations may be vital in implementing sustainable CDW management strategies. Construction companies could use this information to prioritise these areas in their CDW management plans and practices, potentially leading to more sustainable and efficient waste management. Furthermore, the study found that the risk attribute under the social attribute was the most influential in determining the sustainability of CDW management strategies for reuse. Construction companies could use this information to focus on reducing the perceived risks of their CDW management practices to the public and other stakeholders, which could improve public trust and willingness to support sustainable CDW management. Additionally, the study designated the importance of the cost attribute under the economic attribute and the experience attribute under the organisational attribute. Based on these findings, construction companies might concentrate on reducing the cost of their CDW management procedures and developing experience and skills in CDW management. Furthermore, construction companies could improve their reputation, comply with regulations, save money, and help preserve the environment and natural resources.

Second, architects and engineers could use the findings to design buildings and infrastructures to reduce CDW generation and improve their performance. The social attribute, specifically, the risk attribute, was the most influential in determining the sustainability of CDW management strategies for reuse, followed by the economic attribute. Considering this aspect, architects and engineers could design buildings and infrastructures to reduce the perceived risks of CDWs generation, which could improve public trust and willingness to support sustainable CDW management. Additionally, the technical attributes were crucial in

determining the sustainability of CDW management strategies for reuse, specifically, the health-and-safety attribute. This insight could help architects and engineers design buildings and infrastructures with a focus on health and safety during the deconstruction and demolition process. Architects and engineers could also use the findings to design buildings and infrastructures that are easier to deconstruct and recycle, reducing the cost of CDW management and increasing the value for money of the building or infrastructure. This approach would optimise the use of resources and reduce waste in the construction process.

Third, the regulatory attribute, specifically, the compliance attribute, was the most influential amongst all sub-attributes. This finding could help policymakers concentrate on ensuring that rules governing CDW management are followed, which would increase the sustainability of CDW management strategies. Additionally, the economic attribute, specifically, the cost attribute, was important. Policymakers could use this information to focus on reducing the cost of CDW management, which could improve the efficiency and sustainability of the construction industry. Additionally, policymakers can make informed decisions about which strategies to implement to manage CDWs in a sustainable manner. The study can also help policymakers identify and overcome the barriers to reusing CDWs, which can lead to cost savings and reduced environmental effect. Furthermore, policymakers can improve compliance with environmental regulations and laws related to CDW management. Through achieving this objective, construction companies would improve their reputation and image by demonstrating a commitment to sustainable practices and reducing the environmental effect of their operations.

Fourth, the members of the public could benefit from the results by living in a more environmentally friendly and sustainable urban environment, with reduced toxic gas

emissions, energy consumption and water pollution. The results indicated that the social attribute, specifically, the risk attribute, was the most influential in determining the sustainability of CDW management strategies for reuse, followed by the economic attribute. Considering this aspect, members of the public could benefit from reduced perceived risks associated with CDW management, which could improve public trust and willingness to support sustainable CDW management. Furthermore, members of the public could benefit from improved compliance with regulations related to CDW management by addressing the compliance attribute as the most influential amongst all sub-attributes. This approach can lead to better waste management and a more sustainable urban environment. Overall, public members can live in a cleaner, greener, and healthier urban environment by implementing sustainable CDW management strategies, preserving the environment, economy, natural resources, society, and health.

The studies have the potential to be extremely beneficial to a wide range of construction industry stakeholders, including policymakers, the public, and construction companies. Building companies can learn how to drive sustainable CDW management practices by taking social and economic issues into account in addition to regulatory compliance. They can improve waste management's reputation and efficiency while cutting expenses and its negative effects on the environment by giving priority to these areas. The study's conclusions can be used by engineers and architects to create structures and systems that reduce the production of CDW and improve performance by reducing perceived risks and placing a strong emphasis on health and safety issues. These insights can be used by policymakers to create regulations that support sustainable CDW management, increasing industry productivity and improving environmental results. Ultimately, improved waste

management techniques and decreased pollution can lead to a cleaner, greener urban environment for the public. These improvements are supported by increased public trust in sustainable CDW management strategies and increased compliance.

7.5 Limitations of the Research

This research introduces a benchmarking framework for managing Construction and Demolition Waste (CDW) strategies. The framework combines q-ROPHFS–FWZIC and q-ROPHFS–FDOSM using MULTIMOORA. Despite facing limitations and obstacles in the implementation phase, the specific challenges are delineated below and can be addressed in future endeavours.

- i. Only the q-ROPHFAM operator and q-ROPHFS scoring function were applied in the formulation of the q-ROPHFS–FWZIC method.
- ii. Only the q-ROPHFEAM operator and q-ROPHFS scoring function were applied in the formulation of q-ROPHFS–FDOSM.
- iii. The final modelling of the CDW management strategies acquired using MULTIMOORA was based on the aggregation of dominance theory only.
- iv. All the experts/DMs received equal treatment, regardless of their level of expertise.
- v. The opinion matrix of the CDW management strategies and EDM was constructed using five linguistic expressions and numeric scales only.

Due to the exploratory nature of this study, the mentioned limitations have exerted a partial influence on the current findings. These constraints highlight undiscovered and emerging challenges, emphasizing the necessity for further exploratory studies to guide additional research directions. Despite these limitations, the results remain reliable and valid.

The limitations have partially impacted on the current findings because of the exploratory nature of this study. These limitations draw attention to new and unexplored problems and highlight the need for more exploratory research to inform future directions for the field. These restrictions don't affect the results' validity or reliability. In addition, these limitations might be addressed by broadening the study's scope to include a larger sample size or adding more variables for a more thorough analysis. Furthermore, longitudinal studies to evaluate the sustainability and long-term efficacy of CDW management strategies may be the focus of future research initiatives. The viewpoints of various stakeholders, including waste management experts, regional communities, and governmental organizations, should also be investigated as this could offer insightful information about the complex dynamics of sustainable CDW management. In general, the recognition and resolution of these constraints will enhance and progress the understanding of sustainable building and waste control.

7.6 Future Work

This study serves as a foundation for inspiring further research in the future. Here are some potential avenues for exploration:

- i. The integration of additional operators with the q-ROPHFS–FWZIC method and q-ROPHFS–FDOSM could be explored to enhance the aggregation and defuzzification of values.
- ii. Experimenting with alternative aggregation methods, such as Borda and improved Borda Rules or the model position method, in conjunction with MULTIMOORA could provide valuable insights into modelling CDW management strategies.

- iii. Prioritizing and weighting decision-makers based on their experience levels could offer a more nuanced approach to decision-making in the context of CDW management.
- iv. Constructing the opinion matrix of CDW management strategies and Environmental Decision Making (EDM) using varied linguistic expressions and numeric scales, including seven or 11, could contribute to a more comprehensive understanding of the decision-making process.
- v. The proposed framework has the potential to be utilized for benchmarking innovative systems across different categories within the Construction and Demolition Waste (CDW) Industry.

Future research endeavours will be motivated by the findings of this study. Here are a few possible directions to research:

To improve the aggregation and defuzzification of values, it may be possible to integrate extra operators with the q-ROPHFS–FWZIC method and q-ROPHFS–FDOSM. Other operators that could be included in the methodological framework to better handle uncertainty and hesitation are interval-valued hesitant fuzzy sets and hesitant fuzzy linguistic term sets. Furthermore, investigating hybrid approaches that integrate several operators may result in more resilient and adaptable models for sustainable CDW management decision-making. Combining MULTIMOORA with other aggregation techniques, like the model position approach, may yield insightful results for modelling CDW management tactics. Researchers can determine which aggregation technique is best for evaluating and ranking sustainable strategies by testing various approaches and determining how well they capture the complexity of CDW

management decision-making processes. Furthermore, examining how various weighting schemes affect the results of decisions could improve the method's adaptability and suitability in a variety of situations.

References

- Abdulkareem, K. H., Arbaay, N., Zaidan, A. A., Zaidan, B. B., Albahri, O. S., Alsalem, M. A., Salih, M. M. (2020). A Novel Multi-Perspective Benchmarking Framework for Selecting Image Dehazing Intelligent Algorithms Based on BWM and Group VIKOR Techniques. *International Journal of Information Technology & Decision Making*, 19, 909–957. <https://doi.org/10.1142/S0219622020500169>
- Ajayi, S. O., Oyedele, L. O., Bilal, M., Akinade, O. O., Alaka, H. A., Owolabi, H. A., & Kadiri, K. O. (2015). Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements. *Resources, Conservation and Recycling*, 102, 101–112. <https://doi.org/10.1016/j.resconrec.2015.06.001>
- Ajayi, S.O., Oyedele, L.O., Akinade, O.O., Bilal, M., Owolabi, H.A., Alaka, H.A., Kadiri, K.O. (2016). Reducing waste to landfill: A need for cultural change in the UK construction industry. *Journal of Building Engineering*, 5, 185–193. <https://doi.org/10.1016/j.jobe.2015.12.007>.
- Akinade, O. O., & Oyedele, L. O. (2019). Integrating construction supply chains within a circular economy: An ANFIS-based waste analytics system (A-WAS). *Journal of Cleaner Production*, 229, 863–873. <https://doi.org/10.1016/j.jclepro.2019.04.232>
- Alaa, M., Albakri, I. S. M. A., Singh, C. K. S., Hammed, H., Zaidan, A. A., Zaidan, B. B., Albahri, O. S., Alsalem, M. A., Salih, M. M., Almahdi, E. M., Baqer, M. J., Jalood, N. S., Nidhal, S., Shareef, A. H., Jasim, A. N. (2019). Assessment and modeling Framework for the English Skills of Pre-Service Teachers Based on Fuzzy Delphi and TOPSIS Methods. *IEEE Access*, 7, 126201–126223.

<https://doi.org/10.1109/ACCESS.2019.2936898>

- Alamleh, A., Albahri, O. S., Zaidan, A. A., Alamoodi, A. H., Albahri, A. S., Zaidan, B. B., Qahtan, S., Ismail, A. R. B., Malik, R. Q., Baqer, M. J., Jasim, A. N., & Al-Samarraay, M. S. (2022). Multi-attribute decision-making for intrusion detection systems: A systematic review. *International Journal of Information Technology and Decision Making*. <https://doi.org/10.1142/S021962202230004X>.
- Alamleh, A., Albahri, O. S., Zaidan, A. A., Albahri, A. S., Alamoodi, A. H., Zaidan, B. B., Qahtan, S., Alsatar, H. A., Al-Samarraay, M. S., Jasim, A. N. (2022). Federated Learning for IoMT Applications: A Standardisation and Benchmarking Framework of Intrusion Detection Systems. *IEEE Journal of Biomedical and Health Informatics*, 26 (1), 1–1. <https://doi.org/10.1109/JBHI.2022.3167256>
- Albahri, A. S., Zaidan, A. A., AlSattar, H. A., Hamid, R. A., Albahri, O. S., Qahtan, S., Alamoodi, A. H. (2022). Towards physician's experience: Development of machine learning model for the diagnosis of autism spectrum disorders based on complex T-spherical fuzzy-weighted zero-inconsistency method. *Computational Intelligence*. <https://doi.org/10.1111/coin.12562>.
- Albahri, O. S., Zaidan, A. A., Salih, M. M., Zaidan, B. B., Khatari, M. A., Ahmed, M. A., Albahri, A. S., & Alazab, M. (2021). Multidimensional benchmarking of the active queue management methods of network congestion control based on extension of fuzzy decision by opinion score method. *International Journal of Intelligent Systems*, 36(5), 796–831. <https://doi.org/10.1002/int.22322>.
- Almahdi, E. M., Zaidan, A. A., Zaidan, B. B., Alsalem, M. A., Albahri, O. S., Albahri, A. S., et al. (2019). Mobile-Based Patient Monitoring Systems: A Prioritisation Framework

Using Multi-Criteria Decision-Making Techniques. *J. Med. Syst.*, 43, 1–19.

<https://doi.org/10.1007/s10916-019-1339-9>.

Almahdi, E. M., Zaidan, A. A., Zaidan, B. B., Alsalem, M. A., Albahri, O. S., Albahri, A. S., et al. (2019). Mobile Patient Monitoring Systems from a Benchmarking Aspect: Challenges, Open Issues and Recommended Solutions. *J. Med. Syst.*, 43, 1–23.

<https://doi.org/10.1007/s10916-019-1336-z>.

Alnoor, A., Zaidan, A. A., Qahtan, S., Alsattar, H. A., Mohammed, R. T., K, K. W., Alazab, M., Y., T. S., & Albahri, A. S. (2022). Toward a sustainable transportation industry: Oil company benchmarking based on the extension of linear Diophantine fuzzy rough sets and multicriteria decision-making methods. *IEEE Transactions on Fuzzy Systems*. <https://doi.org/10.1109/TFUZZ.2022.3182778>.

Alsalem, M. A., Zaidan, A. A., Zaidan, B. B., Albahri, O. S., Alamoodi, A. H., Albahri, A. S., et al. (2019). Multiclass Benchmarking Framework for Automated Acute Leukaemia Detection and Classification Based on BWM and Group-VIKOR. *J. Med. Syst.*, 43, 1–32. <https://doi.org/10.1007/s10916-019-1338-x>.

Alsattar, H. A., Qahtan, S., Mohammed, R. T., Zaidan, A. A., Albahri, O. S., Kou, G., Alamoodi, A. H., Albahri, A. S., Zaidan, B. B., Al-Samarraay, M. S., Malik, R. Q., Jasim, A. N. (2022). Integration of FDOSM and FWZIC Under Homogeneous Fermatean Fuzzy Environment: A Prioritization of COVID-19 Patients for Mesenchymal Stem Cell Transfusion. *International Journal of Information Technology & Decision Making*. <https://doi.org/10.1142/S0219622022500511>

AlSereidi, A., Salih, S. Q. M., Mohammed, R. T., Zaidan, A. A., Albayati, H., Pamucar, D., ... Al-Samarraay, M. S. (2022). Novel Federated Decision Making for Distribution of

- Anti-SARS-CoV-2 Monoclonal Antibody to Eligible High-Risk Patients. *International Journal of Information Technology & Decision Making*. Advance online publication. <https://doi.org/10.1142/S021962202250050X>
- Arif, M., Bendi, D., Toma-Sabbagh, T., & Sutrisna, M. (2012). Construction waste management in India: An exploratory study. *Construction Innovation*, 12, 133–155. <https://doi.org/10.1108/14714171211215912>
- Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20, 87–96. [https://doi.org/10.1016/S0165-0114\(86\)80034-3](https://doi.org/10.1016/S0165-0114(86)80034-3)
- Atanassov, K. T. (2016). Intuitionistic fuzzy sets. *International Journal of Bioautomation*, 20 (S1-S6). https://doi.org/10.1007/978-3-7908-1870-3_1
- Attaullah, Ashraf, S., Rehman, N., Alsalman, H., Gumaei, A. H. (2022). A Decision-Making Framework Using q-Rung Orthopair Probabilistic Hesitant Fuzzy Rough Aggregation Information for the Drug Selection to Treat COVID-19. *Complexity*, 2022, Article 5556309. <https://doi.org/10.1155/2022/5556309>.
- Baqer, N. S., Albahri, A. S., Mohammed, H. A., Zaidan, A. A., Amjed, R. A., Al-Bakry, A., Albahri, O. S., Alsattar, H. A., Alnoor, A., Alamoodi, A. H., Zaidan, B. B., Malik, R. Q., & Kareem, Z. H. (2022/12//). Indoor air quality pollutants predicting approach using unified labelling process-based multi-criteria decision making and machine learning techniques. *Telecommunication Systems*, 81(4), 591-613. <https://doi.org/10.1007/s11235-022-00959-2>.
- Basta, A., Serror, M. H., & Marzouk, M. (2020). A BIM-based framework for quantitative assessment of steel structure deconstructability. *Automation in Construction*, 111. <https://doi.org/10.1016/j.autcon.2019.103064>.

- Brambilla, G., Lavagna, M., Vasdravellis, G., & Castiglioni, C. A. (2019). Environmental benefits arising from demountable steel-concrete composite floor systems in buildings. *Resources, Conservation and Recycling*, 141, 133–142.
<https://doi.org/10.1016/j.resconrec.2018.10.014>.
- Brauers, W. K. M., & Zavadskas, E. K. (2011). Multimooora optimization used to decide on a bank loan to buy property. *Technological and Economic Development of Economy*, 17(1), 174–188. <https://doi.org/10.3846/13928619.2011.560632>.
- Brauers, W. K. M., & Zavadskas, E. K. (2012). Robustness of MULTIMOORA: A method for multi-objective optimization. *Informatica*, 23(1), 1–25.
<https://doi.org/10.15388/informatica.2012.346>.
- Brütting, J., Desruelle, J., Senatore, G., & Fivet, C. (2019). Design of truss structures through reuse. *Structures*, 18, 128–137. <https://doi.org/10.1016/j.istruc.2018.11.006>.
- Chen, J., Su, Y., Si, H., & Chen, J. (2018). Managerial Areas of Construction and Demolition Waste: A Scientometric Review. *International Journal of Environmental Research and Public Health*, 15(11), 2350. <https://doi.org/10.3390/ijerph15112350>.
- Chen, Z. S., Zhang, X., Rodríguez, R. M., Pedrycz, W., Martínez, L., & Skibniewski, M. J. (2022). Expertise-structure and risk-appetite-integrated two-tiered collective opinion generation framework for large-scale group decision making. *IEEE Transactions on Fuzzy Systems*, 30(12), 5496–5510.
- Chileshe, N., Rameezdeen, R., & Hosseini, M. R. (2015). Barriers to implementing reverse logistics in South Australian construction organizations. *Supply Chain Management*, 20, 179–204. <https://doi.org/10.1108/SCM-10-2014-0325>
- Chileshe, N., Rameezdeen, R., & Hosseini, M. R. (2016). Drivers for adopting reverse

- logistics in the construction industry: A qualitative study. *Engineering, Construction and Architectural Management*, 23, 134–157. <https://doi.org/10.1108/ECAM-06-2014-0087>
- Chinda, T., & Ammarapala, V. (2016). Decision-making on reverse logistics in the construction industry. *Songklanakarin Journal of Science and Technology*, 38, 7–14. <https://www.thaiscience.info/journals/Article/SONG/10981871>
- Chini, A. R., & Acquaye, L. (2001). Grading and strength of salvaged lumber from residential buildings. *Environmental Practice*, 3 (4), 247–256. <https://doi.org/10.1017/S1466046600002805>.
- Coelho, A., & De Brito, J. (2012). Influence of construction and demolition waste management on the environmental impact of buildings. *Waste Management*, 32(3), 532–541. <https://doi.org/10.1016/j.wasman.2011.11.011>.
- Cooper, S., Skelton, A. C. H., Owen, A., Densley-Tingley, D., & Allwood, J. M. (2016). A multi-method approach for analysing the potential employment impacts of material efficiency. *Resources, Conservation & Recycling*, 109, 54–66. <https://doi.org/10.1016/j.resconrec.2015.11.014>.
- Cosgun, N., Ipekci, C.A., Karadayi, T. (2020). Turkish architects' views on construction and demolition waste reduction in the design stage. *Environmental Engineering and Management Journal*, 19, 439–452. <https://doi.org/10.30638/eemj.2020.042>.
- da Rocha, C. G., Sattler, M. A. (2009). A discussion on the reuse of building components in Brazil: An analysis of major social, economical and legal factors. *Resources, Conservation & Recycling*, 54, 104–112. <https://doi.org/10.1016/j.resconrec.2009.07.004>

- Dantata, N., Touran, A., & Wang, J. (2005). An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts. *Resources, Conservation & Recycling*, 44(1), 1–15.
<https://doi.org/10.1016/j.resconrec.2004.09.001>.
- DEFRA. (2019). UK statistics on waste. Government Statistical Service, 1–10. Retrieved from <https://www.gov.uk/government/collections/waste-and-recycling-statistics> (Accessed January 3, 2023).
- Densley Tingley, D., Cooper, S., & Cullen, J. (2017). Understanding and overcoming the barriers to structural steel reuse, a UK perspective. *Journal of Cleaner Production*, 148, 642–652. <https://doi.org/10.1016/j.jclepro.2017.02.006>.
- Deveci, M., Gokasar, I., Castillo, O., & Daim, T. (2022). Evaluation of Metaverse integration of freight fluidity measurement alternatives using fuzzy Dombi EDAS model. *Computers & Industrial Engineering*, 174, 108773.
<https://doi.org/10.1016/j.cie.2022.108773>.
- Duan, H., Li, J. (2016). Construction and demolition waste management: China's lessons. *Waste Management & Research*, 34, 397–398.
<https://doi.org/10.1177/0734242X16647603>.
- Dunant, C. F., Drewniok, M. P., Sansom, M., Corbey, S., Allwood, J. M., & Cullen, J. M. (2017). Real and perceived barriers to steel reuse across the UK construction value chain. *Resources, Conservation and Recycling*, 126, 118–131.
<https://doi.org/10.1016/j.resconrec.2017.07.036>.
- Dunant, C. F., Drewniok, M. P., Sansom, M., Corbey, S., Cullen, J. M., & Allwood, J. M. (2018). Options to make steel reuse profitable: An analysis of cost and risk distribution

- across the UK construction value chain. *Journal of Cleaner Production*, 183, 102–111.
<https://doi.org/10.1016/j.jclepro.2018.02.141>.
- Durão, V., Caixinhas, J., Osório-Peters, S., Den Boer, E., Williams, I. D., Curran, T., & Pertl, A. (2014). Zero-waste networks in construction and demolition in Portugal. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, 167, 153–168. <https://doi.org/10.1680/warm.13.00032>
- Eghbali-Zarch, M., Tavakkoli-Moghaddam, R., Dehghan-Sanej, K., & Kaboli, A. (2021). Prioritizing the effective strategies for construction and demolition waste management using fuzzy IDOCRIW and WASPAS methods. *Engineering Construction and Architectural Management*. <https://doi.org/10.1108/ecam-08-2020-0617>
- Elias Özkan, S. T. (2012). Selective demolition of redundant and earthquake damaged buildings in Turkey. *METU Journal of the Faculty of Architecture*, 29, 139–152.
<https://doi.org/10.4305/METU.JFA.2012.1.8>
- Ferreira, J., Pinheiro, M.D., & De Brito, J. (2015). Economic and environmental savings of structural buildings refurbishment with demolition and reconstruction - A Portuguese benchmarking. *Journal of Building Engineering*, 3, 114–126.
<https://doi.org/10.1016/j.jobbe.2015.07.001>.
- Forsythe, P. (2011). Drivers of housing demolition decision making and the impact on timber waste management. *Australasian Journal of Construction Economics and Building*, 11(1), 1–14. <https://doi.org/10.5130/ajceb.v11i1.1660>
- Gálvez-Martos, J. L., Styles, D., Schoenberger, H., & Zeschmar-Lahl, B. (2018). Construction and demolition waste best management practice in Europe. *Resources, Conservation & Recycling*, 136, 166–178. <https://doi.org/10.1016/j.resconrec.2018.04.016>.

- Gangoellis, M., Casals, M., Forcada, N., & Macarulla, M. (2014). Analysis of the implementation of effective waste management practices in construction projects and sites. *Resources, Conservation & Recycling*, 93, 99–111.
<https://doi.org/10.1016/j.resconrec.2014.10.006>.
- Ghailani, H., Zaidan, A. A., Qahtan, S., Alsattar, H. A., Al-Emran, M., Deveci, M., & Delen, D. (2023). Developing sustainable management strategies in construction and demolition wastes using a q-rung orthopair probabilistic hesitant fuzzy set-based decision modelling approach. *Applied Soft Computing*, 145, 110606. <https://www.sciencedirect.com/science/article/pii/S1568494623006245?via%3Dihub>
- Gorgolewski, M. (2008). Designing with reused building components: Some challenges. *Building Research & Information*, 36(2), 175–188.
<https://doi.org/10.1080/09613210701559499>.
- Gorgolewski, M., Straka, V., Edmonds, J., & Sergio-Dzoutzidis, C. (2008). Designing buildings using reclaimed steel components. *Journal of Green Building*, 3(3), 97–107.
<https://doi.org/10.3992/jgb.3.3.97>
- Guy, B. (2006). The optimization of building deconstruction for department of defense facilities: FT. McClellan deconstruction project. *Journal of Green Building*, 1(1), 102–122. <https://doi.org/10.3992/jgb.1.1.102>.
- Hafezalkotob, A., Hafezalkotob, A., Liao, H., & Herrera, F. (2019). An overview of MULTIMOORA for multi-criteria decision-making: Theory, developments, applications, and challenges. *Information Fusion*, 51, 145–177.
<https://doi.org/10.1016/j.inffus.2018.12.002>.

- Höglmeier, K., Weber-Blaschke, G., & Richter, K. (2013). Potentials for cascading of recovered wood from building deconstruction - A case study for south-east Germany. *Resources, Conservation & Recycling*, 78, 81–91.
<https://doi.org/10.1016/j.resconrec.2013.07.004>.
- Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., & Ren, J. (2018). Construction and demolition waste management in China through the 3R principle. *Resources, Conservation and Recycling*, 129, 36–44.
<https://doi.org/10.1016/j.resconrec.2017.09.029>.
- Huuhka, S., Hakanen, J. H., & Lahdensivu, J. (2015). Potential and barriers for reusing loadbearing building components in Finland. *International Journal of Housing Science and Its Applications*, 39, 215–224. <https://doi.org/10.1016/j.jclepro.2017.08.084>
- Huuhka, S., Kaasalainen, T., Hakanen, J. H., & Lahdensivu, J. (2015). Reusing concrete panels from buildings for building: Potential in Finnish 1970s mass housing. *Resources, Conservation and Recycling*, 101, 105–121.
<https://doi.org/10.1016/j.resconrec.2015.05.017>
- Ibrahim, H. A., Zaidan, A. A., Qahtan, S., Zaidan, B. B., & Zaidan, A. A. (2023). Sustainability assessment of palm oil industry 4.0 technologies in circular economy applications based on interval-valued Pythagorean fuzzy rough set-FWZIC and EDAS methods. *Applied Soft Computing*, 130, 110073.
<https://doi.org/10.1016/j.asoc.2023.110073>.
- Jaillon, L., & Poon, C.S. (2010). Design issues of using prefabrication in Hong Kong building construction. *Construction Management and Economics*, 28(10), 1025–1042.
<https://doi.org/10.1080/01446193.2010.498481>.

- Jaillon, L., & Poon, C.S. (2014). Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong. *Automation in Construction*, 39, 195–202.
<https://doi.org/10.1016/j.autcon.2013.09.006>.
- Jin, R., Li, B., Zhou, T., Wanatowski, D., & Piroozfar, P. (2017). An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. *Resources, Conservation and Recycling*, 126, 86–98.
<https://doi.org/10.1016/j.resconrec.2017.07.034>.
- Jin, R., Yuan, H., Chen, Q. (2019). Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018. *Resources, Conservation & Recycling*, 140, 175–188.
<https://doi.org/10.1016/j.resconrec.2018.09.029>.
- Jumaah, F. M., Zadain, A. A., Zaidan, B. B., Hamzah, A. K., Bahbib, R. (2018). Decision-making solution based multi-measurement design parameter for optimization of GPS receiver tracking channels in static and dynamic real-time positioning multipath environment. *Measurement*, 118, 83–95.
<https://doi.org/10.1016/j.measurement.2018.01.011>
- Jumaah, F. M., Zaidan, A. A., Zaidan, B. B., Bahbib, R., Qahtan, M. Y., & Sali, A. (2018). Technique for order performance by similarity to ideal solution for solving complex situations in multi-criteria optimization of the tracking channels of GPS baseband telecommunication receivers. *Telecommunication Systems*, 68, 425–443.
<https://doi.org/10.1007/s11235-017-0401-5>.
- Kabirifar, K., Mojtahedi, M., Wang, C., Tam, V.W.Y. (2020). Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle

- strategies for effective waste management: A review. *Journal of Cleaner Production*, 263. <https://doi.org/10.1016/j.jclepro.2020.121265>.
- Kahraman, Y. R. (2002). Robust Sensitivity Analysis for Multi-Attribute Deterministic Hierarchical Value Models [Doctoral dissertation, Air Force Institute of Technology, Wright-Patterson AFB, OH]. Retrieved from <http://www.dtic.mil/dtic/tr/fulltext/u2/a400032.pdf>.
- Karaca, F., & Tleuken, A. (2024). Reforming Construction Waste Management for Circular Economy in Kazakhstan: A Cost–Benefit Analysis of Upgrading Construction and Demolition Waste Recycling Centres. *Recycling*, 9(1), 2. <https://doi.org/10.3390/recycling9010002>.
- Khatari, M., Zaidan, A. A., Zaidan, B. B., Albahri, O. S., & Alsalem, M. A. (2019). Multi-Criteria Evaluation and Benchmarking for Active Queue Management Methods: Open Issues, Challenges and Recommended Pathway Solutions. *Int. J. Inf. Technol. Decis. Mak.*, 18, 1187–1242. <https://doi.org/10.1142/S0219622019300039>.
- Klang, A., Vikman, P. Å., & Brattembø, H. (2003). Sustainable management of demolition waste - An integrated model for the evaluation of environmental, economic and social aspects. *Resources, Conservation & Recycling*, 38 (4), 317–334. [https://doi.org/10.1016/S0921-3449\(02\)00167-2](https://doi.org/10.1016/S0921-3449(02)00167-2).
- Klein, J. H., & Kirkwood, C. W. (1998). Strategic Decision Making Multiobjective Decision Analysis with Spreadsheets. *Journal of the Operational Research Society*, 49 (1), 96. <https://doi.org/10.2307/3010661>
- Liu, D., Peng, D., & Liu, Z. (2019). The distance measures between q-rung orthopair hesitant fuzzy sets and their application in multiple criteria decision making. *International*

- Journal of Intelligent Systems, 34 (13), 2104–2121. <https://doi.org/10.1002/int.22133>.
- Liu, S., Yu, W., Liu, L., & Hu, Y. (2019). Variable weights theory and its application to multi-attribute group decision making with intuitionistic fuzzy numbers on determining decision maker's weights. *PloS one*, 14(3), e0212636. <https://doi.org/10.1371/journal.pone.0212636>.
- Machado, R. C., de Souza, H. A., & de S. Veríssimo, G. (2018). Analysis of guidelines and identification of characteristics influencing the deconstruction potential of buildings. *Sustainability*, 10, 2604. <https://doi.org/10.3390/su10082604>.
- MacKinnon, C. T. (2000). School construction and waste diversion: An interorganizational perspective. *Environment and Planning B: Planning and Design*, 27 (6), 877–891. <https://doi.org/10.1068/b2679>.
- Mahmoud, U. S., Albahri, A. S., Alsattar, H. A., Zaidan, A. A., Talal, M., Mohammed, R. A., Albahri, O. S., Zaidan, B. B., Alamoodi, A. H., Qahtan, S. (2022). DAS benchmarking methodology based on FWZIC II and FDOSM II to support industrial community characteristics in the design and implementation of advanced driver assistance systems in vehicles. *Journal of Ambient Intelligence and Humanized Computing*.
- Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resources, Conservation & Recycling*, 134, 216–227. <https://doi.org/10.1016/j.resconrec.2018.01.026>.
- Menegaki, M., Damigos, D. (2018). A review on current situation and challenges of construction and demolition waste management. *Current Opinion in Green and Sustainable Chemistry*, 13, 8–15. <https://doi.org/10.1016/j.cogsc.2018.02.010>.
- Meng, Y., Ling, T.C., Mo, K.H. (2018). Recycling of wastes for value-added applications in

- concrete blocks: An overview. *Resources, Conservation & Recycling*, 138, 298–312.
<https://doi.org/10.1016/j.resconrec.2018.07.029>.
- Mohammed, R. T., Zaidan, A. A., Yaakob, R., Sharef, N. M., Abdullah, R. H., Zaidan, B. B., Albahri, O. S., & Abdulkareem, K. H. (2022). Determining Importance of Many-Objective Optimisation Competitive Algorithms Evaluation Criteria Based on a Novel Fuzzy-Weighted Zero-Inconsistency Method. *International Journal of Information Technology & Decision Making*, 21(1), 195–241.
<https://doi.org/10.1142/S0219622021500140>.
- Napi, N. M., Zaidan, A. A., Zaidan, B. B., Albahri, O. S., Alsalem, M. A., Albahri, A. S., et al. (2019). Medical emergency triage and patient prioritisation in a telemedicine environment: A systematic review. *Health Technol. (Berl)*, 9, 679–700.
<https://doi.org/10.1007/s12553-019-00357-w>.
- Nikmehr, B., Hosseini, M.R., Rameezdeen, R., Chileshe, N., Ghoddousi, P., & Arashpour, M. (2017). An integrated model for factors affecting construction and demolition waste management in Iran. *Engineering, Construction and Architectural Management*, 24, 1246–1268. <https://doi.org/10.1108/ECAM-01-2016-0015>.
- Nordby, A. S., Berge, B., Hakonsen, F., & Hestnes, A. G. (2009). Criteria for salvageability: The reuse of bricks. *Building Research & Information*, 37, 55–67.
<https://doi.org/10.1080/09613210802476023>
- Nußholz, J. L. K., Nygaard Rasmussen, F., & Milios, L. (2019). Circular building materials: Carbon saving potential and the role of business model innovation and public policy. *Resources, Conservation and Recycling*, 141, 308–316.
<https://doi.org/10.1016/j.resconrec.2018.10.036>.

- Pongiglione, M., & Calderini, C. (2014). Material savings through structural steel reuse: A case study in Genoa. *Resources, Conservation and Recycling*, 86, 87–92.
<https://doi.org/10.1016/j.resconrec.2014.02.011>
- Pun, S. K., Liu, C., & Langston, C. (2006). Case study of demolition costs of residential buildings. *Construction Management and Economics*, 24(9), 967–976.
<https://doi.org/10.1080/01446190500512024>.
- Pun, S.K., & Liu, C. (2006). A framework for material management in the building demolition industry. *Architectural Science Review*, 49(4), 391–398.
<https://doi.org/10.3763/asre.2006.4951>.
- Qahtan, S., Alsattar, H. A., Zaidan, A. A., Deveci, M., Pamucar, D. (2023). A novel fuel supply system modelling approach for electric vehicles under Pythagorean probabilistic hesitant fuzzy sets. *Information Sciences*, 622, 1014–1032.
<https://doi.org/10.1016/j.ins.2022.11.166>
- Qahtan, S., Alsattar, H. A., Zaidan, A. A., Deveci, M., Pamucar, D., Delen, D. (2023). Performance Assessment of Sustainable Transportation in the Shipping Industry Using a q-Rung Orthopair Fuzzy Rough Sets-Based Decisioning Methodology. *Expert Systems with Applications*, 119958. <https://doi.org/10.1016/J.ESWA.2023.119958>
- Qahtan, S., Alsattar, H. A., Zaidan, A. A., Deveci, M., Pamucar, D., Martinez, L. (2023). A comparative study of evaluating and benchmarking sign language recognition system-based wearable sensory devices using a single fuzzy set. *Knowledge-Based Systems*, 110519. <https://doi.org/10.1016/J.KNOSYS.2023.110519>
- Qahtan, S., Alsattar, H. A., Zaidan, A. A., Deveci, M., Pamucar, D., Delen, D., & Pedrycz, W. (2023). Evaluation of agriculture-food 4.0 supply chain approaches using Fermatean

- probabilistic hesitant-fuzzy sets based decision making model. *Applied Soft Computing*, 130, 110170. <https://doi.org/10.1016/j.asoc.2023.110170>.
- Qahtan, S., Alsattar, H. A., Zaidan, A. A., Pamucar, D., & Deveci, M. (2022). Integrated sustainable transportation modelling approaches for electronic passenger vehicle in the context of industry 5.0. *J. Innov. Knowl.*, 7, 100277. <https://doi.org/10.1016/j.jik.2022.100277>.
- Qahtan, S., Yatim, K., Zulzalil, H., Osman, M. H., Zaidan, A. A., & Alsattar, H. A. (2022). Review of healthcare industry 4.0 application-based blockchain in terms of security and privacy development attributes: Comprehensive taxonomy, open issues and challenges and recommended solution. *Journal of Network and Computer Applications*, 209, Article 103529. <https://doi.org/10.1016/J.JNCA.2022.103529>
- Rakhshan, K., Morel, J.C., & Daneshkhah, A. (2021). Predicting the technical reusability of load-bearing building components: A probabilistic approach towards developing a Circular Economy framework. *Journal of Building Engineering*, 42, 102791. <https://doi.org/10.1016/j.jobbe.2021.102791>.
- Rakhshan, K., Morel, J.C., Alaka, H., & Charef, R. (2020). Components reuse in the building sector – A systematic review. *Waste Management Research*, 38, 347–370. <https://doi.org/10.1177/0734242X20910463>.
- Rameezdeen, R., Chileshe, N., Hosseini, M. R., & Lehmann, S. (2016). A qualitative examination of major barriers in implementation of reverse logistics within the South Australian construction sector. *International Journal of Construction Management*, 16, 185–196. <https://doi.org/10.1080/15623599.2015.1110275>
- Rodríguez, R. M., Martínez, L., Torra, V., Xu, Z. S., Herrera, F. (2014). Hesitant fuzzy sets:

- State of the art and future directions. *International Journal of Intelligent Systems*, 29(6), 495–524. <https://doi.org/10.1002/int.21654>
- Rogers, S. (2011). Battling construction waste and winning: Lessons from UAE. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, 164(1), 41–48. <https://doi.org/10.1680/cien.2011.164.1.41>.
- Rose, C. M., & Stegemann, J. A. (2018). From waste management to component management in the construction industry. *Sustainability*, 10, 229. <https://doi.org/10.3390/su10010229>.
- Salih, M. M., Zaidan, B. B., & Zaidan, A. A. (2020). Fuzzy decision by opinion score method. *Applied Soft Computing Journal*, 96, 106595. <https://doi.org/10.1016/j.asoc.2020.106595>.
- Sansom, M., & Avery, N. (2014). Reuse and recycling rates of UK steel demolition arisings. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability*, 167, 89–94. <https://doi.org/10.1680/ensu.13.00026>.
- Santos, P., Génesis, C. C., Zaragoza-Benzal, A., Byrne, A., Karaca, F., Ferrández, D., Salles, A., & Bragança, L. (2024). Circular Material Usage Strategies and Principles in Buildings: A Review. *Buildings*, 14(1), 281. <https://doi.org/10.3390/buildings14010281>.
- Sarkar, B. (2010). Fuzzy decision making and its applications in cotton fibre grading. *Soft Computing in Textile Engineering*, 353–383. <https://doi.org/10.1533/9780857090812.5.353>
- Sea-Lim, K., Plianpho, C., Sukmake, P., Pongcharoenkiat, W., & Chinda, T. (2018). Feasibility study of reverse logistic of steel waste in the construction industry.

- Songklanakarin Journal of Science and Technology, 40, 271–277.
<https://doi.org/10.14456/sjst-psu.2018.43>.
- Senapati, T., Yager, R. R. (2020). Fermatean fuzzy sets. Journal of Ambient Intelligence and Humanized Computing, 11(2), 663–674. <https://doi.org/10.1007/s12652-019-01377-0>
- Seror, N., Portnov, B.A. (2018). Identifying areas under potential risk of illegal construction and demolition waste dumping using GIS tools. Waste Management, 75, 22–29.
<https://doi.org/10.1016/j.wasman.2018.01.027>.
- Shahri, M. M., Jahromi, A. E., Houshmand, M. (2021). Failure Mode and Effect Analysis using an integrated approach of clustering and MCDM under pythagorean fuzzy environment. Journal of Loss Prevention in the Process Industries, 72 , 104591.
<https://doi.org/10.1016/j.jlp.2021.104591>
- Shaurette, M. (2006). Demolition contractors’ perceptions of impediments to salvage and reuse of wood structural components. Journal of Green Building, 1(2), 145–163.
<https://doi.org/10.3992/jgb.1.2.145>.
- Simic, V., Gokasar, I., Deveci, M., & Sivadlenka, L. (2022). Mitigating Climate Change Effects of Urban Transportation Using a Type-2 Neutrosophic MEREC-MARCOS Model. IEEE Trans. Eng. Manag., 1–17. <https://doi.org/10.1109/tem.2022.3207375>.
- Tatiya, A., Zhao, D., Syal, M., Berghorn, G. H., & LaMore, R. (2018). Cost prediction model for building deconstruction in urban areas. Journal of Cleaner Production, 195, 1572–1580. <https://doi.org/10.1016/j.jclepro.2017.08.084>
- Torra, V. (2010). Hesitant fuzzy sets. International Journal of Intelligent Systems, 25(6), 529–539. <https://doi.org/10.1002/int.20418>
- Udawatta, N., Zuo, J., Chiveralls, K., Yuan, H., Zillante, G., & Elmualim, A. (2018). Major

- factors impeding the implementation of waste management in Australian construction projects. *Journal of Green Building*, 13, 101–121. <https://doi.org/10.3992/1943-4618.13.3.101>.
- Villoria Sáez, P., Osmani, M. (2019). A diagnosis of construction and demolition waste generation and recovery practice in the European Union. *Journal of Cleaner Production*, 241. <https://doi.org/10.1016/j.jclepro.2019.118400>.
- Yager, R. R. (2017). Generalized Orthopair Fuzzy Sets. *IEEE Transactions on Fuzzy Systems*, 25 (5), 1222–1230. <https://doi.org/10.1109/TFUZZ.2016.2604005>
- Yang, Y., Chen, Z. S., Rodríguez, R. M., Pedrycz, W., & Chin, K. S. (2022). Novel fusion strategies for continuous interval-valued q-rung orthopair fuzzy information: a case study in quality assessment of SmartWatch appearance design. *International Journal of Machine Learning and Cybernetics*, 13, 609–632.
- Yas, Q. M., Zaidan, A. A., Zaidan, B. B., Rahmatullah, B., & Abdul Karim, H. (2018). Comprehensive insights into evaluation and benchmarking of real-time skin detectors: Review, open issues & challenges, and recommended solutions. *Meas. J. Int. Meas. Confed.*, 114, 243–260. <https://doi.org/10.1016/j.measurement.2017.09.027>.
- Yeheyis, M., Hewage, K., Alam, M.S., Eskicioglu, C., & Sadiq, R. (2016). An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. *Clean Technologies and Environmental Policy*, 15, 81–91. <https://doi.org/10.1007/s10098-012-0481-6>.
- Yeung, J., Walbridge, S., & Haas, C. (2015). The role of geometric characterization in supporting structural steel reuse decisions. *Resources, Conservation and Recycling*, 104, 120–130. <https://doi.org/10.1016/j.resconrec.2015.08.017>

- Yeung, J., Walbridge, S., Haas, C., & Saari, R. (2017). Understanding the total life cycle cost implications of reusing structural steel. *Environmental Systems and Decisions*, 37(1), 101–120. <https://doi.org/10.1007/s10669-016-9621-6>.
- Yu, A.T.W., Poon, C.S., Wong, A., Yip, R., & Jaillon, L. (2013). Impact of Construction Waste Disposal Charging Scheme on work practices at construction sites in Hong Kong. *Waste Management*, 33, 138–146. <https://doi.org/10.1016/j.wasman.2012.09.023>.
- Yuan, H., Chini, A. R., Lu, Y., & Shen, L. (2012). A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste. *Waste Management*, 32(3), 521–531. <https://doi.org/10.1016/j.wasman.2011.11.006>
- Yuan, H., Wu, H., & Zuo, J. (2018). Understanding Factors Influencing Project Managers' Behavioral Intentions to Reduce Waste in Construction Projects. *Journal of Management in Engineering*, 34. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000642](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000642).
- Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353. [https://doi.org/10.1016/S0019-9958\(65\)90241-X](https://doi.org/10.1016/S0019-9958(65)90241-X)
- Zaidan, A. A., Zaidan, B. B., Alsalem, M. A., Albahri, O. S., Albahri, A. S., Qahtan, M. Y. (2020). Multi-agent learning neural network and Bayesian model for real-time IoT skin detectors: A new evaluation and benchmarking methodology. *Neural Computing and Applications*, 32, 8315–8366. <https://doi.org/10.1007/s00521-019-04325-3>.
- Zaman, A. U., Arnott, J., McIntyre, K., & Hannon, J. (2018). Resource harvesting through a systematic deconstruction of the residential house: A case study of the "Whole House Reuse" project in Christchurch, New Zealand. *Sustainability*, 10, 3430.

<https://doi.org/10.3390/su10103430>.

Zhang, S., Xu, Z., & He, Y. (2017). Operations and integrations of probabilistic hesitant fuzzy information in decision making. *Information Fusion*, 38, 1–11.

<https://doi.org/10.1016/j.inffus.2017.02.001>

Zhu, B. (2014). Decision method for research and application based on preference relation. Southeast University Nanjing.

Appendices

Appendix A

Invitation to Participate in Research Survey on Strategic Management Approaches for Sustainable CDW Handling

Greetings,

I hope this message finds you well. My name is Hend Ghailani, a Ph.D. candidate at Buid University in Dubai. I am conducting research on Strategic Management Approaches for Sustainable Handling of Construction and Demolition Wastes (CDWs) through a Q-Rung Orthopair Probabilistic Hesitant Fuzzy Set Decision Model.

The objective of this study is to determine the significance of various attributes and sub-attributes related to the barriers to the reuse distribution of CDW management strategies. Your expertise and insights are invaluable for assessing the importance of these factors.

We kindly invite you to participate in this research by evaluating the level of importance of each development barrier attribute and sub-attribute related to the reuse distribution of CDW management strategies. You will be asked to rate these attributes on a scale ranging from "Not Important" to "Very Important."

Your participation is important to the success of this study, and your feedback will greatly contribute to the development of effective strategies for sustainable CDW management.

Brief Overview of the Research:

This research aims to develop and evaluate optimal strategies for managing Construction and Demolition Wastes (CDWs) sustainably. By prioritizing key barrier attributes such as cost,

infrastructure, and policy, the study seeks to identify effective strategies that address CDW challenges and provide benefits to stakeholders in the construction industry.

Part A: Candidate Personal Information

The privacy and confidentiality of participants' personal details will be upheld throughout the study. All information gathered will be used exclusively for research purposes and will not be shared with outside entities.

1. Your current job title:

2. Your organization:

3. Choose your years of experience:

1-2	3-5	6-10	10-15	>15

Part B: Weighting the barrier attributes and sub-attributes for reuse distribution of CDW management strategies.

Please indicate the level of importance for each development barrier attribute and sub-attribute for reuse distribution of the CDW management strategies for reuse distribution.

	Weighting scale/attributes and sub-attributes	Very important	Important	Moderately important	Slight important	Not important
1	Economic					
2	Environmental					
3	Organisational					
4	Regulatory					
5	Social					
6	Technical					
7	Cost					
8	Market					

9	Value-for-money
10	Energy-and-GHG
11	Contracts
12	Experience
13	Infrastructure
14	Management
15	Compliance
16	Incentive
17	Awareness
18	Perception
19	Risk
20	Sustainability
21	Trust
22	Willingness
23	Deconstruction
24	Design
25	Health-and-safety
26	Information

Your participation in this study is greatly appreciated.

Thank you for your valuable assistance.

Appendix B

Table B.1

Decision matrix of the CDW management strategies.

CDW management strategies/attributes	Economic			Environ- mental	Organisational				Regulat- ory		Social					Technical				
	Cost	Market	value-for-money	Energy-and-GHG	Contracts	Experience	Infrastructure	Management	Compliance	Incentive	Awareness	Perception	Risk	Sustainability	Trust	Willingness	Deconstruction	Design	Health-and-safety	Information
Strategy ₁	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Strategy ₂	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	5	0	0
Strategy ₃	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Strategy ₄	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₅	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₆	4	3	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0
Strategy ₇	3	2	0	0	0	1	2	0	1	0	0	1	1	0	0	0	0	0	0	0
Strategy ₈	4	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	5	1	0
Strategy ₉	8	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1
Strategy ₁₀	6	2	0	0	0	1	1	0	2	0	1	3	1	0	0	2	1	5	0	1
Strategy ₁₁	2	1	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	1	0	0
Strategy ₁₂	2	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	2	1	0	0
Strategy ₁₃	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Strategy ₁₄	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₁₅	3	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	0
Strategy ₁₆	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0
Strategy ₁₇	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₁₈	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0
Strategy ₁₉	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Strategy ₂₀	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₂₁	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Strategy ₂₂	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Strategy ₂₃	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0
Strategy ₂₄	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	0
Strategy ₂₅	4	0	0	0	0	1	0	1	2	0	1	3	1	0	0	2	1	0	1	0
Strategy ₂₆	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Strategy ₂₇	3	2	0	1	0	0	0	0	5	0	1	1	1	0	0	1	1	3	1	2
Strategy ₂₈	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	0
Strategy ₂₉	6	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	5	1	2
Strategy ₃₀	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0

Strategy ₃₁	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₃₂	9	2	0	0	0	0	0	0	5	0	2	1	2	0	0	4	0	0	2
Strategy ₃₃	0	2	0	0	0	2	1	0	3	2	3	0	0	0	0	1	1	0	0
Strategy ₃₄	4	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₃₅	4	1	1	0	0	0	0	0	2	1	0	1	1	0	0	0	0	0	1
Strategy ₃₆	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1
Strategy ₃₇	5	2	0	0	0	1	1	0	6	0	0	2	1	0	1	0	1	0	0
Strategy ₃₈	9	3	1	0	1	0	0	0	6	2	1	2	1	0	0	2	3	1	3
Strategy ₃₉	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Strategy ₄₀	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	3	0
Strategy ₄₁	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₄₂	1	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Strategy ₄₃	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Strategy ₄₄	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Strategy ₄₅	3	4	1	0	0	0	1	2	1	1	0	1	0	0	0	1	1	0	1
Strategy ₄₆	9	1	1	0	0	1	1	1	0	0	0	0	2	0	1	0	0	0	0
Strategy ₄₇	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Strategy ₄₈	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0
Strategy ₄₉	1	3	0	1	0	0	1	1	2	1	0	0	0	0	0	1	0	0	0
Strategy ₅₀	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Strategy ₅₁	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0

Table B.2

Preferences of the DMs in linguistic terms (SEJ).

Main attributes/DMs	DM1	DM2	DM3	Sub-attributes/DMs	DM1	DM2	DM3
Economic	I	I	VI	Cost	VI	I	VI
				Market	Av	Av	LI
				Value-for-money	I	Av	I
Environmental	Av	I	Av	Energy-and-GHG	Av	I	Av
				Contracts	Av	Av	I
				Experience	I	VI	VI
Organisational	VLI	LI	LI	Infrastructure	VLI	LI	Av
				Management	I	I	I
				Compliance	VI	VI	I
Regulatory	Av	I	I	Incentive	I	I	Av
				Awareness	Av	Av	Av
				Perception	Av	Av	4
Social	I	VI	VI	Risk	VI	I	VI
				Sustainability	I	I	I
				Trust	I	VI	I

Technical	Av	Av	LI	Willingness	LI	LI	VLI
				Deconstruction	I	Av	Av
				Design	I	I	VI
				Health-and-safety	VI	VI	VI
				Information	LI	LI	VLI

Table B.3

Preferences of the DMs in the numeric scale (EDM).

Main attributes/DMs	DM1	DM2	DM3	Sub-attributes/DMs	DM1	DM2	DM3
Economic	2	2	1	Cost	1	2	1
				Market	3	3	4
				Value-for-money	2	3	2
Environmental	3	2	3	Energy-and-GHG	3	2	3
Organisational	5	4	4	Contracts	3	3	2
				Experience	2	1	1
				Infrastructure	5	4	3
Regulatory	3	2	2	Management	2	2	2
				Compliance	1	1	2
				Incentive	2	2	3
Social	2	1	1	Awareness	3	3	3
				Perception	3	3	4
				Risk	1	2	1
Technical	3	3	4	Sustainability	2	2	2
				Trust	2	1	2
				Willingness	4	4	5
Technical	3	3	4	Deconstruction	2	3	3
				Design	2	2	1
				Health-and-safety	1	1	1
				Information	4	4	5

Table B.4

Opinion matrices of the three DMs.

CDW management strategies	DM1																			
	C os t	Economic Ma rke t	Value- for- money	Environ mental Energy- and- GHG	Cont racts	Organisational Expe rienc e	Infrast ructur e	Mana gemen t	Regulatory Comp liance	Ince ntiv e	Awar eness	Perce ption	Social Ri sk	Sustai nabilit y	Tru st	Willi ngnes s	Decons truction	Technical De sig n	Health- and- safety	Infor matio n
Strategy ₁ [32]	S D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	D	N D	ND	N D	ND	SD	SD	ND	ND
Strategy ₂ [33]	S D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	SD	S D	SD	SD	HD	SD	SD
Strategy ₃ [34]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	B D	HD	D S	SD	SD	SD	SD	SD
Strategy ₄ [20]	D S	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	D S	SD	SD	SD	SD	SD
Strategy ₅ [21]	D B	HD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D S	SD	D S	SD	SD	SD	SD	SD
Strategy ₆ [35]	D B	HD	SD	SD	SD	SD	SD	SD	D	SD	D	SD	S B	SD	D S	SD	SD	SD	D	SD
Strategy ₇ [36]	D B	BD	SD	SD	SD	BD	HD	SD	D	SD	SD	D	D S	SD	D S	SD	SD	SD	SD	SD
Strategy ₈ [37]	D H	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	D S	SD	D S	SD	SD	HD	D	SD
Strategy ₉ [38]	D B	BD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D B	SD	D S	SD	SD	HD	SD	BD
Strategy ₁₀ [39]	D B	BD	SD	SD	SD	BD	BD	SD	D	SD	D	HD	D B	SD	D S	BD	D	HD	SD	BD
Strategy ₁₁ [40]	D	D	SD	SD	SD	SD	SD	SD	D	SD	SD	D	D S	SD	D S	SD	SD	D	SD	SD
Strategy ₁₂ [41]	D N	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	N D	HD	D N	SD	BD	D	SD	SD
Strategy ₁₃ [22]	D N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	D N	ND	SD	ND	ND	ND
Strategy ₁₄ [23]	D N	SD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	D N	ND	ND	ND	ND	ND
Strategy ₁₅ [42]	D S	SD	HD	SD	SD	SD	SD	BD	SD	SD	SD	SD	S D	SD	D S	SD	SD	D	BD	SD
Strategy ₁₆ [43]	D N	SD	SD	SD	SD	SD	SD	HD	SD	BD	SD	SD	D N	SD	D N	SD	SD	SD	SD	SD
Strategy ₁₇ [24]	D S	ND	ND	ND	ND	D	ND	ND	ND	ND	ND	ND	N D	ND	D S	ND	ND	ND	ND	ND
Strategy ₁₈ [44]	D	SD	SD	SD	SD	SD	HD	SD	SD	SD	SD	SD	D S	SD	D S	SD	D	SD	SD	SD

Strategy ₁₉ [25]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₂₀ [26]	N D	ND	ND	ND	ND	D	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₂₁ [45]	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	SD	D	SD	SD	SD	D	SD
Strategy ₂₂ [27]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	SD	N D	ND	N D	ND	BD	ND	ND	ND
Strategy ₂₃ [46]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	BD	SD	SD
Strategy ₂₄ [47]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	S D	SD	S D	D	SD	D	SD	SD
Strategy ₂₅ [48]	B D	SD	SD	SD	SD	BD	SD	BD	D	SD	D	HD	B D	SD	S D	BD	D	SD	D	SD
Strategy ₂₆ [28]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	D	ND	ND
Strategy ₂₇ [49]	D	BD	SD	BD	SD	SD	SD	SD	HD	SD	D	D	D	SD	S	D	D	BD	D	HD
Strategy ₂₈ [50]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	D	SD	SD
Strategy ₂₉ [51]	B D	SD	HD	SD	SD	BD	SD	BD	SD	BD	SD	SD	S D	SD	S	SD	SD	HD	D	HD
Strategy ₃₀ [52]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	D	ND	N	ND	D	ND	ND	ND
Strategy ₃₁ [29]	B D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S	SD	S	SD	SD	SD	SD	SD
Strategy ₃₂ [53]	H D	BD	SD	SD	SD	SD	SD	SD	HD	SD	BD	D	D	SD	D	HD	SD	SD	BD	SD
Strategy ₃₃ [48]	S D	BD	SD	SD	SD	HD	BD	SD	BD	HD	HD	SD	S	SD	S	D	D	SD	SD	SD
Strategy ₃₄ [54]	B D	D	SD	SD	SD	SD	HD	SD	SD	SD	SD	SD	D	SD	S	SD	SD	SD	SD	SD
Strategy ₃₅ [55]	B D	D	HD	SD	SD	SD	SD	SD	D	BD	SD	D	B	SD	S	SD	SD	SD	D	SD
Strategy ₃₆ [56]	B D	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	SD	S	SD	D	D	D	SD
Strategy ₃₇ [57]	B D	BD	SD	SD	SD	BD	BD	SD	HD	SD	SD	BD	B	SD	H	SD	D	SD	SD	SD
Strategy ₃₈ [58]	H D	HD	HD	SD	HD	SD	SD	SD	HD	HD	D	BD	B	SD	S	BD	HD	D	HD	BD
Strategy ₃₉ [59]	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S	SD	S	SD	D	SD	SD	SD
Strategy ₄₀ [60]	S D	SD	SD	SD	SD	SD	BD	SD	SD	SD	SD	SD	S	SD	S	SD	D	BD	SD	SD
Strategy ₄₁ [30]	N D	D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N	ND	N	ND	ND	ND	ND	ND
Strategy ₄₂ [13]	S D	D	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S	SD	S	SD	SD	SD	SD	SD

Strategy ₄₃ [61]	S D	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	BD	SD	SD
Strategy ₄₄ [62]	D	SD	SD	SD	SD	SD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₅ [63]	D	HD	HD	SD	SD	SD	BD	HD	D	BD	SD	D	D	SD	D	D	D	SD	SD	BD
Strategy ₄₆ [64]	H D	D	HD	SD	SD	BD	BD	BD	SD	SD	SD	SD	H D	SD	H D	SD	SD	SD	SD	SD
Strategy ₄₇ [31]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	SD	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₄₈ [65]	S D	SD	HD	SD	SD	BD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₉ [66]	D	HD	SD	BD	SD	SD	BD	BD	D	BD	SD	SD	S D	SD	S D	D	SD	SD	SD	SD
Strategy ₅₀ [67]	S D	SD	SD	HD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	SD	SD	SD
Strategy ₅₁ [68]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	BD	SD	SD	SD

DM2

CDW management strategies																				
	C os t	Economic Ma rke t	Value- for- money	Environ mental Energy- and- GHG	Cont racts	Organisational Expe rienc e	Infrast ructur e	Mana gemen t	Regulatory Comp liance	Ince ntiv e	Awar eness	Perce ption	Social Ri sk	Sustai nabilit y	Tr us t	Willi ngnes s	Decons truction	Technical De sig n	Health- and- safety	Infor matio n
Strategy ₁ [32]	S D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	D	N D	SD	N D	ND	ND	ND	ND	ND
Strategy ₂ [33]	D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	SD	S D	SD	SD	HD	SD	SD
Strategy ₃ [34]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	D B	HD	D S	SD	SD	SD	SD	SD
Strategy ₄ [20]	D B	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D S	SD	D S	SD	SD	SD	SD	SD
Strategy ₅ [21]	S D	HD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D S	SD	D S	SD	SD	SD	SD	SD
Strategy ₆ [35]	B D	HD	SD	SD	SD	SD	SD	SD	D	SD	D	SD	D B	SD	D S	SD	SD	SD	D	SD
Strategy ₇ [36]	D	BD	SD	SD	SD	BD	HD	SD	D	SD	SD	D	D S	SD	D S	SD	SD	SD	SD	SD
Strategy ₈ [37]	B D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	D S	SD	D S	SD	SD	HD	D	SD
Strategy ₉ [38]	H D	BD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D S	SD	D S	SD	SD	HD	SD	BD
Strategy ₁₀ [39]	D B	BD	SD	SD	SD	BD	BD	SD	D	SD	D	HD	D B	SD	D S	BD	D	HD	SD	BD
Strategy ₁₁ [40]	D	D	SD	SD	SD	SD	SD	SD	D	SD	SD	D	D B	SD	D S	SD	SD	D	SD	SD
Strategy ₁₂ [41]	D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	HD	S D	SD	BD	D	SD	SD

Strategy ₁₃ [22]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	SD	ND	ND	ND
Strategy ₁₄ [23]	N D	SD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₁₅ [42]	D	SD	HD	SD	SD	SD	SD	BD	SD	SD	SD	SD	D	SD	D	SD	SD	D	BD	SD
Strategy ₁₆ [43]	S D	SD	SD	SD	SD	SD	SD	HD	SD	BD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₁₇ [24]	N D	ND	ND	ND	ND	D	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₁₈ [44]	S D	SD	SD	SD	SD	SD	HD	SD	D	SD	SD	SD	S D	SD	S D	SD	D	SD	SD	SD
Strategy ₁₉ [25]	N D	ND	ND	ND	ND	ND	ND	ND	SD	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₂₀ [26]	N D	ND	ND	ND	ND	D	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₂₁ [45]	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	D	SD
Strategy ₂₂ [27]	S D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	BD	ND	ND	ND
Strategy ₂₃ [46]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	BD	SD	SD
Strategy ₂₄ [47]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	D	SD	D	D	SD	D	SD	SD
Strategy ₂₅ [48]	B D	SD	SD	SD	SD	BD	SD	BD	D	SD	D	HD	B D	SD	S D	BD	D	SD	D	SD
Strategy ₂₆ [28]	S D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N D	ND	N D	ND	ND	D	ND	ND
Strategy ₂₇ [49]	D	BD	SD	BD	SD	SD	SD	SD	HD	SD	D	D	B D	SD	S D	D	D	BD	D	HD
Strategy ₂₈ [50]	S D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	SD	S D	SD	D	D	SD	SD
Strategy ₂₉ [51]	B D	SD	HD	SD	SD	BD	SD	BD	SD	BD	SD	SD	S D	SD	S D	SD	SD	HD	D	HD
Strategy ₃₀ [52]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	D	ND	D	ND	D	ND	SD	ND
Strategy ₃₁ [29]	B D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₃₂ [53]	H D	BD	SD	SD	SD	SD	SD	SD	HD	SD	BD	D	H D	SD	S D	HD	SD	SD	BD	SD
Strategy ₃₃ [48]	S D	BD	SD	SD	SD	HD	BD	SD	BD	HD	HD	SD	S D	SD	S D	D	D	SD	SD	SD
Strategy ₃₄ [54]	B D	D	SD	SD	SD	SD	HD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₃₅ [55]	B D	D	HD	SD	SD	SD	SD	SD	D	BD	SD	D	B D	SD	S D	SD	SD	SD	D	SD
Strategy ₃₆ [56]	B D	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	D	D	SD

Strategy ₃₇ [57]	B D	BD	SD	SD	SD	BD	BD	SD	HD	SD	SD	BD	B D	SD	H D	SD	D	SD	SD	SD
Strategy ₃₈ [58]	H D	HD	HD	SD	HD	SD	SD	SD	HD	HD	D	BD	B D	SD	S D	BD	HD	D	HD	BD
Strategy ₃₉ [59]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D S	SD	D S	SD	D	SD	SD	SD
Strategy ₄₀ [60]	S D	SD	SD	SD	SD	SD	BD	SD	SD	SD	SD	SD	D S	SD	D S	SD	D	BD	SD	SD
Strategy ₄₁ [30]	N D	D	ND	ND	ND	ND	ND	ND	SD	ND	ND	ND	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₄₂ [13]	S D	D	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₃ [61]	S D	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	BD	SD	SD
Strategy ₄₄ [62]	S D	SD	SD	SD	SD	SD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₅ [63]	D	HD	HD	SD	SD	SD	BD	HD	D	BD	SD	D	D H	SD	D H	D	D	SD	SD	BD
Strategy ₄₆ [64]	H D	D	HD	SD	SD	BD	BD	BD	SD	SD	SD	SD	D N	SD	D N	SD	SD	SD	SD	SD
Strategy ₄₇ [31]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	SD	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₄₈ [65]	S D	SD	HD	SD	SD	BD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₉ [66]	D	HD	SD	BD	SD	SD	BD	BD	D	BD	SD	SD	D S	SD	D S	D	SD	SD	SD	SD
Strategy ₅₀ [67]	S D	SD	SD	HD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	SD	SD	SD
Strategy ₅₁ [68]	S D	SD	SD	SD	SD	ND	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	BD	SD	SD	SD

DM3

CDW management strategies																				
	C os t	Economic Ma rke t	Value- for- money	Environ mental Energy- and- GHG	Cont racts	Organisational Expe rienc e	Infrast ructur e	Mana gemen t	Regulatory Comp liance	Ince ntiv e	Awar eness	Perce ption	Social Ri sk	Sustai nabilit y	Tru st	Willi ngnes s	Decons truction	Technical De sign	Health- and- safety	Infor matio n
Strategy ₁ [32]	S D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	D	S D	ND	N D	ND	ND	SD	ND	ND
Strategy ₂ [33]	D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	SD	D S	SD	SD	HD	SD	SD
Strategy ₃ [34]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	B D	HD	S D	SD	SD	SD	SD	SD
Strategy ₄ [20]	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D S	SD	D S	SD	SD	SD	SD	SD
Strategy ₅ [21]	S D	HD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	ND	SD	SD	SD
Strategy ₆ [35]	B D	HD	SD	SD	SD	SD	SD	SD	D	SD	D	SD	S D	SD	D S	SD	SD	SD	D	SD

Strategy ₇ [36]	D	BD	SD	SD	SD	BD	HD	SD	D	SD	SD	D	B	SD	S	SD	SD	SD	SD	SD
Strategy ₈ [37]	B	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S	SD	S	SD	SD	HD	D	SD
Strategy ₉ [38]	H	BD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S	SD	S	SD	SD	HD	SD	BD
Strategy ₁₀ [39]	D	BD	SD	SD	SD	BD	BD	SD	D	SD	D	HD	B	SD	S	BD	D	HD	SD	BD
Strategy ₁₁ [40]	D	D	SD	SD	SD	SD	SD	SD	D	SD	SD	D	B	SD	S	SD	SD	D	SD	SD
Strategy ₁₂ [41]	D	SD	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S	HD	S	SD	BD	D	SD	SD
Strategy ₁₃ [22]	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N	ND	N	ND	SD	ND	ND	ND
Strategy ₁₄ [23]	N	SD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N	ND	N	ND	ND	ND	ND	ND
Strategy ₁₅ [42]	D	SD	HD	SD	SD	SD	SD	BD	SD	SD	SD	SD	S	SD	S	SD	SD	D	BD	SD
Strategy ₁₆ [43]	S	SD	SD	SD	SD	SD	SD	HD	SD	BD	SD	SD	S	SD	S	SD	SD	SD	SD	SD
Strategy ₁₇ [24]	D	ND	ND	ND	ND	D	ND	ND	ND	ND	ND	ND	N	ND	N	ND	ND	ND	ND	ND
Strategy ₁₈ [44]	S	SD	SD	SD	SD	SD	HD	SD	D	SD	SD	SD	S	SD	S	SD	D	SD	SD	SD
Strategy ₁₉ [25]	N	ND	ND	ND	ND	ND	ND	ND	SD	ND	ND	ND	N	ND	N	ND	ND	ND	ND	ND
Strategy ₂₀ [26]	N	ND	ND	ND	ND	D	ND	ND	ND	ND	ND	ND	N	ND	N	ND	ND	ND	ND	ND
Strategy ₂₁ [45]	S	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S	SD	S	SD	SD	SD	D	SD
Strategy ₂₂ [27]	S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	S	ND	N	ND	BD	ND	ND	ND
Strategy ₂₃ [46]	S	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S	SD	S	SD	D	BD	SD	SD
Strategy ₂₄ [47]	S	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	D	D	SD	D	D	SD	D	SD	SD
Strategy ₂₅ [48]	B	SD	SD	SD	SD	BD	SD	BD	D	SD	D	HD	B	SD	S	BD	D	SD	D	SD
Strategy ₂₆ [28]	D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N	ND	N	ND	ND	D	ND	ND
Strategy ₂₇ [49]	D	BD	SD	BD	SD	SD	SD	SD	HD	SD	D	D	B	SD	S	D	D	BD	D	HD
Strategy ₂₈ [50]	S	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S	SD	S	SD	D	D	SD	SD
Strategy ₂₉ [51]	B	SD	HD	SD	SD	BD	SD	BD	SD	BD	SD	SD	S	SD	S	SD	SD	HD	D	HD
Strategy ₃₀ [52]	N	ND	ND	ND	ND	ND	ND	ND	ND	SD	SD	ND	D	ND	N	ND	D	ND	ND	SD

Strategy ₃₁ [29]	B D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₃₂ [53]	H D	BD	SD	SD	SD	SD	SD	SD	HD	SD	BD	D	H D	SD	S D	HD	SD	SD	BD	SD
Strategy ₃₃ [48]	S D	BD	SD	SD	SD	HD	BD	SD	BD	HD	HD	SD	S D	SD	S D	D	D	SD	SD	SD
Strategy ₃₄ [54]	B D	D	SD	SD	SD	SD	HD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₃₅ [55]	B D	D	HD	SD	SD	SD	SD	SD	D	BD	SD	D	B D	SD	S D	SD	SD	SD	D	SD
Strategy ₃₆ [56]	B D	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	BD	D	SD
Strategy ₃₇ [57]	B D	BD	SD	SD	SD	BD	BD	SD	HD	SD	SD	BD	B D	SD	H D	SD	D	SD	SD	SD
Strategy ₃₈ [58]	H D	HD	HD	SD	HD	SD	SD	SD	HD	HD	D	BD	B D	SD	S D	BD	HD	D	HD	BD
Strategy ₃₉ [59]	D	ND	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	SD	SD	SD
Strategy ₄₀ [60]	S D	SD	SD	SD	SD	SD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	BD	SD	SD
Strategy ₄₁ [30]	N D	D	ND	ND	ND	SD	ND	ND	ND	ND	ND	ND	S D	ND	N D	ND	ND	ND	ND	ND
Strategy ₄₂ [13]	S D	D	SD	SD	SD	SD	SD	SD	D	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₃ [61]	S D	D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	BD	SD	SD
Strategy ₄₄ [62]	D	SD	SD	SD	SD	SD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	ND	SD	SD	SD
Strategy ₄₅ [63]	D	HD	HD	SD	SD	SD	BD	HD	D	BD	SD	D	S D	SD	S D	D	D	SD	SD	BD
Strategy ₄₆ [64]	H D	D	HD	SD	SD	BD	BD	BD	SD	SD	SD	SD	H D	SD	H D	SD	SD	SD	SD	SD
Strategy ₄₇ [31]	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	SD	N D	ND	N D	ND	ND	ND	ND	ND
Strategy ₄₈ [65]	D	SD	HD	SD	SD	BD	BD	SD	SD	SD	SD	SD	S D	SD	S D	SD	SD	SD	SD	SD
Strategy ₄₉ [66]	D	HD	SD	BD	SD	SD	BD	BD	D	BD	SD	SD	S D	SD	S D	D	SD	SD	SD	SD
Strategy ₅₀ [67]	S D	SD	SD	HD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	D	SD	SD	SD
Strategy ₅₁ [68]	S D	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	S D	SD	S D	SD	BD	SD	SD	SD

Table B.5Group scoring results of the CDW management strategies per seven q values.

CDW management strategies	$q = 4$					
	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.3431	0.5239	0.0001	0.0004	0.1774	0.1937
Strategy ₂ [33]	0.5126	0.5536	0.4780	0.5360	0.4782	0.9224
Strategy ₃ [34]	0.4778	0.5536	0.4780	0.4776	0.8589	0.4780
Strategy ₄ [20]	0.5887	0.5536	0.4780	0.4776	0.4782	0.4780
Strategy ₅ [21]	0.6421	0.5536	0.4780	0.4776	0.4782	0.4632
Strategy ₆ [35]	0.8226	0.5536	0.4780	0.5360	0.4856	0.5172
Strategy ₇ [36]	0.5792	0.5536	0.7289	0.5360	0.6264	0.4780
Strategy ₈ [37]	0.7061	0.5536	0.4780	0.5360	0.4782	0.9424
Strategy ₉ [38]	1.0980	0.5536	0.4780	0.4776	0.4782	0.9285
Strategy ₁₀ [39]	0.7402	0.5536	0.6863	0.5360	0.7107	0.9364
Strategy ₁₁ [40]	0.5395	0.5536	0.4780	0.5360	0.6264	0.5128
Strategy ₁₂ [41]	0.5300	0.5536	0.4780	0.5360	0.7632	0.5883
Strategy ₁₃ [22]	0.0003	0.5239	0.0001	0.0004	0.0000	0.1241
Strategy ₁₄ [23]	0.0835	0.5239	0.0001	0.0004	0.0000	0.0002
Strategy ₁₅ [42]	0.8932	0.5536	0.6115	0.4776	0.4782	0.6822
Strategy ₁₆ [43]	0.4778	0.5536	0.8511	0.6312	0.4782	0.4780
Strategy ₁₇ [24]	0.0003	0.5239	0.3581	0.0004	0.0000	0.0002
Strategy ₁₈ [44]	0.4778	0.5536	0.5609	0.5165	0.4782	0.4940
Strategy ₁₉ [25]	0.0003	0.5239	0.0001	0.2479	0.0000	0.0002
Strategy ₂₀ [26]	0.0003	0.5239	0.3581	0.0004	0.0000	0.0002
Strategy ₂₁ [45]	0.5126	0.5536	0.4780	0.4776	0.4782	0.5172
Strategy ₂₂ [27]	0.2288	0.5239	0.0001	0.0004	0.0901	0.2958
Strategy ₂₃ [46]	0.4778	0.5536	0.4780	0.4776	0.4782	0.6517
Strategy ₂₄ [47]	0.4778	0.5536	0.4780	0.4776	0.4861	0.5128
Strategy ₂₅ [48]	0.7061	0.5536	0.7616	0.5360	0.7107	0.5320
Strategy ₂₆ [28]	0.1145	0.5239	0.0001	0.0004	0.0000	0.3090
Strategy ₂₇ [49]	0.5792	0.5754	0.4780	1.1251	0.6332	0.7087
Strategy ₂₈ [50]	0.4778	0.5536	0.4780	0.4970	0.4782	0.5278
Strategy ₂₉ [51]	0.9996	0.5536	0.7616	0.6312	0.4782	0.9640
Strategy ₃₀ [52]	0.0003	0.5239	0.0001	0.0789	0.3577	0.2349
Strategy ₃₁ [29]	0.7061	0.5536	0.4780	0.4776	0.4782	0.4780
Strategy ₃₂ [53]	1.0980	0.5536	0.4780	1.1251	0.9182	0.6578
Strategy ₃₃ [48]	0.5325	0.5536	1.0022	1.0441	0.5989	0.4940
Strategy ₃₄ [54]	0.7128	0.5536	0.5609	0.4776	0.4782	0.4780
Strategy ₃₅ [55]	1.0042	0.5536	0.4780	0.6745	0.6264	0.5172
Strategy ₃₆ [56]	0.7128	0.5536	0.4780	0.4776	0.4782	0.6022
Strategy ₃₇ [57]	0.7402	0.5536	0.6863	1.1251	0.9464	0.4940

Strategy ₃₈ [58]	1.3140	0.5536	0.7352	1.3127	0.6574	1.1140
Strategy ₃₉ [59]	0.5049	0.5536	0.4780	0.4776	0.4782	0.4940
Strategy ₄₀ [60]	0.4778	0.5536	0.5047	0.4776	0.4782	0.6517
Strategy ₄₁ [30]	0.1059	0.5239	0.0971	0.1242	0.0739	0.0002
Strategy ₄₂ [13]	0.4884	0.5536	0.4780	0.5360	0.4782	0.4780
Strategy ₄₃ [61]	0.4884	0.5536	0.4780	0.4776	0.4782	0.6402
Strategy ₄₄ [62]	0.5126	0.5536	0.5047	0.4776	0.4782	0.4632
Strategy ₄₅ [63]	0.9902	0.5536	0.8651	0.6745	0.4861	0.5065
Strategy ₄₆ [64]	1.2668	0.5536	0.7764	0.4776	1.1155	0.4780
Strategy ₄₇ [31]	0.0003	0.5239	0.0001	0.0004	0.0485	0.0002
Strategy ₄₈ [65]	0.8740	0.5536	0.6863	0.4776	0.4782	0.4780
Strategy ₄₉ [66]	0.6819	0.5754	0.6313	0.6745	0.4801	0.4780
Strategy ₅₀ [67]	0.4778	0.6055	0.4780	0.4776	0.4782	0.4940
Strategy ₅₁ [68]	0.4778	0.5536	0.4283	0.4776	0.4782	0.5588

 $q = 5$

CDW management strategies	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.3563	0.4699	0.0002	0.0005	0.1640	0.1883
Strategy ₂ [33]	0.4586	0.4834	0.4333	0.4740	0.4335	0.8172
Strategy ₃ [34]	0.4331	0.4834	0.4333	0.4330	0.7338	0.4333
Strategy ₄ [20]	0.5186	0.4834	0.4333	0.4330	0.4335	0.4333
Strategy ₅ [21]	0.5228	0.4834	0.4333	0.4330	0.4335	0.4256
Strategy ₆ [35]	0.6769	0.4834	0.4333	0.4740	0.4367	0.4613
Strategy ₇ [36]	0.4939	0.4834	0.6174	0.4740	0.5505	0.4333
Strategy ₈ [37]	0.6131	0.4834	0.4333	0.4740	0.4335	0.8304
Strategy ₉ [38]	1.0118	0.4834	0.4333	0.4330	0.4335	0.8194
Strategy ₁₀ [39]	0.6281	0.4834	0.5936	0.4740	0.5940	0.8231
Strategy ₁₁ [40]	0.4752	0.4834	0.4333	0.4740	0.5505	0.4568
Strategy ₁₂ [41]	0.4714	0.4834	0.4333	0.4740	0.6553	0.4993
Strategy ₁₃ [22]	0.0004	0.4699	0.0002	0.0005	0.0000	0.1010
Strategy ₁₄ [23]	0.0566	0.4699	0.0002	0.0005	0.0000	0.0002
Strategy ₁₅ [42]	0.7452	0.4834	0.5245	0.4330	0.4335	0.5863
Strategy ₁₆ [43]	0.4331	0.4834	0.7296	0.5285	0.4335	0.4333
Strategy ₁₇ [24]	0.0004	0.4699	0.3706	0.0005	0.0000	0.0002
Strategy ₁₈ [44]	0.4331	0.4834	0.4770	0.4603	0.4335	0.4415
Strategy ₁₉ [25]	0.0004	0.4699	0.0002	0.2472	0.0000	0.0002
Strategy ₂₀ [26]	0.0004	0.4699	0.3706	0.0005	0.0000	0.0002
Strategy ₂₁ [45]	0.4586	0.4834	0.4333	0.4330	0.4335	0.4613
Strategy ₂₂ [27]	0.2377	0.4699	0.0002	0.0005	0.0933	0.2358
Strategy ₂₃ [46]	0.4331	0.4834	0.4333	0.4330	0.4335	0.5577
Strategy ₂₄ [47]	0.4331	0.4834	0.4333	0.4330	0.4367	0.4568
Strategy ₂₅ [48]	0.6131	0.4834	0.6467	0.4740	0.5940	0.4685
Strategy ₂₆ [28]	0.1190	0.4699	0.0002	0.0005	0.0000	0.3046
Strategy ₂₇ [49]	0.4939	0.4912	0.4333	1.0316	0.5530	0.5880

Strategy ₂₈ [50]	0.4331	0.4834	0.4333	0.4467	0.4335	0.4642
Strategy ₂₉ [51]	0.8442	0.4834	0.6467	0.5285	0.4335	0.8401
Strategy ₃₀ [52]	0.0004	0.4699	0.0002	0.0691	0.3640	0.2037
Strategy ₃₁ [29]	0.6131	0.4834	0.4333	0.4330	0.4335	0.4333
Strategy ₃₂ [53]	1.0118	0.4834	0.4333	1.0316	0.8243	0.5718
Strategy ₃₃ [48]	0.4592	0.4834	0.9266	0.8679	0.5011	0.4415
Strategy ₃₄ [54]	0.6155	0.4834	0.4770	0.4330	0.4335	0.4333
Strategy ₃₅ [55]	0.8461	0.4834	0.4333	0.5578	0.5505	0.4613
Strategy ₃₆ [56]	0.6155	0.4834	0.4333	0.4330	0.4335	0.5179
Strategy ₃₇ [57]	0.6281	0.4834	0.5936	1.0316	0.8413	0.4415
Strategy ₃₈ [58]	1.1883	0.4834	0.6135	1.1872	0.5635	0.9809
Strategy ₃₉ [59]	0.4557	0.4834	0.4333	0.4330	0.4335	0.4415
Strategy ₄₀ [60]	0.4331	0.4834	0.4457	0.4330	0.4335	0.5577
Strategy ₄₁ [30]	0.0707	0.4699	0.1051	0.1238	0.0824	0.0002
Strategy ₄₂ [13]	0.4376	0.4834	0.4333	0.4740	0.4335	0.4333
Strategy ₄₃ [61]	0.4376	0.4834	0.4333	0.4330	0.4335	0.5525
Strategy ₄₄ [62]	0.4586	0.4834	0.4457	0.4330	0.4335	0.4256
Strategy ₄₅ [63]	0.8037	0.4834	0.7361	0.5578	0.4367	0.4461
Strategy ₄₆ [64]	1.1571	0.4834	0.6533	0.4330	1.0351	0.4333
Strategy ₄₇ [31]	0.0004	0.4699	0.0002	0.0005	0.0328	0.0002
Strategy ₄₈ [65]	0.7315	0.4834	0.5936	0.4330	0.4335	0.4333
Strategy ₄₉ [66]	0.5529	0.4912	0.5334	0.5578	0.4341	0.4333
Strategy ₅₀ [67]	0.4331	0.5067	0.4333	0.4330	0.4335	0.4415
Strategy ₅₁ [68]	0.4331	0.4834	0.3857	0.4330	0.4335	0.4796

 $q = 6$

CDW management strategies	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.3470	0.4134	0.0002	0.0005	0.1498	0.1778
Strategy ₂ [33]	0.4053	0.4194	0.3879	0.4150	0.3880	0.7201
Strategy ₃ [34]	0.3877	0.4194	0.3879	0.3877	0.6194	0.3879
Strategy ₄ [20]	0.4509	0.4194	0.3879	0.3877	0.3880	0.3879
Strategy ₅ [21]	0.4347	0.4194	0.3879	0.3877	0.3880	0.3840
Strategy ₆ [35]	0.5592	0.4194	0.3879	0.4150	0.3893	0.4068
Strategy ₇ [36]	0.4238	0.4194	0.5224	0.4150	0.4768	0.3879
Strategy ₈ [37]	0.5245	0.4194	0.3879	0.4150	0.3880	0.7285
Strategy ₉ [38]	0.9352	0.4194	0.3879	0.3877	0.3880	0.7209
Strategy ₁₀ [39]	0.5310	0.4194	0.5091	0.4150	0.4991	0.7225
Strategy ₁₁ [40]	0.4154	0.4194	0.3879	0.4150	0.4768	0.4029
Strategy ₁₂ [41]	0.4140	0.4194	0.3879	0.4150	0.5558	0.4259
Strategy ₁₃ [22]	0.0005	0.4134	0.0002	0.0005	0.0000	0.0793
Strategy ₁₄ [23]	0.0364	0.4134	0.0002	0.0005	0.0000	0.0002
Strategy ₁₅ [42]	0.6159	0.4194	0.4469	0.3877	0.3880	0.4990
Strategy ₁₆ [43]	0.3877	0.4194	0.6183	0.4448	0.3880	0.3879
Strategy ₁₇ [24]	0.0005	0.4134	0.3603	0.0005	0.0000	0.0002

Strategy ₁₈ [44]	0.3877	0.4194	0.4103	0.4059	0.3880	0.3919
Strategy ₁₉ [25]	0.0005	0.4134	0.0002	0.2357	0.0000	0.0002
Strategy ₂₀ [26]	0.0005	0.4134	0.3603	0.0005	0.0000	0.0002
Strategy ₂₁ [45]	0.4053	0.4194	0.3879	0.3877	0.3880	0.4068
Strategy ₂₂ [27]	0.2315	0.4134	0.0002	0.0005	0.0930	0.1833
Strategy ₂₃ [46]	0.3877	0.4194	0.3879	0.3877	0.3880	0.4743
Strategy ₂₄ [47]	0.3877	0.4194	0.3879	0.3877	0.3892	0.4029
Strategy ₂₅ [48]	0.5245	0.4194	0.5447	0.4150	0.4991	0.4102
Strategy ₂₆ [28]	0.1160	0.4134	0.0002	0.0005	0.0000	0.2893
Strategy ₂₇ [49]	0.4238	0.4222	0.3879	0.9484	0.4776	0.4906
Strategy ₂₈ [50]	0.3877	0.4194	0.3879	0.3968	0.3880	0.4064
Strategy ₂₉ [51]	0.7033	0.4194	0.5447	0.4448	0.3880	0.7328
Strategy ₃₀ [52]	0.0005	0.4134	0.0002	0.0586	0.3508	0.1753
Strategy ₃₁ [29]	0.5245	0.4194	0.3879	0.3877	0.3880	0.3879
Strategy ₃₂ [53]	0.9352	0.4194	0.3879	0.9484	0.7454	0.4907
Strategy ₃₃ [48]	0.3995	0.4194	0.8609	0.7150	0.4242	0.3919
Strategy ₃₄ [54]	0.5253	0.4194	0.4103	0.3877	0.3880	0.3879
Strategy ₃₅ [55]	0.7040	0.4194	0.3879	0.4639	0.4768	0.4068
Strategy ₃₆ [56]	0.5253	0.4194	0.3879	0.3877	0.3880	0.4437
Strategy ₃₇ [57]	0.5310	0.4194	0.5091	0.9484	0.7457	0.3919
Strategy ₃₈ [58]	1.0744	0.4194	0.5123	1.0735	0.4821	0.8685
Strategy ₃₉ [59]	0.4042	0.4194	0.3879	0.3877	0.3880	0.3919
Strategy ₄₀ [60]	0.3877	0.4194	0.3934	0.3877	0.3880	0.4743
Strategy ₄₁ [30]	0.0451	0.4134	0.1064	0.1181	0.0860	0.0002
Strategy ₄₂ [13]	0.3895	0.4194	0.3879	0.4150	0.3880	0.3879
Strategy ₄₃ [61]	0.3895	0.4194	0.3879	0.3877	0.3880	0.4721
Strategy ₄₄ [62]	0.4053	0.4194	0.3934	0.3877	0.3880	0.3840
Strategy ₄₅ [63]	0.6495	0.4194	0.6212	0.4639	0.3892	0.3935
Strategy ₄₆ [64]	1.0549	0.4194	0.5476	0.3877	0.9584	0.3879
Strategy ₄₇ [31]	0.0005	0.4134	0.0002	0.0005	0.0210	0.0002
Strategy ₄₈ [65]	0.6066	0.4194	0.5091	0.3877	0.3880	0.3879
Strategy ₄₉ [66]	0.4564	0.4222	0.4508	0.4639	0.3882	0.3879
Strategy ₅₀ [67]	0.3877	0.4300	0.3879	0.3877	0.3880	0.3919
Strategy ₅₁ [68]	0.3877	0.4194	0.3422	0.3877	0.3880	0.4134

 $q = 7$

CDW management strategies	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.3232	0.3605	0.0002	0.0005	0.1350	0.1644
Strategy ₂ [33]	0.3552	0.3631	0.3438	0.3613	0.3439	0.6331
Strategy ₃ [34]	0.3437	0.3631	0.3438	0.3437	0.5193	0.3438
Strategy ₄ [20]	0.3892	0.3631	0.3438	0.3437	0.3439	0.3438
Strategy ₅ [21]	0.3678	0.3631	0.3438	0.3437	0.3439	0.3420
Strategy ₆ [35]	0.4644	0.3631	0.3438	0.3613	0.3444	0.3562
Strategy ₇ [36]	0.3650	0.3631	0.4421	0.3613	0.4097	0.3438

Strategy ₈ [37]	0.4456	0.3631	0.3438	0.3613	0.3439	0.6383
Strategy ₉ [38]	0.8646	0.3631	0.3438	0.3437	0.3439	0.6334
Strategy ₁₀ [39]	0.4484	0.3631	0.4346	0.3613	0.4214	0.6341
Strategy ₁₁ [40]	0.3615	0.3631	0.3438	0.3613	0.4097	0.3531
Strategy ₁₂ [41]	0.3610	0.3631	0.3438	0.3613	0.4686	0.3653
Strategy ₁₃ [22]	0.0005	0.3605	0.0002	0.0005	0.0000	0.0607
Strategy ₁₄ [23]	0.0225	0.3605	0.0002	0.0005	0.0000	0.0002
Strategy ₁₅ [42]	0.5077	0.3631	0.3805	0.3437	0.3439	0.4234
Strategy ₁₆ [43]	0.3437	0.3631	0.5201	0.3770	0.3439	0.3438
Strategy ₁₇ [24]	0.0005	0.3605	0.3345	0.0005	0.0000	0.0002
Strategy ₁₈ [44]	0.3437	0.3631	0.3552	0.3555	0.3439	0.3457
Strategy ₁₉ [25]	0.0005	0.3605	0.0002	0.2173	0.0000	0.0002
Strategy ₂₀ [26]	0.0005	0.3605	0.3345	0.0005	0.0000	0.0002
Strategy ₂₁ [45]	0.3552	0.3631	0.3438	0.3437	0.3439	0.3562
Strategy ₂₂ [27]	0.2156	0.3605	0.0002	0.0005	0.0896	0.1402
Strategy ₂₃ [46]	0.3437	0.3631	0.3438	0.3437	0.3439	0.4030
Strategy ₂₄ [47]	0.3437	0.3631	0.3438	0.3437	0.3443	0.3531
Strategy ₂₅ [48]	0.4456	0.3631	0.4577	0.3613	0.4214	0.3577
Strategy ₂₆ [28]	0.1080	0.3605	0.0002	0.0005	0.0000	0.2679
Strategy ₂₇ [49]	0.3650	0.3641	0.3438	0.8730	0.4100	0.4118
Strategy ₂₈ [50]	0.3437	0.3631	0.3438	0.3496	0.3439	0.3547
Strategy ₂₉ [51]	0.5812	0.3631	0.4577	0.3770	0.3439	0.6402
Strategy ₃₀ [52]	0.0005	0.3605	0.0002	0.0484	0.3256	0.1500
Strategy ₃₁ [29]	0.4456	0.3631	0.3438	0.3437	0.3439	0.3438
Strategy ₃₂ [53]	0.8646	0.3631	0.3438	0.8730	0.6773	0.4189
Strategy ₃₃ [48]	0.3488	0.3631	0.8018	0.5867	0.3629	0.3457
Strategy ₃₄ [54]	0.4459	0.3631	0.3552	0.3437	0.3439	0.3438
Strategy ₃₅ [55]	0.5815	0.3631	0.3438	0.3892	0.4097	0.3562
Strategy ₃₆ [56]	0.4459	0.3631	0.3438	0.3437	0.3439	0.3800
Strategy ₃₇ [57]	0.4484	0.3631	0.4346	0.8730	0.6598	0.3457
Strategy ₃₈ [58]	0.9720	0.3631	0.4294	0.9713	0.4118	0.7737
Strategy ₃₉ [59]	0.3548	0.3631	0.3438	0.3437	0.3439	0.3457
Strategy ₄₀ [60]	0.3437	0.3631	0.3462	0.3437	0.3439	0.4030
Strategy ₄₁ [30]	0.0277	0.3605	0.1022	0.1089	0.0852	0.0002
Strategy ₄₂ [13]	0.3444	0.3631	0.3438	0.3613	0.3439	0.3438
Strategy ₄₃ [61]	0.3444	0.3631	0.3438	0.3437	0.3439	0.4020
Strategy ₄₄ [62]	0.3552	0.3631	0.3462	0.3437	0.3439	0.3420
Strategy ₄₅ [63]	0.5264	0.3631	0.5214	0.3892	0.3443	0.3463
Strategy ₄₆ [64]	0.9603	0.3631	0.4589	0.3437	0.8856	0.3438
Strategy ₄₇ [31]	0.0005	0.3605	0.0002	0.0005	0.0129	0.0002
Strategy ₄₈ [65]	0.5017	0.3631	0.4346	0.3437	0.3439	0.3438
Strategy ₄₉ [66]	0.3827	0.3641	0.3822	0.3892	0.3439	0.3438
Strategy ₅₀ [67]	0.3437	0.3680	0.3438	0.3437	0.3439	0.3457

Strategy ₅₁ [68]	0.3437	0.3631	0.3000	0.3437	0.3439	0.3575
$q = 8$						
CDW management strategies	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.2923	0.3129	0.0002	0.0004	0.1200	0.1497
Strategy ₂ [33]	0.3097	0.3141	0.3025	0.3135	0.3025	0.5560
Strategy ₃ [34]	0.3024	0.3141	0.3025	0.3024	0.4341	0.3025
Strategy ₄ [20]	0.3347	0.3141	0.3025	0.3024	0.3025	0.3025
Strategy ₅ [21]	0.3146	0.3141	0.3025	0.3024	0.3025	0.3016
Strategy ₆ [35]	0.3877	0.3141	0.3025	0.3135	0.3027	0.3103
Strategy ₇ [36]	0.3150	0.3141	0.3743	0.3135	0.3507	0.3025
Strategy ₈ [37]	0.3775	0.3141	0.3025	0.3135	0.3025	0.5591
Strategy ₉ [38]	0.7984	0.3141	0.3025	0.3024	0.3025	0.5561
Strategy ₁₀ [39]	0.3787	0.3141	0.3701	0.3135	0.3569	0.5564
Strategy ₁₁ [40]	0.3135	0.3141	0.3025	0.3135	0.3507	0.3081
Strategy ₁₂ [41]	0.3134	0.3141	0.3025	0.3135	0.3943	0.3146
Strategy ₁₃ [22]	0.0004	0.3129	0.0002	0.0004	0.0000	0.0456
Strategy ₁₄ [23]	0.0134	0.3129	0.0002	0.0004	0.0000	0.0001
Strategy ₁₅ [42]	0.4191	0.3141	0.3247	0.3024	0.3025	0.3593
Strategy ₁₆ [43]	0.3024	0.3141	0.4356	0.3214	0.3025	0.3025
Strategy ₁₇ [24]	0.0004	0.3129	0.3010	0.0004	0.0000	0.0001
Strategy ₁₈ [44]	0.3024	0.3141	0.3083	0.3098	0.3025	0.3034
Strategy ₁₉ [25]	0.0004	0.3129	0.0002	0.1957	0.0000	0.0001
Strategy ₂₀ [26]	0.0004	0.3129	0.3010	0.0004	0.0000	0.0001
Strategy ₂₁ [45]	0.3097	0.3141	0.3025	0.3024	0.3025	0.3103
Strategy ₂₂ [27]	0.1950	0.3129	0.0002	0.0004	0.0839	0.1058
Strategy ₂₃ [46]	0.3024	0.3141	0.3025	0.3024	0.3025	0.3427
Strategy ₂₄ [47]	0.3024	0.3141	0.3025	0.3024	0.3027	0.3081
Strategy ₂₅ [48]	0.3775	0.3141	0.3847	0.3135	0.3569	0.3110
Strategy ₂₆ [28]	0.0977	0.3129	0.0002	0.0004	0.0000	0.2437
Strategy ₂₇ [49]	0.3150	0.3145	0.3025	0.8035	0.3508	0.3476
Strategy ₂₈ [50]	0.3024	0.3141	0.3025	0.3061	0.3025	0.3088
Strategy ₂₉ [51]	0.4787	0.3141	0.3847	0.3214	0.3025	0.5600
Strategy ₃₀ [52]	0.0004	0.3129	0.0002	0.0391	0.2947	0.1279
Strategy ₃₁ [29]	0.3775	0.3141	0.3025	0.3024	0.3025	0.3025
Strategy ₃₂ [53]	0.7984	0.3141	0.3025	0.8035	0.6170	0.3568
Strategy ₃₃ [48]	0.3046	0.3141	0.7467	0.4812	0.3124	0.3034
Strategy ₃₄ [54]	0.3776	0.3141	0.3083	0.3024	0.3025	0.3025
Strategy ₃₅ [55]	0.4788	0.3141	0.3025	0.3292	0.3507	0.3103
Strategy ₃₆ [56]	0.3776	0.3141	0.3025	0.3024	0.3025	0.3258
Strategy ₃₇ [57]	0.3787	0.3141	0.3701	0.8035	0.5832	0.3034
Strategy ₃₈ [58]	0.8800	0.3141	0.3614	0.8795	0.3516	0.6930
Strategy ₃₉ [59]	0.3096	0.3141	0.3025	0.3024	0.3025	0.3034
Strategy ₄₀ [60]	0.3024	0.3141	0.3035	0.3024	0.3025	0.3427

Strategy ₄₁ [30]	0.0165	0.3129	0.0944	0.0981	0.0813	0.0001
Strategy ₄₂ [13]	0.3027	0.3141	0.3025	0.3135	0.3025	0.3025
Strategy ₄₃ [61]	0.3027	0.3141	0.3025	0.3024	0.3025	0.3423
Strategy ₄₄ [62]	0.3097	0.3141	0.3035	0.3024	0.3025	0.3016
Strategy ₄₅ [63]	0.4293	0.3141	0.4362	0.3292	0.3027	0.3036
Strategy ₄₆ [64]	0.8732	0.3141	0.3853	0.3024	0.8169	0.3025
Strategy ₄₇ [31]	0.0004	0.3129	0.0002	0.0004	0.0077	0.0001
Strategy ₄₈ [65]	0.4154	0.3141	0.3701	0.3024	0.3025	0.3025
Strategy ₄₉ [66]	0.3245	0.3145	0.3254	0.3292	0.3026	0.3025
Strategy ₅₀ [67]	0.3024	0.3163	0.3025	0.3024	0.3025	0.3034
Strategy ₅₁ [68]	0.3024	0.3141	0.2605	0.3024	0.3025	0.3098

 $q = 9$

CDW management strategies	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.2598	0.2711	0.0002	0.0003	0.1054	0.1349
Strategy ₂ [33]	0.2692	0.2716	0.2647	0.2715	0.2647	0.4881
Strategy ₃ [34]	0.2646	0.2716	0.2647	0.2646	0.3625	0.2647
Strategy ₄ [20]	0.2875	0.2716	0.2647	0.2646	0.2647	0.2647
Strategy ₅ [21]	0.2709	0.2716	0.2647	0.2646	0.2647	0.2643
Strategy ₆ [35]	0.3251	0.2716	0.2647	0.2715	0.2648	0.2696
Strategy ₇ [36]	0.2721	0.2716	0.3172	0.2715	0.2998	0.2647
Strategy ₈ [37]	0.3196	0.2716	0.2647	0.2715	0.2647	0.4900
Strategy ₉ [38]	0.7360	0.2716	0.2647	0.2646	0.2647	0.4881
Strategy ₁₀ [39]	0.3202	0.2716	0.3149	0.2715	0.3031	0.4883
Strategy ₁₁ [40]	0.2715	0.2716	0.2647	0.2715	0.2998	0.2680
Strategy ₁₂ [41]	0.2714	0.2716	0.2647	0.2715	0.3317	0.2714
Strategy ₁₃ [22]	0.0003	0.2711	0.0002	0.0003	0.0000	0.0338
Strategy ₁₄ [23]	0.0078	0.2711	0.0002	0.0003	0.0000	0.0001
Strategy ₁₅ [42]	0.3473	0.2716	0.2778	0.2646	0.2647	0.3052
Strategy ₁₆ [43]	0.2646	0.2716	0.3641	0.2754	0.2647	0.2647
Strategy ₁₇ [24]	0.0003	0.2711	0.2659	0.0003	0.0000	0.0001
Strategy ₁₈ [44]	0.2646	0.2716	0.2676	0.2692	0.2647	0.2651
Strategy ₁₉ [25]	0.0003	0.2711	0.0002	0.1735	0.0000	0.0001
Strategy ₂₀ [26]	0.0003	0.2711	0.2659	0.0003	0.0000	0.0001
Strategy ₂₁ [45]	0.2692	0.2716	0.2647	0.2646	0.2647	0.2696
Strategy ₂₂ [27]	0.1733	0.2711	0.0002	0.0003	0.0769	0.0790
Strategy ₂₃ [46]	0.2646	0.2716	0.2647	0.2646	0.2647	0.2920
Strategy ₂₄ [47]	0.2646	0.2716	0.2647	0.2646	0.2648	0.2680
Strategy ₂₅ [48]	0.3196	0.2716	0.3240	0.2715	0.3031	0.2699
Strategy ₂₆ [28]	0.0868	0.2711	0.0002	0.0003	0.0000	0.2191
Strategy ₂₇ [49]	0.2721	0.2717	0.2647	0.7390	0.2998	0.2947
Strategy ₂₈ [50]	0.2646	0.2716	0.2647	0.2669	0.2647	0.2684
Strategy ₂₉ [51]	0.3943	0.2716	0.3240	0.2754	0.2647	0.4903
Strategy ₃₀ [52]	0.0003	0.2711	0.0002	0.0309	0.2623	0.1088

Strategy ₃₁ [29]	0.3196	0.2716	0.2647	0.2646	0.2647	0.2647
Strategy ₃₂ [53]	0.7360	0.2716	0.2647	0.7390	0.5626	0.3039
Strategy ₃₃ [48]	0.2655	0.2716	0.6944	0.3953	0.2698	0.2651
Strategy ₃₄ [54]	0.3197	0.2716	0.2676	0.2646	0.2647	0.2647
Strategy ₃₅ [55]	0.3943	0.2716	0.2647	0.2802	0.2998	0.2696
Strategy ₃₆ [56]	0.3197	0.2716	0.2647	0.2646	0.2647	0.2797
Strategy ₃₇ [57]	0.3202	0.2716	0.3149	0.7390	0.5152	0.2651
Strategy ₃₈ [58]	0.7975	0.2716	0.3054	0.7972	0.3002	0.6235
Strategy ₃₉ [59]	0.2691	0.2716	0.2647	0.2646	0.2647	0.2651
Strategy ₄₀ [60]	0.2646	0.2716	0.2651	0.2646	0.2647	0.2920
Strategy ₄₁ [30]	0.0096	0.2711	0.0851	0.0869	0.0755	0.0001
Strategy ₄₂ [13]	0.2647	0.2716	0.2647	0.2715	0.2647	0.2647
Strategy ₄₃ [61]	0.2647	0.2716	0.2647	0.2646	0.2647	0.2918
Strategy ₄₄ [62]	0.2692	0.2716	0.2651	0.2646	0.2647	0.2643
Strategy ₄₅ [63]	0.3528	0.2716	0.3643	0.2802	0.2648	0.2652
Strategy ₄₆ [64]	0.7936	0.2716	0.3242	0.2646	0.7526	0.2647
Strategy ₄₇ [31]	0.0003	0.2711	0.0002	0.0003	0.0045	0.0001
Strategy ₄₈ [65]	0.3450	0.2716	0.3149	0.2646	0.2647	0.2647
Strategy ₄₉ [66]	0.2772	0.2717	0.2781	0.2802	0.2647	0.2647
Strategy ₅₀ [67]	0.2646	0.2726	0.2647	0.2646	0.2647	0.2651
Strategy ₅₁ [68]	0.2646	0.2716	0.2244	0.2646	0.2647	0.2685

$q = 10$

CDW management strategies	Economic	Environmental	Organisational	Regulatory	Social	Technical
Strategy ₁ [32]	0.2284	0.2346	0.0001	0.0002	0.0916	0.1205
Strategy ₂ [33]	0.2334	0.2348	0.2307	0.2348	0.2307	0.4286
Strategy ₃ [34]	0.2307	0.2348	0.2307	0.2307	0.3031	0.2307
Strategy ₄ [20]	0.2468	0.2348	0.2307	0.2307	0.2307	0.2307
Strategy ₅ [21]	0.2339	0.2348	0.2307	0.2307	0.2307	0.2305
Strategy ₆ [35]	0.2738	0.2348	0.2307	0.2348	0.2308	0.2337
Strategy ₇ [36]	0.2351	0.2348	0.2691	0.2348	0.2562	0.2307
Strategy ₈ [37]	0.2708	0.2348	0.2307	0.2348	0.2307	0.4297
Strategy ₉ [38]	0.6773	0.2348	0.2307	0.2307	0.2307	0.4286
Strategy ₁₀ [39]	0.2710	0.2348	0.2678	0.2348	0.2580	0.4286
Strategy ₁₁ [40]	0.2348	0.2348	0.2307	0.2348	0.2562	0.2327
Strategy ₁₂ [41]	0.2348	0.2348	0.2307	0.2348	0.2795	0.2345
Strategy ₁₃ [22]	0.0002	0.2346	0.0001	0.0002	0.0000	0.0248
Strategy ₁₄ [23]	0.0044	0.2346	0.0001	0.0002	0.0000	0.0001
Strategy ₁₅ [42]	0.2891	0.2348	0.2383	0.2307	0.2307	0.2598
Strategy ₁₆ [43]	0.2307	0.2348	0.3043	0.2367	0.2307	0.2307
Strategy ₁₇ [24]	0.0002	0.2346	0.2324	0.0002	0.0000	0.0001
Strategy ₁₈ [44]	0.2307	0.2348	0.2322	0.2334	0.2307	0.2309
Strategy ₁₉ [25]	0.0002	0.2346	0.0001	0.1524	0.0000	0.0001
Strategy ₂₀ [26]	0.0002	0.2346	0.2324	0.0002	0.0000	0.0001

Strategy ₂₁ [45]	0.2334	0.2348	0.2307	0.2307	0.2307	0.2337
Strategy ₂₂ [27]	0.1523	0.2346	0.0001	0.0002	0.0695	0.0585
Strategy ₂₃ [46]	0.2307	0.2348	0.2307	0.2307	0.2307	0.2493
Strategy ₂₄ [47]	0.2307	0.2348	0.2307	0.2307	0.2308	0.2327
Strategy ₂₅ [48]	0.2708	0.2348	0.2734	0.2348	0.2580	0.2339
Strategy ₂₆ [28]	0.0763	0.2346	0.0001	0.0002	0.0000	0.1953
Strategy ₂₇ [49]	0.2351	0.2348	0.2307	0.6791	0.2562	0.2508
Strategy ₂₈ [50]	0.2307	0.2348	0.2307	0.2321	0.2307	0.2328
Strategy ₂₉ [51]	0.3254	0.2348	0.2734	0.2367	0.2307	0.4298
Strategy ₃₀ [52]	0.0002	0.2346	0.0001	0.0240	0.2309	0.0925
Strategy ₃₁ [29]	0.2708	0.2348	0.2307	0.2307	0.2307	0.2307
Strategy ₃₂ [53]	0.6773	0.2348	0.2307	0.6791	0.5131	0.2590
Strategy ₃₃ [48]	0.2311	0.2348	0.6446	0.3259	0.2334	0.2309
Strategy ₃₄ [54]	0.2708	0.2348	0.2322	0.2307	0.2307	0.2307
Strategy ₃₅ [55]	0.3254	0.2348	0.2307	0.2397	0.2562	0.2337
Strategy ₃₆ [56]	0.2708	0.2348	0.2307	0.2307	0.2307	0.2404
Strategy ₃₇ [57]	0.2710	0.2348	0.2678	0.6791	0.4551	0.2309
Strategy ₃₈ [58]	0.7235	0.2348	0.2590	0.7233	0.2564	0.5629
Strategy ₃₉ [59]	0.2334	0.2348	0.2307	0.2307	0.2307	0.2309
Strategy ₄₀ [60]	0.2307	0.2348	0.2309	0.2307	0.2307	0.2493
Strategy ₄₁ [30]	0.0055	0.2346	0.0754	0.0763	0.0686	0.0001
Strategy ₄₂ [13]	0.2307	0.2348	0.2307	0.2348	0.2307	0.2307
Strategy ₄₃ [61]	0.2307	0.2348	0.2307	0.2307	0.2307	0.2492
Strategy ₄₄ [62]	0.2334	0.2348	0.2309	0.2307	0.2307	0.2305
Strategy ₄₅ [63]	0.2921	0.2348	0.3044	0.2397	0.2308	0.2309
Strategy ₄₆ [64]	0.7213	0.2348	0.2735	0.2307	0.6927	0.2307
Strategy ₄₇ [31]	0.0002	0.2346	0.0001	0.0002	0.0026	0.0001
Strategy ₄₈ [65]	0.2877	0.2348	0.2678	0.2307	0.2307	0.2307
Strategy ₄₉ [66]	0.2378	0.2348	0.2385	0.2397	0.2307	0.2307
Strategy ₅₀ [67]	0.2307	0.2353	0.2307	0.2307	0.2307	0.2309
Strategy ₅₁ [68]	0.2307	0.2348	0.1922	0.2307	0.2307	0.2327

Table B.6

Modelling results of the CDW management strategies per seven q values.

CDW management strategies	$q = 4$							
	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	model	Score	model	Score	model	Score	model
Strategy ₁ [32]	0.0576	41	0.0802	41	0.0186	42	10	41
Strategy ₂ [33]	0.1321	25	0.0545	18	0.1299	26	25	25
Strategy ₃ [34]	0.1530	13	0.0531	13	0.1445	16	34	12

Strategy ₄ [20]	0.1275	28	0.0545	18	0.1273	27	23	27
Strategy ₅ [21]	0.1306	26	0.0545	18	0.1303	25	25	25
Strategy ₆ [35]	0.1461	17	0.0538	16	0.1446	15	32	15
Strategy ₇ [36]	0.1434	20	0.0467	8	0.1421	20	32	15
Strategy ₈ [37]	0.1447	18	0.0545	18	0.1429	18	30	20
Strategy ₉ [38]	0.1669	9	0.0545	18	0.1591	10	33	14
Strategy ₁₀ [39]	0.1677	8	0.0364	3	0.1655	7	44	6
Strategy ₁₁ [40]	0.1401	21	0.0492	10	0.1387	21	31	18
Strategy ₁₂ [41]	0.1523	14	0.0498	12	0.1482	13	36	10
Strategy ₁₃ [22]	0.0196	49	0.0953	46	0.0003	49	3	49
Strategy ₁₄ [23]	0.0229	47	0.0953	46	0.0011	46	4	46
Strategy ₁₅ [42]	0.1507	15	0.0545	18	0.1477	14	32	15
Strategy ₁₆ [43]	0.1290	27	0.0545	18	0.1272	28	23	27
Strategy ₁₇ [24]	0.0195	50	0.0953	46	0.0002	50	2	50
Strategy ₁₈ [44]	0.1228	34	0.0545	18	0.1221	35	16	34
Strategy ₁₉ [25]	0.0283	46	0.0953	46	0.0006	48	4	46
Strategy ₂₀ [26]	0.0195	50	0.0953	46	0.0002	50	2	50
Strategy ₂₁ [45]	0.1232	32	0.0545	18	0.1229	30	19	31
Strategy ₂₂ [27]	0.0444	43	0.0876	43	0.0137	43	8	42
Strategy ₂₃ [46]	0.1231	33	0.0545	18	0.1221	34	17	33
Strategy ₂₄ [47]	0.1216	39	0.0538	14	0.1209	39	13	38
Strategy ₂₅ [48]	0.1596	12	0.0386	5	0.1580	11	40	8
Strategy ₂₆ [28]	0.0297	45	0.0953	46	0.0019	45	6	45
Strategy ₂₇ [49]	0.1725	6	0.0467	8	0.1659	6	44	6
Strategy ₂₈ [50]	0.1220	38	0.0545	18	0.1214	38	13	38
Strategy ₂₉ [51]	0.1693	7	0.0545	18	0.1644	8	34	12
Strategy ₃₀ [52]	0.0552	42	0.0834	42	0.0074	44	8	42
Strategy ₃₁ [29]	0.1349	24	0.0545	18	0.1342	24	27	24
Strategy ₃₂ [53]	0.2283	2	0.0169	1	0.2230	2	50	1
Strategy ₃₃ [48]	0.1617	11	0.0496	11	0.1549	12	38	9
Strategy ₃₄ [54]	0.1358	23	0.0545	18	0.1350	23	28	23
Strategy ₃₅ [55]	0.1757	5	0.0418	7	0.1731	5	45	5
Strategy ₃₆ [56]	0.1373	22	0.0545	18	0.1366	22	29	22
Strategy ₃₇ [57]	0.2065	4	0.0364	3	0.1985	4	48	3
Strategy ₃₈ [58]	0.2363	1	0.0392	6	0.2260	1	46	4
Strategy ₃₉ [59]	0.1224	37	0.0545	18	0.1220	36	14	36
Strategy ₄₀ [60]	0.1233	31	0.0545	18	0.1222	32	19	31
Strategy ₄₁ [30]	0.0365	44	0.0890	44	0.0196	41	8	42
Strategy ₄₂ [13]	0.1236	30	0.0545	18	0.1230	29	21	29
Strategy ₄₃ [61]	0.1236	29	0.0545	18	0.1228	31	20	30
Strategy ₄₄ [62]	0.1225	35	0.0545	18	0.1221	33	16	34
Strategy ₄₅ [63]	0.1646	10	0.0538	14	0.1606	9	36	10
Strategy ₄₆ [64]	0.2265	3	0.0362	2	0.2108	3	49	2

Strategy ₄₇ [31]	0.0217	48	0.0912	45	0.0010	47	4	46
Strategy ₄₈ [65]	0.1467	16	0.0545	18	0.1439	17	31	18
Strategy ₄₉ [66]	0.1436	19	0.0543	17	0.1428	19	30	20
Strategy ₅₀ [67]	0.1224	36	0.0545	18	0.1214	37	14	36
Strategy ₅₁ [68]	0.1214	40	0.0545	18	0.1207	40	12	40
$q = 5$								
CDW management strategies	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	mode l	Score	mode l	Score	mode l	Score	model
Strategy ₁ [32]	0.0632	41	0.0959	42	0.0252	41	10	41
Strategy ₂ [33]	0.1303	25	0.0662	18	0.1288	27	24	26
Strategy ₃ [34]	0.1552	12	0.0601	13	0.1476	13	36	10
Strategy ₄ [20]	0.1289	27	0.0662	18	0.1288	26	24	26
Strategy ₅ [21]	0.1292	26	0.0662	18	0.1291	25	25	25
Strategy ₆ [35]	0.1440	17	0.0659	14	0.1430	17	33	14
Strategy ₇ [36]	0.1422	19	0.0552	8	0.1409	19	33	14
Strategy ₈ [37]	0.1427	18	0.0662	18	0.1414	18	30	20
Strategy ₉ [38]	0.1725	6	0.0662	18	0.1636	6	34	13
Strategy ₁₀ [39]	0.1620	9	0.0485	4	0.1605	8	43	6
Strategy ₁₁ [40]	0.1404	20	0.0567	10	0.1390	20	32	17
Strategy ₁₂ [41]	0.1521	13	0.0570	11	0.1484	12	37	9
Strategy ₁₃ [22]	0.0159	49	0.1139	46	0.0003	49	3	49
Strategy ₁₄ [23]	0.0192	47	0.1139	46	0.0011	47	4	46
Strategy ₁₅ [42]	0.1490	15	0.0662	18	0.1467	15	32	17
Strategy ₁₆ [43]	0.1272	28	0.0662	18	0.1261	28	23	28
Strategy ₁₇ [24]	0.0159	50	0.1139	46	0.0002	50	2	50
Strategy ₁₈ [44]	0.1235	36	0.0662	18	0.1230	34	15	35
Strategy ₁₉ [25]	0.0254	46	0.1139	46	0.0006	48	4	46
Strategy ₂₀ [26]	0.0159	50	0.1139	46	0.0002	50	2	50
Strategy ₂₁ [45]	0.1245	29	0.0662	18	0.1242	29	22	29
Strategy ₂₂ [27]	0.0465	43	0.1036	43	0.0181	43	8	42
Strategy ₂₃ [46]	0.1235	35	0.0662	18	0.1228	36	15	35
Strategy ₂₄ [47]	0.1227	39	0.0659	15	0.1222	39	13	38
Strategy ₂₅ [48]	0.1569	11	0.0485	4	0.1559	10	41	8
Strategy ₂₆ [28]	0.0276	45	0.1139	46	0.0018	45	6	45
Strategy ₂₇ [49]	0.1679	7	0.0552	8	0.1609	7	43	6
Strategy ₂₈ [50]	0.1231	37	0.0662	18	0.1225	37	14	37
Strategy ₂₉ [51]	0.1642	8	0.0662	18	0.1601	9	33	14
Strategy ₃₀ [52]	0.0600	42	0.0945	41	0.0082	44	8	42
Strategy ₃₁ [29]	0.1365	24	0.0662	18	0.1359	24	27	24
Strategy ₃₂ [53]	0.2386	2	0.0232	1	0.2338	1	50	1
Strategy ₃₃ [48]	0.1520	14	0.0588	12	0.1468	14	36	10
Strategy ₃₄ [54]	0.1368	23	0.0662	18	0.1362	23	28	23
Strategy ₃₅ [55]	0.1736	5	0.0533	7	0.1716	5	45	5

Strategy ₃₆ [56]	0.1376	22	0.0662	18	0.1371	22	29	22
Strategy ₃₇ [57]	0.2089	4	0.0446	3	0.2008	4	48	3
Strategy ₃₈ [58]	0.2358	3	0.0519	6	0.2242	3	46	4
Strategy ₃₉ [59]	0.1240	32	0.0662	18	0.1237	32	19	32
Strategy ₄₀ [60]	0.1236	34	0.0662	18	0.1229	35	16	34
Strategy ₄₁ [30]	0.0350	44	0.1049	44	0.0220	42	8	42
Strategy ₄₂ [13]	0.1243	30	0.0662	18	0.1237	31	20	30
Strategy ₄₃ [61]	0.1238	33	0.0662	18	0.1232	33	18	33
Strategy ₄₄ [62]	0.1241	31	0.0662	18	0.1238	30	20	30
Strategy ₄₅ [63]	0.1584	10	0.0659	15	0.1556	11	35	12
Strategy ₄₆ [64]	0.2466	1	0.0325	2	0.2304	2	50	1
Strategy ₄₇ [31]	0.0183	48	0.1103	45	0.0012	46	4	46
Strategy ₄₈ [65]	0.1464	16	0.0662	18	0.1443	16	31	19
Strategy ₄₉ [66]	0.1377	21	0.0661	17	0.1374	21	30	20
Strategy ₅₀ [67]	0.1230	38	0.0662	18	0.1223	38	13	38
Strategy ₅₁ [68]	0.1225	40	0.0662	18	0.1220	40	12	40

 $q = 6$

CDW management strategies	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	mode l	Score	mode l	Score	mode l	Score	model
Strategy ₁ [32]	0.0677	41	0.1122	42	0.0316	41	10	41
Strategy ₂ [33]	0.1288	26	0.0791	18	0.1277	26	25	26
Strategy ₃ [34]	0.1554	10	0.0666	8	0.1489	12	39	9
Strategy ₄ [20]	0.1294	25	0.0791	18	0.1293	25	26	25
Strategy ₅ [21]	0.1278	27	0.0791	18	0.1277	27	24	27
Strategy ₆ [35]	0.1414	17	0.0790	14	0.1408	16	33	13
Strategy ₇ [36]	0.1405	18	0.0668	10	0.1393	19	33	13
Strategy ₈ [37]	0.1404	19	0.0791	18	0.1396	18	30	20
Strategy ₉ [38]	0.1790	5	0.0791	18	0.1685	5	34	12
Strategy ₁₀ [39]	0.1566	9	0.0637	4	0.1556	9	43	5
Strategy ₁₁ [40]	0.1396	20	0.0668	10	0.1383	20	32	17
Strategy ₁₂ [41]	0.1506	13	0.0641	6	0.1473	13	39	9
Strategy ₁₃ [22]	0.0126	51	0.1329	46	0.0002	49	1	51
Strategy ₁₄ [23]	0.0154	47	0.1329	46	0.0010	47	4	46
Strategy ₁₅ [42]	0.1464	14	0.0791	18	0.1449	14	32	17
Strategy ₁₆ [43]	0.1261	28	0.0791	18	0.1254	28	23	28
Strategy ₁₇ [24]	0.0126	49	0.1329	46	0.0002	50	2	49
Strategy ₁₈ [44]	0.1241	34	0.0791	18	0.1237	33	17	33
Strategy ₁₉ [25]	0.0217	46	0.1329	46	0.0005	48	4	46
Strategy ₂₀ [26]	0.0126	49	0.1329	46	0.0002	50	2	49
Strategy ₂₁ [45]	0.1251	29	0.0791	18	0.1249	29	22	29
Strategy ₂₂ [27]	0.0487	43	0.1201	43	0.0226	42	9	42
Strategy ₂₃ [46]	0.1240	36	0.0791	18	0.1234	36	15	36
Strategy ₂₄ [47]	0.1236	39	0.0790	15	0.1231	39	13	38

Strategy ₂₅ [48]	0.1536	11	0.0637	4	0.1529	10	41	6
Strategy ₂₆ [28]	0.0254	45	0.1329	46	0.0017	45	6	45
Strategy ₂₇ [49]	0.1634	7	0.0667	9	0.1563	7	41	6
Strategy ₂₈ [50]	0.1238	37	0.0791	18	0.1234	37	14	37
Strategy ₂₉ [51]	0.1593	8	0.0791	18	0.1560	8	33	13
Strategy ₃₀ [52]	0.0644	42	0.1042	41	0.0086	44	8	43
Strategy ₃₁ [29]	0.1366	23	0.0791	18	0.1362	23	27	23
Strategy ₃₂ [53]	0.2501	2	0.0295	2	0.2458	2	50	2
Strategy ₃₃ [48]	0.1439	16	0.0741	13	0.1402	17	33	13
Strategy ₃₄ [54]	0.1367	22	0.0791	18	0.1363	22	28	22
Strategy ₃₅ [55]	0.1696	6	0.0668	10	0.1681	6	41	6
Strategy ₃₆ [56]	0.1371	21	0.0791	18	0.1367	21	29	21
Strategy ₃₇ [57]	0.2104	4	0.0527	3	0.2018	4	48	3
Strategy ₃₈ [58]	0.2355	3	0.0661	7	0.2224	3	45	4
Strategy ₃₉ [59]	0.1249	31	0.0791	18	0.1246	31	20	31
Strategy ₄₀ [60]	0.1240	35	0.0791	18	0.1235	35	16	35
Strategy ₄₁ [30]	0.0332	44	0.1211	44	0.0223	43	8	43
Strategy ₄₂ [13]	0.1246	32	0.0791	18	0.1241	32	19	32
Strategy ₄₃ [61]	0.1241	33	0.0791	18	0.1236	34	17	33
Strategy ₄₄ [62]	0.1250	30	0.0791	18	0.1247	30	21	30
Strategy ₄₅ [63]	0.1525	12	0.0790	15	0.1506	11	35	11
Strategy ₄₆ [64]	0.2674	1	0.0285	1	0.2512	1	51	1
Strategy ₄₇ [31]	0.0148	48	0.1301	45	0.0012	46	4	46
Strategy ₄₈ [65]	0.1447	15	0.0791	18	0.1433	15	31	19
Strategy ₄₉ [66]	0.1333	24	0.0791	17	0.1332	24	27	23
Strategy ₅₀ [67]	0.1236	38	0.0791	18	0.1231	38	13	38
Strategy ₅₁ [68]	0.1234	40	0.0791	18	0.1230	40	12	40

 $q = 7$

CDW management strategies	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	mode l	Score	mode l	Score	mode l	Score	model
Strategy ₁ [32]	0.0708	41	0.1289	42	0.0375	41	10	41
Strategy ₂ [33]	0.1274	26	0.0931	18	0.1267	26	25	26
Strategy ₃ [34]	0.1540	9	0.0727	5	0.1485	11	40	7
Strategy ₄ [20]	0.1291	25	0.0931	18	0.1290	25	26	25
Strategy ₅ [21]	0.1266	27	0.0931	18	0.1264	27	24	27
Strategy ₆ [35]	0.1387	16	0.0930	14	0.1383	16	33	14
Strategy ₇ [36]	0.1384	17	0.0818	10	0.1373	18	34	12
Strategy ₈ [37]	0.1379	19	0.0931	18	0.1374	17	30	19
Strategy ₉ [38]	0.1857	5	0.0931	18	0.1730	5	34	12
Strategy ₁₀ [39]	0.1516	10	0.0797	6	0.1509	9	41	5
Strategy ₁₁ [40]	0.1379	18	0.0818	10	0.1368	19	33	14
Strategy ₁₂ [41]	0.1481	12	0.0716	4	0.1453	13	39	10
Strategy ₁₃ [22]	0.0098	51	0.1521	46	0.0002	49	1	51

Strategy ₁₄ [23]	0.0120	47	0.1521	46	0.0008	47	4	46
Strategy ₁₅ [42]	0.1433	14	0.0931	18	0.1423	14	32	17
Strategy ₁₆ [43]	0.1253	28	0.0931	18	0.1248	31	20	30
Strategy ₁₇ [24]	0.0098	49	0.1521	46	0.0002	50	2	49
Strategy ₁₈ [44]	0.1243	33	0.0931	18	0.1239	33	18	33
Strategy ₁₉ [25]	0.0179	46	0.1521	46	0.0004	48	4	46
Strategy ₂₀ [26]	0.0098	49	0.1521	46	0.0002	50	2	49
Strategy ₂₁ [45]	0.1252	29	0.0931	18	0.1250	28	22	28
Strategy ₂₂ [27]	0.0504	43	0.1367	43	0.0270	42	9	42
Strategy ₂₃ [46]	0.1242	36	0.0931	18	0.1237	37	14	36
Strategy ₂₄ [47]	0.1240	39	0.0930	15	0.1236	38	13	38
Strategy ₂₅ [48]	0.1498	11	0.0797	6	0.1494	10	40	7
Strategy ₂₆ [28]	0.0234	45	0.1521	46	0.0015	45	6	45
Strategy ₂₇ [49]	0.1587	7	0.0817	9	0.1517	8	40	7
Strategy ₂₈ [50]	0.1241	37	0.0931	18	0.1237	36	14	36
Strategy ₂₉ [51]	0.1544	8	0.0931	18	0.1519	7	33	14
Strategy ₃₀ [52]	0.0680	42	0.1124	41	0.0089	44	8	43
Strategy ₃₁ [29]	0.1356	23	0.0931	18	0.1354	22	27	23
Strategy ₃₂ [53]	0.2624	2	0.0358	2	0.2585	2	50	2
Strategy ₃₃ [48]	0.1376	20	0.0898	13	0.1352	23	29	20
Strategy ₃₄ [54]	0.1357	22	0.0931	18	0.1355	21	28	22
Strategy ₃₅ [55]	0.1645	6	0.0818	10	0.1634	6	41	5
Strategy ₃₆ [56]	0.1359	21	0.0931	18	0.1356	20	29	20
Strategy ₃₇ [57]	0.2110	4	0.0606	3	0.2017	4	48	3
Strategy ₃₈ [58]	0.2351	3	0.0814	8	0.2202	3	44	4
Strategy ₃₉ [59]	0.1251	31	0.0931	18	0.1249	30	20	30
Strategy ₄₀ [60]	0.1242	35	0.0931	18	0.1237	35	16	35
Strategy ₄₁ [30]	0.0315	44	0.1375	44	0.0211	43	8	43
Strategy ₄₂ [13]	0.1246	32	0.0931	18	0.1242	32	19	32
Strategy ₄₃ [61]	0.1242	34	0.0931	18	0.1238	34	17	34
Strategy ₄₄ [62]	0.1252	30	0.0931	18	0.1249	29	21	29
Strategy ₄₅ [63]	0.1470	13	0.0930	15	0.1459	12	35	11
Strategy ₄₆ [64]	0.2884	1	0.0245	1	0.2724	1	51	1
Strategy ₄₇ [31]	0.0116	48	0.1499	45	0.0011	46	4	46
Strategy ₄₈ [65]	0.1422	15	0.0931	18	0.1413	15	31	18
Strategy ₄₉ [66]	0.1302	24	0.0930	17	0.1301	24	27	23
Strategy ₅₀ [67]	0.1240	38	0.0931	18	0.1236	39	13	38
Strategy ₅₁ [68]	0.1239	40	0.0931	18	0.1235	40	12	40

 $q = 8$

CDW management strategies	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	mode I	Score	mode I	Score	mode I	Score	model
Strategy ₁ [32]	0.0726	41	0.1460	42	0.0426	41	10	41
Strategy ₂ [33]	0.1262	26	0.1078	18	0.1256	26	25	26

Strategy ₃ [34]	0.1514	8	0.0802	4	0.1469	9	43	5
Strategy ₄ [20]	0.1282	24	0.1078	18	0.1281	24	26	24
Strategy ₅ [21]	0.1255	27	0.1078	18	0.1253	27	24	27
Strategy ₆ [35]	0.1359	17	0.1077	14	0.1357	16	33	14
Strategy ₇ [36]	0.1361	16	0.0977	10	0.1350	18	34	12
Strategy ₈ [37]	0.1354	19	0.1078	18	0.1350	17	30	19
Strategy ₉ [38]	0.1920	5	0.1078	18	0.1770	5	34	12
Strategy ₁₀ [39]	0.1470	10	0.0964	6	0.1464	10	41	6
Strategy ₁₁ [40]	0.1359	18	0.0977	10	0.1348	19	33	14
Strategy ₁₂ [41]	0.1450	12	0.0885	5	0.1426	12	40	8
Strategy ₁₃ [22]	0.0076	49	0.1711	46	0.0002	49	3	49
Strategy ₁₄ [23]	0.0092	47	0.1711	46	0.0006	47	4	46
Strategy ₁₅ [42]	0.1399	14	0.1078	18	0.1393	14	32	17
Strategy ₁₆ [43]	0.1246	31	0.1078	18	0.1242	31	20	31
Strategy ₁₇ [24]	0.0076	50	0.1711	46	0.0002	50	2	50
Strategy ₁₈ [44]	0.1241	33	0.1078	18	0.1237	33	18	33
Strategy ₁₉ [25]	0.0144	46	0.1711	46	0.0003	48	4	46
Strategy ₂₀ [26]	0.0076	50	0.1711	46	0.0002	50	2	50
Strategy ₂₁ [45]	0.1249	28	0.1078	18	0.1246	28	23	28
Strategy ₂₂ [27]	0.0517	43	0.1536	43	0.0308	42	9	42
Strategy ₂₃ [46]	0.1240	37	0.1078	18	0.1236	37	14	37
Strategy ₂₄ [47]	0.1239	38	0.1077	15	0.1235	38	14	37
Strategy ₂₅ [48]	0.1459	11	0.0964	6	0.1455	11	40	8
Strategy ₂₆ [28]	0.0215	45	0.1711	46	0.0014	45	6	45
Strategy ₂₇ [49]	0.1538	7	0.0976	9	0.1472	8	40	8
Strategy ₂₈ [50]	0.1240	35	0.1078	18	0.1236	35	16	35
Strategy ₂₉ [51]	0.1494	9	0.1078	18	0.1477	7	33	14
Strategy ₃₀ [52]	0.0710	42	0.1193	41	0.0089	44	8	43
Strategy ₃₁ [29]	0.1340	22	0.1078	18	0.1339	22	27	23
Strategy ₃₂ [53]	0.2752	2	0.0419	2	0.2715	2	50	2
Strategy ₃₃ [48]	0.1329	23	0.1057	13	0.1312	23	29	20
Strategy ₃₄ [54]	0.1340	21	0.1078	18	0.1339	21	28	22
Strategy ₃₅ [55]	0.1588	6	0.0977	10	0.1581	6	41	6
Strategy ₃₆ [56]	0.1341	20	0.1078	18	0.1340	20	29	20
Strategy ₃₇ [57]	0.2110	4	0.0680	3	0.2009	4	48	3
Strategy ₃₈ [58]	0.2346	3	0.0975	8	0.2177	3	44	4
Strategy ₃₉ [59]	0.1248	30	0.1078	18	0.1245	30	21	30
Strategy ₄₀ [60]	0.1240	36	0.1078	18	0.1236	36	15	36
Strategy ₄₁ [30]	0.0301	44	0.1541	44	0.0191	43	8	43
Strategy ₄₂ [13]	0.1243	32	0.1078	18	0.1239	32	19	32
Strategy ₄₃ [61]	0.1240	34	0.1078	18	0.1236	34	17	34
Strategy ₄₄ [62]	0.1248	29	0.1078	18	0.1245	29	22	29
Strategy ₄₅ [63]	0.1421	13	0.1077	15	0.1415	13	35	11

Strategy ₄₆ [64]	0.3090	1	0.0207	1	0.2937	1	51	1
Strategy ₄₇ [31]	0.0090	48	0.1695	45	0.0010	46	4	46
Strategy ₄₈ [65]	0.1392	15	0.1078	18	0.1387	15	31	18
Strategy ₄₉ [66]	0.1278	25	0.1078	17	0.1277	25	26	24
Strategy ₅₀ [67]	0.1239	39	0.1078	18	0.1235	39	13	39
Strategy ₅₁ [68]	0.1238	40	0.1078	18	0.1235	40	12	40

$q = 9$

CDW management strategies	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	mode l	Score	mode l	Score	mode l	Score	model
Strategy ₁ [32]	0.0733	41	0.1633	42	0.0465	41	10	41
Strategy ₂ [33]	0.1248	26	0.1231	18	0.1243	26	25	26
Strategy ₃ [34]	0.1480	8	0.0984	4	0.1443	7	44	4
Strategy ₄ [20]	0.1269	24	0.1231	18	0.1268	24	26	24
Strategy ₅ [21]	0.1243	27	0.1231	18	0.1240	27	24	27
Strategy ₆ [35]	0.1331	18	0.1231	14	0.1330	16	33	14
Strategy ₇ [36]	0.1336	16	0.1142	10	0.1326	17	35	11
Strategy ₈ [37]	0.1327	19	0.1231	18	0.1325	18	30	19
Strategy ₉ [38]	0.1978	5	0.1231	18	0.1803	5	34	13
Strategy ₁₀ [39]	0.1425	10	0.1134	6	0.1421	10	41	6
Strategy ₁₁ [40]	0.1335	17	0.1142	10	0.1325	19	33	14
Strategy ₁₂ [41]	0.1415	12	0.1062	5	0.1395	12	40	8
Strategy ₁₃ [22]	0.0059	49	0.1898	46	0.0002	49	3	49
Strategy ₁₄ [23]	0.0069	47	0.1898	46	0.0005	47	4	46
Strategy ₁₅ [42]	0.1364	14	0.1231	18	0.1361	14	32	17
Strategy ₁₆ [43]	0.1237	31	0.1231	18	0.1233	31	20	31
Strategy ₁₇ [24]	0.0058	50	0.1898	46	0.0002	50	2	50
Strategy ₁₈ [44]	0.1235	33	0.1231	18	0.1231	33	18	33
Strategy ₁₉ [25]	0.0114	46	0.1898	46	0.0002	48	4	46
Strategy ₂₀ [26]	0.0058	50	0.1898	46	0.0002	50	2	50
Strategy ₂₁ [45]	0.1240	28	0.1231	18	0.1237	28	23	28
Strategy ₂₂ [27]	0.0524	43	0.1705	43	0.0340	42	9	42
Strategy ₂₃ [46]	0.1234	37	0.1231	18	0.1230	37	14	37
Strategy ₂₄ [47]	0.1233	38	0.1231	15	0.1230	38	14	37
Strategy ₂₅ [48]	0.1419	11	0.1134	6	0.1416	11	40	8
Strategy ₂₆ [28]	0.0199	45	0.1898	46	0.0013	45	6	45
Strategy ₂₇ [49]	0.1489	7	0.1142	9	0.1427	9	40	8
Strategy ₂₈ [50]	0.1234	34	0.1231	18	0.1230	34	17	34
Strategy ₂₉ [51]	0.1446	9	0.1231	18	0.1434	8	33	14
Strategy ₃₀ [52]	0.0732	42	0.1249	41	0.0085	44	8	43
Strategy ₃₁ [29]	0.1319	22	0.1231	18	0.1319	22	27	23
Strategy ₃₂ [53]	0.2879	2	0.0479	2	0.2846	2	50	2
Strategy ₃₃ [48]	0.1292	23	0.1218	13	0.1281	23	29	20
Strategy ₃₄ [54]	0.1319	21	0.1231	18	0.1319	21	28	22

Strategy ₃₅ [55]	0.1530	6	0.1142	10	0.1525	6	41	6
Strategy ₃₆ [56]	0.1320	20	0.1231	18	0.1319	20	29	20
Strategy ₃₇ [57]	0.2107	4	0.0748	3	0.1997	4	48	3
Strategy ₃₈ [58]	0.2341	3	0.1141	8	0.2149	3	44	4
Strategy ₃₉ [59]	0.1240	30	0.1231	18	0.1237	30	21	30
Strategy ₄₀ [60]	0.1234	36	0.1231	18	0.1230	36	15	36
Strategy ₄₁ [30]	0.0291	44	0.1708	44	0.0167	43	8	43
Strategy ₄₂ [13]	0.1236	32	0.1231	18	0.1232	32	19	32
Strategy ₄₃ [61]	0.1234	35	0.1231	18	0.1230	35	16	35
Strategy ₄₄ [62]	0.1240	29	0.1231	18	0.1237	29	22	29
Strategy ₄₅ [63]	0.1377	13	0.1231	15	0.1374	13	35	11
Strategy ₄₆ [64]	0.3293	1	0.0174	1	0.3148	1	51	1
Strategy ₄₇ [31]	0.0068	48	0.1887	45	0.0007	46	4	46
Strategy ₄₈ [65]	0.1359	15	0.1231	18	0.1357	15	31	18
Strategy ₄₉ [66]	0.1258	25	0.1231	17	0.1256	25	26	24
Strategy ₅₀ [67]	0.1233	39	0.1231	18	0.1230	39	13	39
Strategy ₅₁ [68]	0.1233	40	0.1231	18	0.1229	40	12	40

$q = 10$

CDW management strategies	Ratio-system method		Reference-point method		Full-multiplicative form		Aggregation results	
	Score	mode l	Score	mode l	Score	mode l	Score	model
Strategy ₁ [32]	0.0731	42	0.1808	42	0.0490	41	10	41
Strategy ₂ [33]	0.1233	26	0.1389	19	0.1228	26	24	26
Strategy ₃ [34]	0.1441	7	0.1172	4	0.1411	7	45	4
Strategy ₄ [20]	0.1252	24	0.1389	19	0.1251	24	25	24
Strategy ₅ [21]	0.1229	27	0.1389	19	0.1226	27	23	27
Strategy ₆ [35]	0.1302	18	0.1389	15	0.1302	16	32	15
Strategy ₇ [36]	0.1309	16	0.1313	10	0.1300	17	35	11
Strategy ₈ [37]	0.1300	19	0.1389	19	0.1299	19	29	19
Strategy ₉ [38]	0.2028	5	0.1389	19	0.1827	5	33	14
Strategy ₁₀ [39]	0.1382	10	0.1307	6	0.1379	10	41	6
Strategy ₁₁ [40]	0.1309	17	0.1313	10	0.1300	18	34	12
Strategy ₁₂ [41]	0.1379	12	0.1243	5	0.1361	12	40	8
Strategy ₁₃ [22]	0.0045	49	0.2083	46	0.0001	49	3	49
Strategy ₁₄ [23]	0.0052	47	0.2083	46	0.0004	47	4	46
Strategy ₁₅ [42]	0.1329	14	0.1389	19	0.1327	14	31	17
Strategy ₁₆ [43]	0.1225	31	0.1389	19	0.1221	31	19	31
Strategy ₁₇ [24]	0.0045	50	0.2083	46	0.0001	50	2	50
Strategy ₁₈ [44]	0.1224	33	0.1389	19	0.1220	33	17	33
Strategy ₁₉ [25]	0.0089	46	0.2083	46	0.0002	48	4	46
Strategy ₂₀ [26]	0.0045	50	0.2083	46	0.0001	50	2	50
Strategy ₂₁ [45]	0.1228	28	0.1389	19	0.1225	28	22	28
Strategy ₂₂ [27]	0.0527	43	0.1874	43	0.0363	42	9	42
Strategy ₂₃ [46]	0.1224	37	0.1389	19	0.1220	37	13	37

Strategy ₂₄ [47]	0.1224	38	0.1389	16	0.1220	38	13	37
Strategy ₂₅ [48]	0.1379	11	0.1307	6	0.1376	11	40	8
Strategy ₂₆ [28]	0.0184	45	0.2083	46	0.0012	45	6	45
Strategy ₂₇ [49]	0.1440	8	0.1313	9	0.1384	9	40	8
Strategy ₂₈ [50]	0.1224	34	0.1389	19	0.1220	34	16	34
Strategy ₂₉ [51]	0.1398	9	0.1389	19	0.1392	8	32	15
Strategy ₃₀ [52]	0.0747	41	0.1389	14	0.0076	44	8	43
Strategy ₃₁ [29]	0.1295	22	0.1389	19	0.1295	22	26	23
Strategy ₃₂ [53]	0.3006	2	0.0540	2	0.2976	2	50	2
Strategy ₃₃ [48]	0.1261	23	0.1381	13	0.1253	23	29	19
Strategy ₃₄ [54]	0.1295	21	0.1389	19	0.1295	21	27	22
Strategy ₃₅ [55]	0.1473	6	0.1313	10	0.1470	6	41	6
Strategy ₃₆ [56]	0.1296	20	0.1389	19	0.1295	20	28	21
Strategy ₃₇ [57]	0.2102	4	0.0811	3	0.1982	4	48	3
Strategy ₃₈ [58]	0.2335	3	0.1312	8	0.2120	3	44	5
Strategy ₃₉ [59]	0.1228	30	0.1389	19	0.1225	30	20	30
Strategy ₄₀ [60]	0.1224	36	0.1389	19	0.1220	36	14	36
Strategy ₄₁ [30]	0.0282	44	0.1877	44	0.0144	43	8	43
Strategy ₄₂ [13]	0.1225	32	0.1389	19	0.1221	32	18	32
Strategy ₄₃ [61]	0.1224	35	0.1389	19	0.1220	35	15	35
Strategy ₄₄ [62]	0.1228	29	0.1389	19	0.1225	29	21	29
Strategy ₄₅ [63]	0.1336	13	0.1389	16	0.1335	13	34	12
Strategy ₄₆ [64]	0.3492	1	0.0145	1	0.3356	1	51	1
Strategy ₄₇ [31]	0.0052	48	0.2075	45	0.0005	46	4	46
Strategy ₄₈ [65]	0.1326	15	0.1389	19	0.1324	15	30	18
Strategy ₄₉ [66]	0.1239	25	0.1389	18	0.1236	25	25	24
Strategy ₅₀ [67]	0.1224	39	0.1389	19	0.1220	39	12	39
Strategy ₅₁ [68]	0.1223	40	0.1389	19	0.1219	40	11	40

Table B.7

Modelling results of the CDW management strategies per seven q values using the proposed method and VIKOR.

CDW management strategies	$q = 4$		$q = 5$		$q = 6$		$q = 7$		$q = 8$		$q = 9$		$q = 10$	
	VI KO R	MULTI MOOR A	VI KO R	MULTI MOOR A	VI KO R	MULTI MOOR A	VI KO R	MULTI MOOR A	VI KO R	MULTI MOOR A	VI KO R	MULTI MOOR A	VI KO R	MULTI MOOR A
Strategy ₁ [32]	41	41	41	41	41	41	41	42	41	42	41	42	41	42
Strategy ₂ [33]	25	26	26	26	26	27	26	27	26	27	26	27	26	27

Strategy ₃ [34]	12	18	10	14	9	11	7	7	5	5	4	6	4	6
Strategy ₄ [20]	27	28	26	28	25	26	25	26	24	26	24	25	24	25
Strategy ₅ [21]	25	27	25	27	27	28	27	28	27	28	27	28	27	28
Strategy ₆ [35]	15	19	14	19	13	19	14	19	14	19	14	18	15	18
Strategy ₇ [36]	15	13	14	13	13	12	12	12	12	12	11	12	11	12
Strategy ₈ [37]	20	21	20	21	20	20	19	20	19	20	19	19	19	19
Strategy ₉ [38]	14	11	13	9	12	9	12	6	12	6	13	5	14	5
Strategy ₁₀ [39]	6	5	6	5	5	7	5	10	6	10	6	10	6	10
Strategy ₁₁ [40]	18	17	17	16	17	13	14	13	14	13	14	13	12	13
Strategy ₁₂ [41]	10	14	9	10	9	10	10	9	8	7	8	7	8	7
Strategy ₁₃ [22]	49	51	49	49	51	49	51	49	49	49	49	49	49	49
Strategy ₁₄ [23]	46	48	46	48	46	48	46	48	46	48	46	48	46	48
Strategy ₁₅ [42]	15	16	17	17	17	17	17	17	17	16	17	16	17	16
Strategy ₁₆ [43]	27	29	28	29	28	29	30	30	31	32	31	32	31	32
Strategy ₁₇ [24]	50	49	50	50	49	50	49	50	50	50	50	50	50	50
Strategy ₁₈ [44]	34	37	35	38	33	35	33	34	33	34	33	34	33	34
Strategy ₁₉ [25]	46	47	46	47	46	47	46	46	46	46	46	46	46	46
Strategy ₂₀ [26]	50	49	50	50	49	50	49	50	50	50	50	50	50	50
Strategy ₂₁ [45]	31	31	29	30	29	30	28	29	28	29	28	29	28	29
Strategy ₂₂ [27]	42	43	42	43	42	43	42	43	42	43	42	43	42	43
Strategy ₂₃ [46]	33	36	35	37	36	37	36	37	37	37	37	38	37	38
Strategy ₂₄ [47]	38	39	38	35	38	38	38	38	37	39	37	39	37	39
Strategy ₂₅ [48]	8	7	8	7	6	8	7	11	8	11	8	11	8	11
Strategy ₂₆ [28]	45	46	45	45	45	45	45	45	45	45	45	45	45	45
Strategy ₂₇ [49]	6	8	6	8	6	6	7	8	8	9	8	9	8	9
Strategy ₂₈ [50]	38	38	37	39	37	39	36	39	35	38	34	36	34	35
Strategy ₂₉ [51]	12	9	14	11	13	14	14	14	14	14	14	14	15	14
Strategy ₃₀ [52]	42	42	42	42	43	42	43	41	43	41	43	41	43	41
Strategy ₃₁ [29]	24	25	24	25	23	25	23	24	23	24	23	23	23	23
Strategy ₃₂ [53]	1	1	1	1	2	2	2	2	2	2	2	2	2	2
Strategy ₃₃ [48]	9	10	10	12	13	15	20	16	20	18	20	24	19	24
Strategy ₃₄ [54]	23	24	23	24	22	24	22	23	22	23	22	22	22	22
Strategy ₃₅ [55]	5	6	5	6	6	5	5	5	6	8	6	8	6	8
Strategy ₃₆ [56]	22	23	22	23	21	23	20	22	20	22	20	21	21	21
Strategy ₃₇ [57]	3	4	3	4	3	4	3	3	3	3	3	3	3	3

