




Review

Review on Sustainable Construction and Demolition Waste Management—Challenges and Research Prospects

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Abstract: (1) Background: Globally, numerous development projects are being undertaken to expand and improve urban infrastructure facilities, which result in around 30% to 40% of construction and demolition (C&D) waste in the total waste generation. Due to its detrimental impacts on the environment and human health, several researchers have been striving to find effective methods to manage these large amounts of C&D wastes to minimise environmental impacts and maximise the economic and social benefits. Despite these efforts, limited studies have focused on comprehensively reviewing the integrated sustainable management of C&D waste. Thus, this study aims to conduct a comprehensive review of the published literature to identify barriers that hinder sustainable C&D waste management practices and map future research areas for effective C&D waste management. (2) Methods: A two-step systematic approach was adopted where the first step involved a bibliometric assessment of the published literature from 2002 to 2022, and then the most significant publications were reviewed from the bibliometric findings to achieve this study aim. (3) Results: The review findings identifies several research gaps which were categorised according to seven themes, including limitations in operational aspects, the lack of monitoring of legislation and regulations, an inadequate market for recycled products, inefficient stakeholder engagement and management, limitations of effective framework/models for sustainable C&D waste management, limited research on social performance, and inadequate integration of information technology in C&D waste management. This study's findings are invaluable for researchers, industry professionals, and policymakers for in-depth understanding of the boundaries and potential future research areas to enhance sustainable C&D waste management practices.

Keywords: construction and demolition waste; waste management; sustainability; sustainable management



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1. Introduction

Rapid urbanization has highlighted the growing need for expanding and improving urban landscapes, transportation networks, and infrastructure facilities to fulfil the needs of the increasing population [1]. These demands have resulted in massive urban, national, and global infrastructure developments. Globally, more than 10 billion tons of construction and demolition (C&D) waste are produced yearly from building and infrastructure construction, demolition, and land excavation activities [2,3]. Developed and industrial economies like China, India, the European Union (EU), and the USA have produced 2.3 billion, 750 million, 700 million, and 600 million tonnes (Mt) of annual C&D waste, respectively [2,4–6]. In contrast, developing economies such as Brazil and Istanbul had an annual C&D waste generation of 45 Mt and 14 Mt, respectively [7–11]. Among the total C&D waste generation, 35% of the total C&D waste is sent to landfills. The United Kingdom, Brazil, Australia, and the USA are the major contributors, with shares of 50%, 40%, 35%, and 30%, respectively [10,12]. The above statistics reflect a strong correlation between the volume of C&D waste production and the growth in population and economic development of a nation.

C&D waste includes inert and non-inert waste, which can be hazardous or non-hazardous waste produced from new development and redevelopment activities [10]. The nature and large quantity (30–40% of the total waste generation globally) of C&D waste generation contribute to several negative impacts on the environment, economy, and society. For example, the deterioration of productive land, biodiversity loss, air, soil, and water contamination, and the development of chronic and cancerous diseases on human health are some examples of environmental impacts. Noise, odour, dust pollutions, carbon dioxide (CO₂) and methane (CH₄) release, particulate emissions, asbestos, and hazardous chemical contaminations are common environmental problems with C&D waste handling and disposal [13–15]. Furthermore, C&D activities consume significant amounts of energy, water, air, and raw material resources from the earth [3,16,17].

In addition, the C&D waste management process demands substantial financial investments and human resources. It involves setting up specialised equipment for waste collection, sorting, and transportation, as well as facilities for recycling, energy recovery, and larger landfill capacities to dispose of waste [18]. Lack of financial incentives for stakeholders and inadequate well-established recycled products markets are two significant economic barriers that impact the efficient management of C&D waste management practices [19]. The sustainable management of C&D waste encompasses various social aspects, including the consideration of short and lifelong health consequences for workers engaged in C&D waste handling and disposal processes. Additionally, a critical barrier lies in addressing project stakeholders' limited awareness and reluctance to embrace using recycled products produced from C&D waste, which heavily impacts sustainable C&D waste management practices [14].

Sustainable management of C&D waste has become a growing concern worldwide due to the large volume of C&D waste production and its negative impacts on the environment, economy, and society [2]. To respond to such barriers, a significant number of studies identified various factors that affect sustainable C&D waste management practices. Some studies concentrate on stakeholders' negative attitudes towards minimising C&D waste through the reuse of C&D waste components and utilisation of recycled products in construction and renovation. In addition, inconsistent waste disposal charging policies and lack of incentives for stakeholders' to use eco-friendly products affect the efficiency of sustainable C&D waste management practices [7,16,20–25]. Furthermore, some studies have evaluated economic feasibility and performance to enhance C&D waste management efficiency [26–28]. Conversely, some review articles emphasised the general perspectives of C&D waste management, including sustainability, feasibility, viability, and waste management efficiency [26,27]. Other studies specifically presented the development of quantification methods for calculating waste generation and physicochemical properties of recycled aggregate to improve concrete production [29–32]. However, there is a limited depth of investigation holistically exploring the barriers and drivers contributing to sustainable C&D waste management practices.

The aim of this study is to examine the current research trends in the field of C&D waste management and identify opportunities for future research that will promote sustainable practices. This will be achieved through a comprehensive review of published papers. The insights gained from this study will be valuable to researchers and practitioners interested in sustainable C&D waste management.

2. Research Methodology

Globally, numerous studies have been focused on various aspects of C&D waste management. This review paper uses a two-step methodology to understand the barriers in current C&D waste management practices, to inform future research opportunities for sustainable C&D waste management. The first step involves a bibliometric assessment of the previously published literature from a period of two decades (2002–2022) to investigate current C&D waste research trends and identify gaps for future research areas. Based on the findings, the most significant publications related to C&D waste management were selected

for further assessment. The second step includes a comprehensive review of selected publications (from step 1) on C&D waste management, outlining the barriers, and future directions. A systemic methodological process, as shown in Figure 1, was implemented in this study.

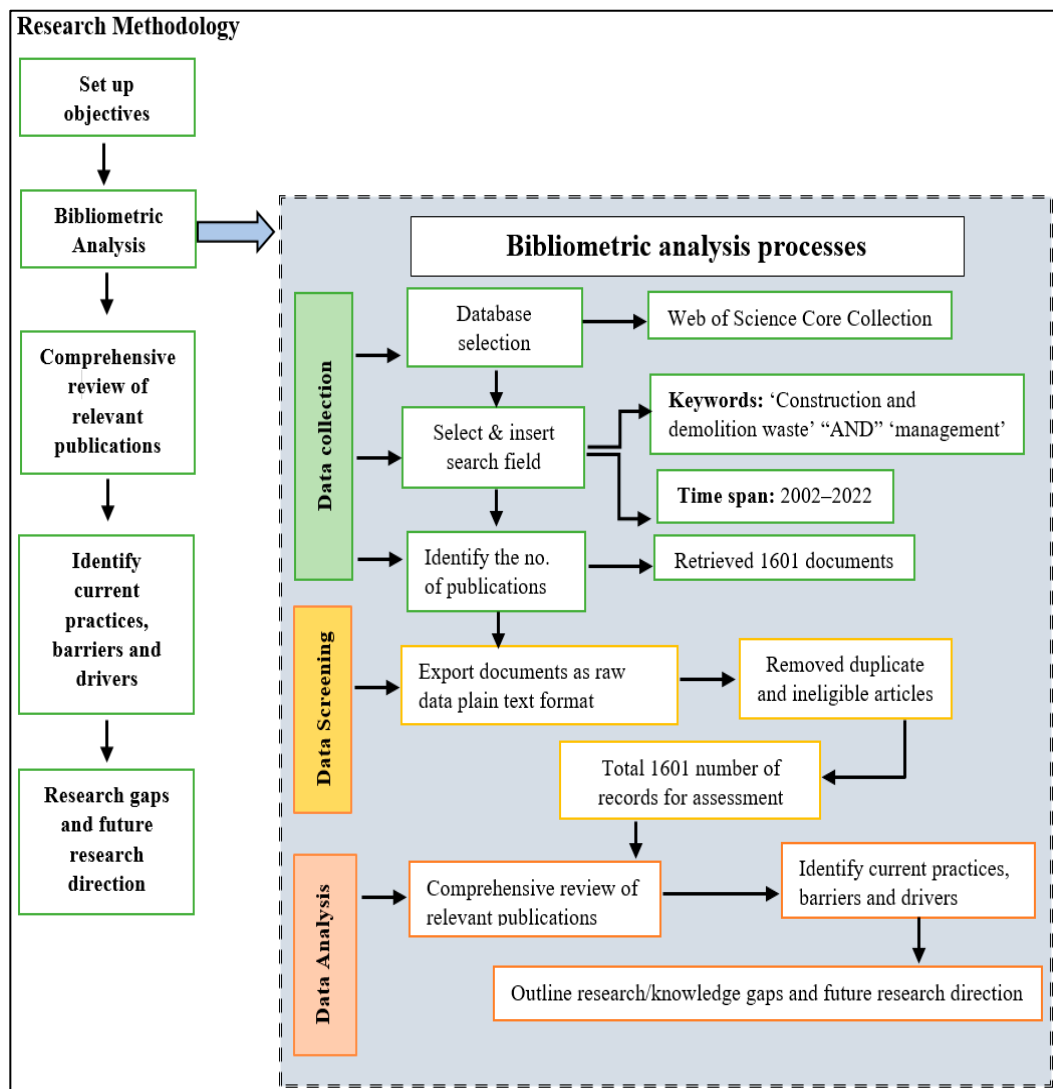


Figure 1. Research methodology.

This study employed the 'bibliometric analysis' statistical technique to evaluate the scientific impact, influence, and relationships among earlier published articles [33] and to analyse the situation and knowledge gaps [34]. The feature enables the user to capture a sequence of snapshots of a particular domain over a period, predicting the future trends of a given area and identify the collaborative structure of interdisciplinary fields [35–37]. The total outputs through the detailed search can be analysed quantitatively and systematically provide visual graphics for effective presentation [38]. For this study, the 'Web of Science (WoS) Core Collection' database was chosen due to its wide range of publications in science, technology, and social sciences compared to databases like Pubmed (mainly biomedicine), Scopus, Google Scholar, etc. [39]. The reason for selecting WoS database is that it is the oldest citation index for the sciences and broadly illustrates a well-interconnected core citation network. In contrast, Scopus enables the observation of some transfer from fundamental to empirical research [40,41]. 'Construction and demolition waste' and 'waste management' keywords were used to obtain relevant articles from 2002 to 2022 using the

“AND” Boolean operator. The search included various published documents, e.g., journal articles, conference proceeding papers, editorial materials, and book chapters. The data screening resulted in zero duplicates, and 1601 number documents were retrieved, which were then used for detailed assessment.

3. Bibliometric Findings

3.1. Overview of the Assessment

The key findings obtained from the bibliometric assessment is presented in Table 1. Out of the 1601 documents, 1206 were journal articles, and 156 were review papers. The bibliometric analysis revealed that there were a total of 4004 authors who collaborated on multi-authored documents, which signifies a strong collaboration among researchers. The “Authors per document” (2.55) parameter indicated an average of three authors per article.

Table 1. Main information from the bibliometric analysis.

Description	Results
Timespan	2002:2022
Documents	1601
Sources (Journals, Books, etc.)	450
Average years from publication	5.5
Average citations per document	24.34
Average citations per year per doc	3.823
Articles	1206
Review Articles	156
Proceedings Paper	213
Book Chapters	18
Editorial Material	8
Author’s Keywords (DE)	3555
Authors	4082
Author Appearances	6124
Authors of single-authored documents	78
Authors of multi-authored documents	4004
Single-authored documents	92
Documents per Author	0.392
Authors per Document	2.55
Co-Authors per Documents	3.83
Collaboration Index	2.65

The observed results also indicate a high average of citations per document (around 24), which shows the high relevance of the research area. Based on the WoS thematic categorisation, more than half (approximately 53% of 1601) of the observed publications fall into the ‘Environmental Sciences’ category, followed by Environmental Engineering (39%) and Green Sustainable Science and Technology (25%). In contrast, only 4% of publications fall under the management category, which indicates a lack of research focus on the sustainable management area.

Figure 2 illustrates the total number of publications and the total citations of the publications on the selected keywords. The analyses indicated limited research output until 2006; however, it gradually increased, and the exponential growth of research on C&D waste management has increased since 2016. C&D work requires natural resource extraction and generates large quantities of C&D waste, adversely impacting air, water, soil, human health, and the ecosystem. Many regional and international policies and strategies have been developed to promote sustainable C&D waste management practices for minimising the negative impact of C&D waste generation and disposal [42]. For instance, in 2004, the Organisation for Economic Co-operation and Development (OECD) introduced a new integrated approach that is ‘Sustainable Material Management (SMM)’. The aim is to develop policy and technical guidelines for waste in a more environmentally sound and economically efficient way [43]. This could influence the significant increase in research focused on

the sustainable management of C&D waste. In 2005, the European Union (EU) published a thematic strategy on the prevention and recycling of waste management framework to reduce landfill disposal [44]. European Commission's waste management strategies outlined a hierarchy for establishing preferred priorities (prevention/reduction, reuse, recycling, recovery, and disposal) based on sustainability concept [45]. In the hierarchical framework, the most preferred option is to avoid C&D waste through proper design in the planning phase [46]. The UK government introduced the "SMARTWaste" tool through the Waste and Resource Action Programme (WRAP) for facilitating on-site auditing, waste management, and cost analysis to improve C&D waste management efficiency [47].

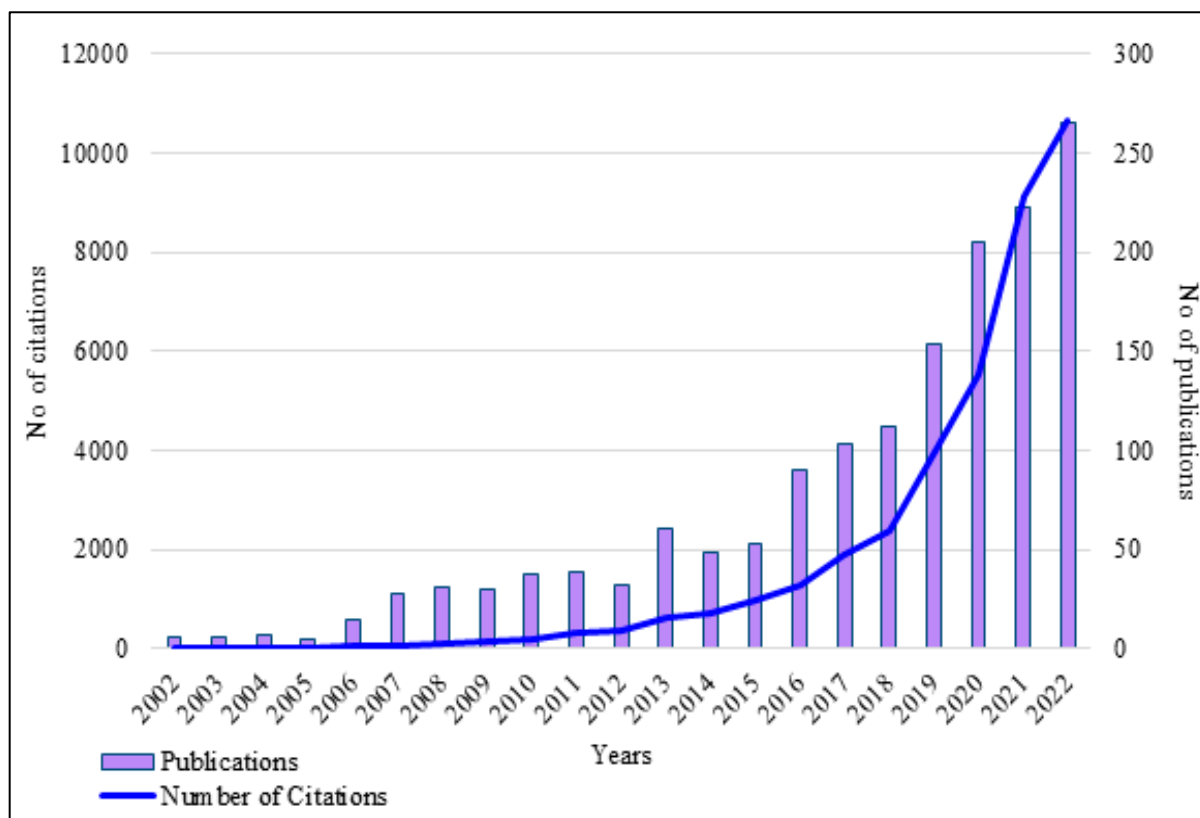


Figure 2. Annual scientific publications and citations (Web of Science assessment).

Furthermore, in Figure 2, there has been a significant increase in sustainable C&D waste management publications. This growth can be attributed to the United Nations (UN) 2030 agenda for sustainable development, which declared 17 sustainable development goals (SDGs) declared in 2015. The SDG-12 (12.5) outlined a goal to 'reduce waste generation through prevention, reduction, recycling, and reuse by 2030' [48]. Furthermore, exponential growth is noticeable in Figure 2 from 2020 to 2022, with more than 200 publications and increased citations per year focusing on the circular economy (CE). The reason is that the circular economy agenda was integrated into the 2018 high-level political forum for achieving Goal 12 of the SDGs by reducing waste generation and promoting the reuse and recycling of waste materials [49].

3.2. Assessment of Sources

Figure 3 depicts the top 15 productive publishing sources/journals and the number of documents published from 2002 to 2022. As observed, *The Journal of Cleaner Production*, *Waste Management*, and *Resources Conservation and Recycling* have published the highest number of publications, with a combined 377 publications. Further analysis revealed that most of these publications were related to the fields of environmental sciences and environmental engineering. Environmental sciences and engineering-related articles have

raised concerns about the impact of C&D waste on surface and groundwater and soils. These concerns are based on the results of leaching tests, which have shown that C&D waste can contain a variety of pollutants, including heavy metals, carbon, sulphate, and hydrogen sulphide. These pollutants can harm the environment, and control and mitigation solutions have been proposed to address them. In addition, some studies have concentrated on the lifecycle assessment (LCA) of C&D waste, such as energy consumption, lifecycle costing, economic impact and viability analysis, and cost–benefit analysis. Some other studies cover 3R (reduce, reuse, recycle) principles such as the waste reduction, reuse, and recycling of C&D waste materials such as recycled aggregates concrete and prefabrications, in addition to investigating resource recovery and the environmental analysis of recycling materials. Few studies discussed sustainable development, such as environmental impact and barriers to applying circular economy and management practices. Some others have focused on industrial ecology, material flow analysis, and quantification of mechanical properties and the compressive strength of C&D waste materials. This also includes the leaching of harmful pollutants from C&D waste disposal landfills, which pollute soil and groundwater with toxic chemical agents that are detrimental to ecology and human health. This means that researchers have focused more on environmental issues, such as the ecological impacts of C&D waste, than on waste management.

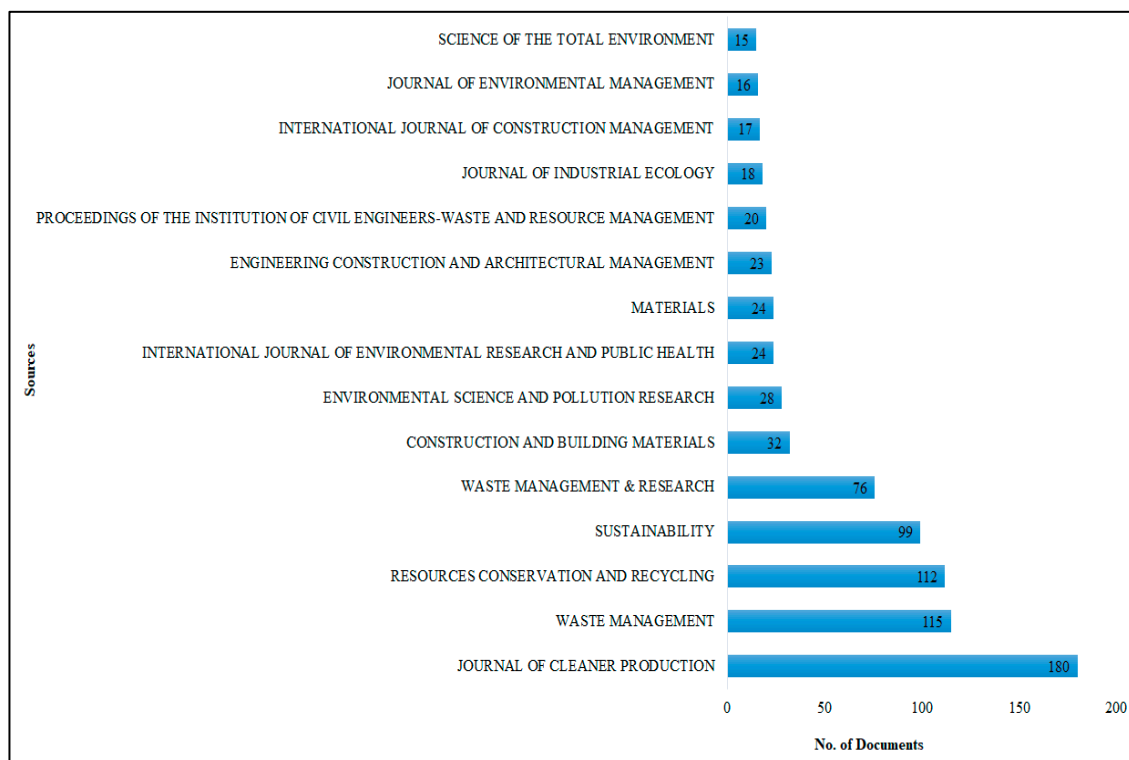


Figure 3. Publishing source vs. number of publications.

3.3. Assessment of Authors' Contribution

Figure 4 illustrates the top 10 authors' production from 2002 to 2022. The red dotted line represents the distribution of the author's total citations, and the blue bar illustrates the total number of publications over two decades. The total number of publications measures productivity, and the total number of citations measures the overall impact [50]. The overall effect of an article's or author's influence on academia is measured by combining the number of publications and citation records [51]. This refers to the h-index, which reflects not only the number of papers or citations but also an indication of the well-cited papers [50].

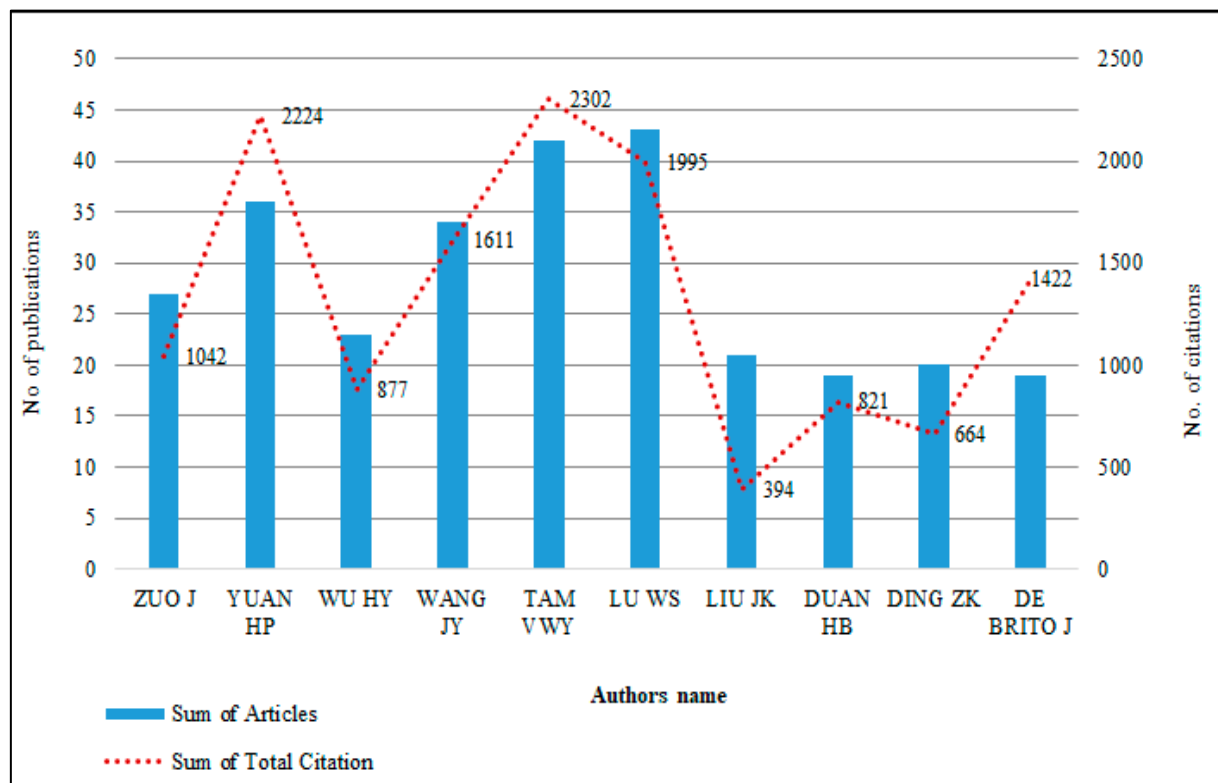


Figure 4. Total number of publications and citations of top ten (10) authors from 2002 to 2022.

As shown in Figure 4, Lu WS (Lu Weisheng) and Tam VWY (Tam, Vivian WY) have published more than 40 articles in the past two decades. Lu WS's publications primarily focus on the economic analysis of C&D waste and the circular economy. For instance, his research examines key areas like estimating C&D waste generation and management costs, as well as quantifying the potential for recycling different materials. In addition, he developed a framework using big data to help China and Hong Kong manage their construction waste, drawing on insights from various stakeholders. Tam VWY (Tam, Vivian WY) articles are highly cited by scholars and publications mainly focused on C&D waste minimization through the recycling of C&D waste materials, e.g., concrete recycling, adoption of prefabrication, and recycled aggregates. In addition, some articles highlighted recycling practices and stakeholders' willingness to reuse recycling material from C&D waste. Based on the productivity (total number of publications) and scholarly impacts (number of citations by other researchers), both authors have contributed significantly to sustainable C&D waste management research, which shows that they have significant implications in this field.

Furthermore, Yuan, HP (Yuan, Hongping) and Wang, JY (Wang, Jiayuan) have published more than 30 articles; however, the number of citations is higher for Yuan than Wang, at 2224 and 1611, respectively. Yuan's review papers on 'C&D waste management research and trends' have been cited by many authors. Nevertheless, only some of his studies have identified factors (e.g., barriers) that impact C&D waste management practices and the economic and social impacts of C&D waste management. Wang's research focuses on environmental science and engineering, including minimising carbon dioxide emissions from building demolition waste and implementing design strategies for reducing construction waste, utilising lifecycle assessment (LCA) and building information modelling (BIM) methods. In contrast, the total number of publications by De Brito J (De Brito Jorge) is lower than that of other top authors (depicted in Figure 4); however, the number of citations (88.24 average citation/item) by different scholars is very high. The high number of citations by other researchers indicates De Brito J's scientific contributions and research novelty in C&D waste recycling aspects, specifically recycled aggregates (e.g., concrete,

rendering mortars), lifecycle analysis and supply chain analysis. Despite having a high number of publications, authors like Liu JK (21), Ding ZK (20), Duan HB (19), and Wu Hy (23) did not receive significant citations from other researchers. Hence, an author's scholarly contribution cannot be judged solely based on the number of publications. It is also crucial to consider the impact of their work by measuring how other researchers have utilised those works. Researchers in engineering and environmental engineering fields have shown significant interest in studies on recycled aggregates for reducing environmental impacts through carbon waste minimization, recycling technologies, and artificial intelligence. These studies have been highly cited, indicating that they have made considerable contributions to developing recycled materials from C&D waste to minimising environmental impacts.

3.4. Trends of Research Topic

To analyse the trends in research outputs, 'Author's Keywords' was selected as the method parameter that refers to the words provided or used by the original authors in their article. We have also considered the number of words per year and the frequency of each word for graphical analysis presentation. Figure 5 below shows the trends in research areas or topics over the last two decades. The bar chart represents the frequency of words used by the authors over the given period. The orange line indicates the year when a keyword was first used, and the purple line indicates the year when the specific keyword was last used.

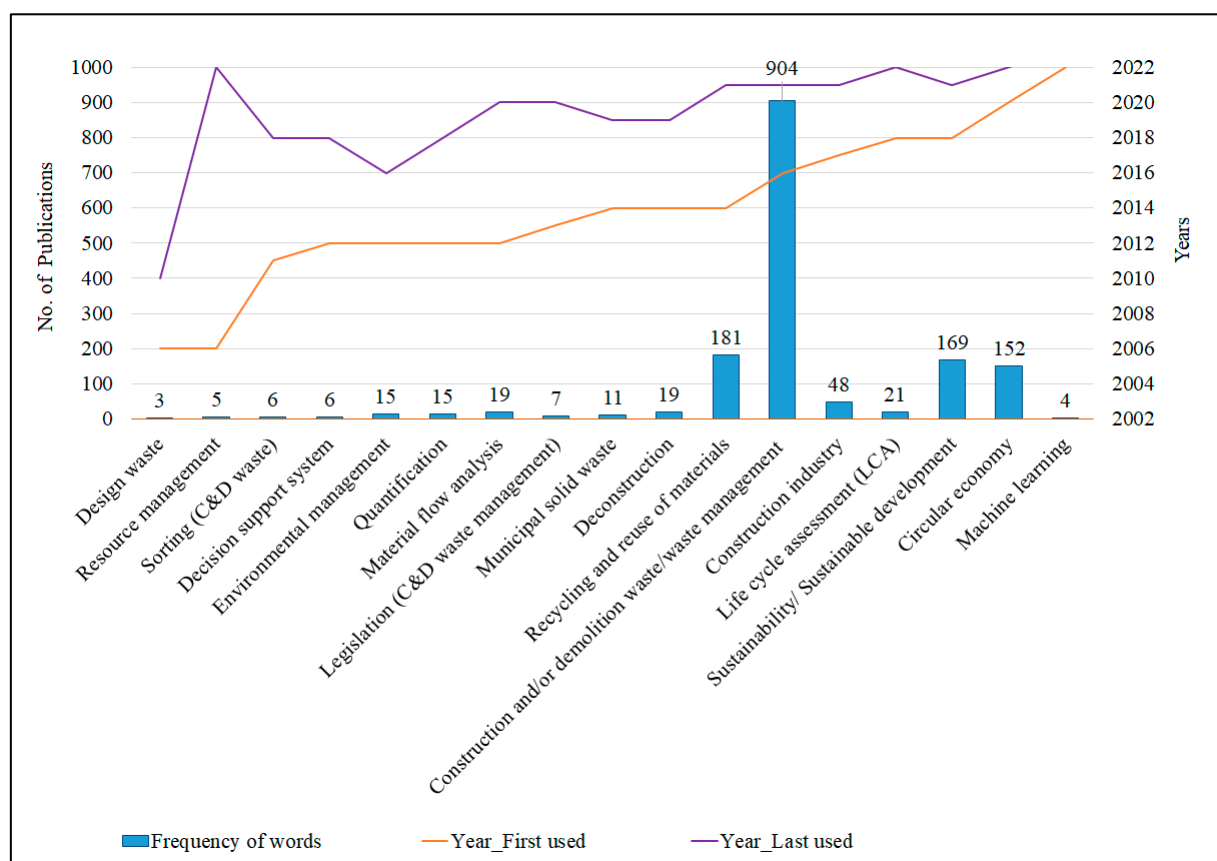


Figure 5. Topic trend utilising authors' keywords (source: Biblioshiny database).

The trends indicated that C&D waste management was the most commonly used keyword by the authors. However, this keyword overlaps with 'construction and demolition waste', 'waste management system', 'waste management', etc. This is likely due to how authors have used these terms in their publications. In addition, post-2015, 'recycling',

‘recycling materials’, ‘sustainable construction’, and ‘sustainable development’ became more focal research areas. As shown in Figure 5, C&D waste management has been the most utilised keyword over the period. However, after the 2015 UN Sustainable Development Summit, the terms ‘sustainable development’ and ‘sustainable management of C&D waste’ became prioritised issues, as they are embedded in the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development. The new United Nations agenda includes several important goals that were not part of the previous Millennium Development Goals agenda, which are Goals 9, 11, 12, 13, and 17. Goal 9 focuses on building resilient infrastructure, promoting sustainable industrialization, and fostering innovation. Goal 11 aims to make cities and human settlements inclusive, safe, resilient, and sustainable. Goal 12 focuses on ensuring sustainable consumption and production patterns. Furthermore, Goal 13 emphasises urgent action to combat climate change and its impacts, whereas Goal 17 aims to strengthen global partnerships for sustainable development.

Besides this, the Organisation for Economic Co-operation and Development (OECD) has a hierarchical approach (top priority prevention/minimisation/reduction followed by reuse, recycling, energy recovery, and disposal) to manage waste sustainably [52]. In 2004, the OECD introduced a new approach, ‘sustainable materials management (SMM)’, which emphasises that materials are managed cost-effectively from start to end life [43]. The focus of global research has been directed towards sustainable management of C&D waste, which includes reuse, recycling, and resource recovery issues. However, since 2020, there has been a shift in research trends towards a circular economy, which aims to minimise the environmental impacts and economic costs of waste for sustainable development. Thus, 263 articles related to the circular economy have been published. In 2021, machine learning (12 articles) has gained attraction in the research domain due to technological interventions and innovation in sustainable C&D waste management.

3.5. Conceptual Structure: Factorial Analysis of the Most Cited Papers vs. Most Contributing Papers

The structure of concepts in bibliometric analysis aids in comprehending topics covered by scholars, and facilitates identification of important and recent issues, which in turn assists in tracking the evolution of research over time [53]. Citations are an essential metric to measure the quality and impact of a scientific paper. The number of times that an article is cited in other published studies is a direct reflection of its overall scientific quality, influence, and timeliness. A paper that receives more citations is considered to have a greater impact on the scientific community, and the author/s of that paper are recognised for their contribution to the field [54].

Figure 6 below illustrates the most cited and most contributing papers over the last two decades, and the analysis has been sorted by the most cited papers (highest to lowest). Contributing papers are publications that add significant value to the body of knowledge, either by introducing a new approach or by contributing to the existing subject matter.

As depicted in Figure 6, Tam et al. (2007) [55] and Rao et al. (2007) [56] articles are the most contributing and cited papers, respectively. Both papers are based on recycled aggregates (RA) produced from C&D waste and their utilisation in concrete and published in the same year. Rao et al. (2007) [56] investigated the shortage of natural aggregates in the environment for producing new concrete. On the other hand, the enormous amount of demolished concrete generated from old structures is creating significant ecological and environmental problems. Thus, the authors suggested using demolished waste concrete as aggregates, and such recycled aggregate can be used as an alternative to natural aggregates in concrete construction as an alternative solution. Besides this, Tam et al.’s [55] experimental research focused on evaluating and improving the quality and behaviour of recycled aggregate (RA) through three pre-soaking treatment approaches and comparing the results with traditional methods. Based on Figure 6, Tam et al.’s [55] paper is the most contributing paper because of its new contribution (recycled aggregates) that added significant value to the body of knowledge in C&D waste management. However, in terms of the number

of citations, the paper by Rao et al. [56] is the most cited article, which may be due to the novelty of their research areas. On the other hand, Huang et al.'s [57] paper, which was published in 2018, has reached the third highest citation. This might be because the paper focused on the contemporary global policy and strategies for the circular economy in the C&D waste industry. This includes the identification of barriers at the policy and management levels and providing recommendations for improving the current situation and practices. Table 2 below represents the key aspects/attributes covered based on the number of citations (highest to lowest).

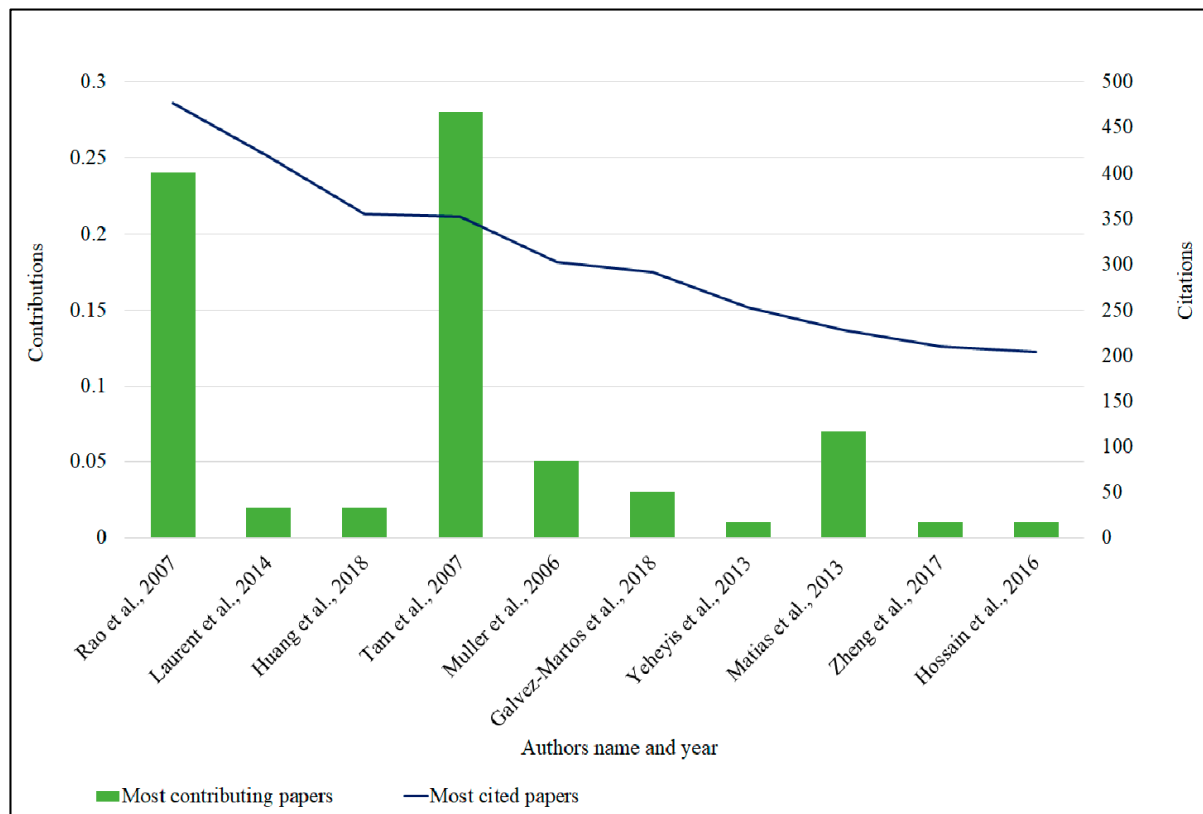


Figure 6. Conceptual structure: factorial map of the documents with most cited documents [5,55–63].

Table 2. Top ten highly cited papers.

Authors	Article Type	Key Attributes
Rao et al., 2007 [56]	Original	Problems associated with C&D waste management and recycling of C&D waste through recycled aggregates (RA) produced from C&D waste and their utilisation in concrete.
Laurent et al., 2014 [58]	Review	Mapping waste through lifecycle assessment tools, modelling of environmental impacts and benefits of solid waste management, and recommended improvements.
Huang et al., 2018 [57]	Original	Challenges in adopting the circular economy in the C&D waste industry in China through investigating existing policies and management situations focusing on 3R (reduce, reuse, and recycle) principles.

Table 2. Cont.

Authors	Article Type	Key Attributes
Tam et al., 2007 [55]	Experimental	Experimented with three pre-soaking treatment approaches, namely compressive strength, flexural strength, and modulus of elasticity of recycled aggregate (RA) concrete, to compare with traditional approaches in order to improve the behaviour and quality of recycled aggregate. A dynamic material-flow analysis model to analyse concrete diffusion in Dutch homes.
Muller et al., 2006 [59]	Methods	
Galvez-Martos et al., 2018 [60]	Original research	Principles and systematic documentation of best practices for environmental management practice of C&D waste across Europe.
Yeheyis et al., 2013 [61]	Review	C&D waste types/compositions and recycling/reuse potential (e.g., biodegradable, landfilling, and incineration). Authors outlined challenges and opportunities for C&D waste management in the Canadian context.
Matias et al., 2013 [62]	Experimental	Experimented with the impact of superplasticizers on the mechanical properties of concrete made with recycled concrete aggregates and compared with natural aggregates.
Zheng et al., 2017 [5]	Methods	Evaluated various methods and approaches to quantify C&D waste generation and economic analysis. These include Record-based Accounting Material Flow Analysis, geographic information system (GIS), and a weight-per-construction-area estimation method.
Hossain et al., 2016 [63]	Case study	Investigated environmental performance of building construction waste through a lifecycle assessment (LCA) approach.

Summary of findings

The following key findings were found from the initial assessment of WoS database.

- A significant number of publications (458) related to C&D waste management and sustainability were observed while using a ‘refine’ search in the ‘Language’ and ‘Publication Year’ (only 2002–2022) categories of the WoS database. Articles considered for review are those that are published in the English language. Environmental sciences and engineering technology related to sustainable C&D waste management is the most extensively researched field. After 2015, research interest shifted towards the fields of sustainability and sustainable C&D waste management due to the United Nations (UN)’s declaration to achieve Sustainable Development Goals (SDGs) to reduce climate change impacts and enhance economic benefits and social equity in the globe.
- Furthermore, only 52 publications discussed the sustainable C&D waste management barriers, and among these publications, 28 of the studies provided future research directions along with the discussion.
- After refining the results, only 114 out of 1601 articles that are related to infrastructure were observed. The majority of these articles covered environmental and technical aspects.
- Inadequate research publications were found on excavation (17), contaminated soil and/or rock (19), and tunnel (3) related to C&D waste management. The issues covered in related articles mainly focus on the environmental aspects of excavated materials (e.g., rock and soil), for example, identifying the physical, chemical, and

mechanical properties of excavated rock and soil, assessing the environmental impacts of carbon dioxide emissions caused by excavation works, etc.

- Only a handful of studies have been conducted on sustainable management of excavated soil and rock. These [64–68] studies focus on material flow analysis and management practices to enhance resource efficiency. These practices include the reuse of excavated rock and soils in concrete production and geo-polymer production, utilising clay-sealing for embankment and landfilling, implementing re-cultivation and agricultural usage as mixed soil material.
- Studies on excavation, excavated materials, and tunnel construction are predominantly conducted in the United Kingdom, Australia, Sweden, the United States, Austria, and Brazil, respectively, ranked in descending order. Tunnel- and deep excavation-related studies are historically prevalent in European nations, as well as the mitigation of environmental impacts by reusing and recycling excavated materials, especially soil and rock, through policies and practices.
- C&D waste management research has been receiving a lot of attention in China, and the reason for this may be that China is the biggest C&D waste generator and contributes significantly to climate change, the global economy, and society.
- There have been many studies conducted on this subject, with a particular focus on exploring the potential of using big data in C&D waste management by gathering insights from stakeholders. However, Vivian WY Tam's work stands out as highly influential among scholars and publications focused on minimising C&D waste through concrete recycling, prefabrication, and recycled aggregates. Tam's research also highlights recycling practices and stakeholder receptiveness to reusing C&D waste materials. With a prolific publication record and numerous citations, Tam is widely regarded as a leading researcher in C&D waste management.

4. Analysis of the Findings

4.1. Overview of Top Ten Authors' Review Papers

The top 10 authors (depicted in Figure 4) publications were screened through the WoS database 'researchers profile' and 'quick filters' categories to identify only the review articles published by the top ten authors. The refined result filtered fifteen (15) review articles where the top ten authors were not necessarily the first author but could be associated as co-authors in any order. For example, Vivian Tam is one of the top 10 authors; however, in the selected review paper of Kabirifar et al. (2020a) [22], she (Vivian Tam) is the last author. On the other hand, three (3) articles were excluded because of a lack of research focus on the broader field of C&D waste management. Finally, 12 relevant review articles were selected based on the research focus and the highest number of citations (e.g., Kabirifar et al. (2020a) [22] total citations—215, etc.) to gain valuable insights into present research trends and comprehend the obstacles that impede the sustainable management of C&D waste worldwide. Among these 12 articles, the majority (9 out of 12) were published in 2019 or later, emphasising the environmental impacts and C&D waste management in China and Australia. Critical attributes from the twelve selected review papers of the top ten authors are listed in Table 3.

Table 3. Attributes from twelve selected review papers.

No	Key Attributes/Aspects Reviewed	Year	Reference
1.	Environmental, economic, and social barriers are identified based on the 3R (reduce, reuse, and recycle) principles. The analyses were conducted across the planning, designing, procurement, and construction stages.	2020	[22]

Table 3. Cont.

No	Key Attributes/Aspects Reviewed	Year	Reference
2.	The authors investigated C&D waste diversion practices, quantification methods for estimating C&D waste generations, and inadequate utilisation of information technology for C&D waste management.	2019	[9]
3.	The authors identified barriers affecting construction and operation stages, including environmental and industrial ecological consequences, recycled product performance, and behaviour testing.	2019	[29,69]
4.	The authors evaluated the Hong Kong government's policies, regulations, codes, and initiatives implemented for C&D waste management.	2013	[70]
5.	The authors investigated environmental risks and impacts caused by improper management of C&D waste in China.	2015	[71]
6.	Sustainability-based, system thinking-based, and lifecycle thinking-based models (three in total) were studied for evaluating C&D waste management performance.	2019	[18]
7.	The authors assessed the application of information technologies (e.g., building information modelling (BIM), geographic information system (GIS), big data, radio frequency identification, image recognition technology, image analysis, global positioning system (GPS), and barcode technology in C&D waste management).	2020	[72]
8.	The authors examined the impact of toxicity and eco-toxicity exposure from C&D waste on human health and the ecosystem.	2021	[73]
9.	The authors evaluated system dynamics (SD) and agent-based modelling (ABM) approaches to develop a novel model for effectively managing construction waste.	2018	[74]
10.	The authors evaluated the current situations and reasons for the illegal dumping of C&D waste. Also, future research areas, namely environmental science and toxicology, economics and management, and the use of emerging technologies to manage C&D waste efficiently were investigated.	2021	[75]
11.	The authors proposed a model for conducting literature reviews in C&D waste management using Latent Dirichlet Allocation, word2vec, and community detection algorithm on Python, an alternative to traditional review and science mapping methods.	2021	[76]

Current C&D Waste Management Practices

Globally, C&D waste management is still very challenging because of the continuous and massive waste generation from construction, demolition, and renovation work. Waste management demands the reliable technical evaluation of risks and community

involvement and deliberation of practical and effective implementation of C&D waste management regulations and strategies. In addition, stakeholders' commitments and willingness to adopt environmentally friendly practices that are critical for sustainable C&D waste management [77]. Developed and developing economies have implemented several national action plans and legislations aligned with global sustainability and circular economy principles to minimise C&D waste generation and maximise recyclability and reusability. Despite national and international policies, the construction industry is still struggling to improve its environmental performance because the extraction of natural resources is 1.6 times higher than the regeneration capacity [78]. Additionally, the lack of concern and efforts to minimise C&D waste generation in the design stage, stakeholders' attitudes and behaviour towards the utilisation of recycling materials, and the lack of economic incentives for using recyclable C&D materials are critical barriers to efficient C&D waste management [69].

A significant number of studies have investigated the sustainable management of C&D waste. However, the majority of these studies have primarily focused on environmental and economic factors [18]. Only a handful of studies have covered all aspects of sustainability in order to assess C&D waste management performance [14,79–81]. Previous research had only examined the management or technical aspects of C&D waste rather than considering the three aspects holistically to investigate and analyse how these factors are interconnected. Additionally, concrete, mortar, brick, and glass have received significant attention as recyclable C&D waste materials compared to other materials (e.g., soil, rock, etc.), which have been either overlooked or studied to a limited extent. The oversight has failed to recognise the potential for reusing or recycling these materials, leading to an underestimation of their environmental and socio-economic impacts.

It has been observed that the number of publications on C&D waste production has increased eightfold between 2007 and 2017. Undeniably, the increase in C&D waste production is a direct result of the exponential growth of new or redeveloped buildings and infrastructure works. Additionally, the global shift towards sustainability and circular economy adds to the urgency of addressing this issue results in more research and publications. However, research on C&D waste is mainly conducted on environmental and ecological aspects and a significant portion of it is experimental studies to test the recyclability, performance, and behaviour of recycled products derived from C&D waste. For example, some studies have focused on understanding the complexity of pollutants and developing comprehensive pollutant control measures for treating and disposing of C&D waste. Another experimental research developed more testing methods to assess the environmental impacts caused by C&D waste. These research studies play a crucial in developing effective measures for treating and disposing of C&D waste to minimise its environmental impacts. However, there is a need for research that addresses other aspects of C&D waste management, such as specific planning for waste reduction in the design stage, implementing waste disposal charging systems, creating practical performance evaluation frameworks, and incorporating information technology to improve C&D waste management practices [18,29,60].

4.2. Review of Barriers and Drivers in C&D Waste Management

4.2.1. Barriers in C&D Waste Management

It is indeed crucial to identify and understand the barriers that hinder the development of eco-friendly, economically feasible, socially acceptable, and safe C&D waste management strategies. Various studies across the globe have discussed C&D waste management barriers. Based on those studies' findings, these barriers are categorised into seven sub-categories: operational, governance (regulatory), stakeholder engagement and management, market, economic, social, and technological barriers.

Operational Barriers

Recent studies have focused on waste reuse and recycling with less emphasis on preventing waste generation in the design stage [69]. Internal and external factors are associated with C&D waste diversion practices. A lack of government support, inadequate markets for recycled products, limited landfill space for C&D waste disposal in urban areas, etc., are some key external barriers to the diversion of C&D waste. In addition, project stakeholders' preference towards a conventional C&D management approach is an example of an internal barrier [9]. On the other hand, a lack in the identification of correct disposal routes in the planning stage, inadequate knowledge of design documentation, and poor supervision and site management result in rework and significant waste generation [25,82]. Furthermore, the improper management of stakeholders can impede the effective implementation of waste reduction strategies (Kabirifar et al., 2020a) [22]. Thus, it is critical to ensure that all stakeholders are appropriately informed to achieve waste reduction goals. Besides this, a lack of client interest in waste reduction and management, insufficient training and education, a shortage of skilled labour, market competition, inadequate policy action, and a lack of innovative design and documentation by architects are considered major barriers to efficient C&D waste management in India [7]. In a similar context in Iran, incomplete drawings and documentation, frequent changes in orders and specifications leading to rework, a lack of waste management knowledge, and workforce culture among construction professionals are some critical barriers that affect efficient C&D waste management. Furthermore, the absence of incentives from regulatory authorities, a lack of coherent policies, and a lack of well-developed economically viable reuse and recycling facilities are critical barriers that heavily affect C&D waste management [75,83]. Additionally, limited on-site storage capacity, a lack of off-site recycling facilities, and inadequate government policy support hinder the C&D waste recycling process in Hong Kong [84]. A lack of fabrication facilities, an insufficient skilled workforce for handling materials, and a lack of equipment operators are also some operational barriers identified in studies conducted in low- and middle-income economies [85].

Governance Barriers

Many developed and developing economies have regulatory bodies to implement sustainability frameworks for reducing the environmental, economic, and social impacts of C&D waste generated from building and infrastructure projects. However, these frameworks consist of complex decision-making hierarchies and lengthy approval processes [86,87]. Despite several environmental management frameworks, researchers have discovered these frameworks are not functioning properly due to inadequate enforcement and monitoring by the regulatory authorities [87]. Several studies have outlined that the lack of uniform C&D waste management strategies within states and at the national level hinders overall C&D waste management performance goals. For example, in the UK, the 3R strategy of waste management hierarchy is used, wherein a waste reduction strategy is the top priority measure to minimise waste before construction works. However, this strategy was shown to have failed to meet all parameters due to the unpredictable nature of the waste occurrence during the architectural design stage [47]. Furthermore, in Australia, levy/tax imposition, waste disposal requirements, and the design of landfills vary across jurisdictions and from metropolitan to regional areas. As a result, waste was transported from NSW to QLD because there were no waste disposal levy fees in QLD before 2019 [88,89]. Apart from this, other studies concluded that both developed and developing economies found similar issues like underdeveloped or inefficient legislation and inadequate execution of existing regulations and guidelines hindering the efficiency of C&D waste management processes [16,90,91].

Stakeholder Engagement and Management Barriers

Various studies have examined how different stakeholders' perceptions, attitudes, behaviours, and expectations affect the sustainable management of C&D waste [24,92,93].

Inadequate communication and inefficient conflict management between stakeholders' affect in C&D waste management [22]. Furthermore, the lack of financial incentives demotivates stakeholders to change their behaviour and negative attitude towards reusing eco-friendly by-products produced from C&D waste materials. Consequently, this attitude makes them put little effort into preventing the generation of C&D waste at the design stage [29,70,76,92,94]. Beside this, poor understanding of C&D waste management strategies and frameworks among stakeholders (e.g., local contractors, construction staff, and architects) is a common barrier both in developing (India) and developed (Australia) economies [7]. Furthermore, controlling and regulating various stakeholders' expectations and sustainable C&D waste management performance is challenging, especially in mega projects [22,95]. Inadequate knowledge of waste management strategies and approaches among local contractors, construction staff, and architects has been identified as a critical barrier to reducing C&D waste in India [7]. Contractors' attitudes towards sustainable C&D waste management depend on factors such as the size of the company, waste reduction measures, frequency of waste collection, skill development training programs, and C&D waste reuse, recycling, or disposal methods [24].

Economic Barriers

Economic factors related to C&D waste management include the costs of waste transportation, disposal, recycling, and reuse, and the expenses relating to materials and labour [22]. Studies have found that a greater distance between the C&D sites and treatment or landfill facilities leads to higher transportation costs, which increases treatment, recycling, and disposal costs, as well increases the carbon footprint [26,76]. This often results in illegal dumping practices that negatively affect sustainable C&D waste management practices [18,57,96]. In addition, recycling costs are strongly associated with construction site conditions, waste transporter speed, and the quantity of recyclable C&D waste materials [26]. On the other hand, developed economies (e.g., Australia) exported C&D waste materials to developing economies (e.g., Malaysia, Indonesia) for the recycling of products, which causes financial losses in the Australian economy [3].

Market Barriers

Researchers have identified various impediments that impact the marketability and usability of recycled products derived from C&D waste. These obstacles encompass the substandard quality of recycled products [97], inadequate awareness about the importance of waste reduction [98], underdeveloped recycling products markets for reused eco-materials from C&D waste [19], and additional costs to develop recycling products from C&D wastes [99]. Furthermore, researchers across the globe have been discussing the lack of a well-operated integrated end-market of C&D for the last decades [19,95]. Unfortunately, the recycling market is still very limited, which largely affects sustainable C&D waste management [100,101].

Social Barriers

Social factors play a significant role in C&D waste management. For instance, the health and safety impacts of C&D waste handlers, attitudes of stakeholders, and public awareness of the impacts of C&D waste handling and disposal are crucial considerations for assessing social impacts [22]. Li, Zhang [102], Lu and Yuan [103], and Yuan and Shen [104] highlighted that the effective management of C&D waste transportation and disposal to neighbouring landfills requires community engagement through participation and dialogue. However, some studies have identified social barriers such as a lack of proper physical working conditions in the C&D sites lead to higher chances of accidents [46,105]. Besides this, in Australia, a significant amount of C&D waste materials, specifically metal, plastic, and paper, are exported overseas for recycling purposes. These traditional C&D waste management practices hinder the creation of full-time employment opportunities for local Australian communities, resulting in a loss of social benefits [3].

Technological Barriers

Studies have identified technological barriers in C&D waste management due to inadequate use of BIM, GPS, GIS, and big data [27,106]. For example, GPS tracking systems are established for monitoring C&D waste movement in some Australian jurisdictions, specifically South Australia, Victoria, and the Northern Territory. Other jurisdictions either partially tracked or have not established any waste tracking systems yet [2]. Thus, no uniform waste tracking data platform has been established, leading to inaccurate waste estimation by over- or under-counting information [1]. Several studies have highlighted the importance of the application of BIM in the design stage to minimise C&D waste generation before construction starts [27,107]. However, the authors did not provide specific guidance on utilising BIM successfully for effective C&D management [29]. Moreover, there has been inadequate research conducted on stakeholders' insights and expectations regarding the application of BIM in sustainable C&D waste management. Another barrier is that most waste estimation tools are specific to geographical locations, making them not universally applicable [108]. Additionally, data errors may occur due to the high level of a human involvement required to manage C&D waste. Therefore, more research is necessary to integrate information technologies into sustainable C&D waste management practices.

4.2.2. Drivers of Effective C&D Waste Management

Integrating sustainable criteria into C&D waste management is critical as these balance environmental, social, and economic benefits. Effective waste management decision-making plans in project design, planning, and tendering stages are vital to minimising material waste [9]. Many studies have claimed that C&D waste can be reduced by approximately 40% through proper design in the planning stage [25,74,109]. In addition, Wu et al. (2017) argued that stakeholders' behaviour could be controlled through government regulations imposing penalties, subsidies, and waste disposal charges [23,110,111]. Imposing charges and penalties also enhances the economic feasibility of C&D waste management [112]. Pressure from clients, as well as the strict enforcement of C&D waste management legislation from government regulatory bodies can facilitate the reduction in the generation of C&D waste management in construction sites [91]. The financial benefit is essential for decision-makers because they often calculate the landfilling cost vs. treatment or recycling costs [27]. Therefore, a landfill tax and financial subsidies are two economic drivers that encourage stakeholders in the waste minimizations process [57].

Besides this, government laws and regulations, designated areas for C&D waste disposal, low-waste construction technologies, and an organisational culture to support sustainable C&D waste management to reduce waste in the construction industry are recommended [94]. Additionally, training, promotional activities, education programmes can help improve stakeholders' awareness and attitudes towards waste minimisation [14,113]. Using temporary bins in construction sites can prevent soil contamination from mixing with C&D waste [114]. Providing adequate on-site space for sorting of C&D waste materials can also improve C&D waste management practices, thus saving the cost and time that would have been spent disposing of waste in recycling facilities or landfills [115].

On the other hand, utilising big data in C&D waste management has become increasingly popular over the last few years. Using big data platforms can bring several benefits to avoid illegal dumping. One example is the application of GIS, which is a crucial component of big data and helps construction waste transporters track and monitor transportation routes and disposal processes [116]. Furthermore, stakeholders like contractors and government department officials can monitor C&D waste transportation management through real-time tracking systems to prevent illegal dumping [117]. The GIS can map C&D waste management data through a virtual simulation system and accurately evaluate environmental impacts. For instance, GIS applications has been used in multiple projects of different geographic locations in city areas to assess the ecological impacts of demolition waste [118].

The circular utilisation of C&D waste is critical for achieving ‘Zero Waste’ goals. Therefore, it is important to promote the reuse and recycling of materials from C&D waste for sustainable management. This can be achieved by establishing recycling factories, creating recycling markets, and promoting the use of recycled products and technologies to reduce C&D waste [57,113,116]. Additionally, creating C&D waste recycling facilities can provide job opportunities for local communities, thereby enhancing their social and economic benefits [3]. To increase demands for using recycled materials, standardised products with high quality and an affordable price are crucial for stakeholder buy-in [96].

4.3. Review of Frameworks and Models for Efficient Management of C&D Waste

In order to manage C&D waste in sustainable manner, researchers have proposed different frameworks and models to reduce the generation of C&D waste at the design stage and promoting the reuse and recycling C&D waste materials in the construction stage. Analysing the key attributes from studies in sustainable management of C&D waste, researchers have significantly contributed by developing/proposing frameworks/models to reduce environmental impacts and enhance economic benefits (depicted in Table 4).

Table 4. Sustainable frameworks and models for C&D waste management.

No	Category	Key Attributes	Region	Reference/s
1.	Management	Improvement in stakeholders’ attitudes and C&D waste management practices.	Portugal	[119]
2.		The authors proposed an analytical framework consisting of three components to assess current C&D waste management practices and achieve ‘Zero Waste’ goals.	China	[120]
3.		C&D waste lifecycle assessment in Canada by utilising stakeholders’ involvement in the decision support tool.	Canada	[61]
4.		The authors proposed management strategies to improve C&D waste management practices.	United Kingdom	[27]
5.		The authors evaluated C&D waste management effectiveness.	China	[14]
6.		The authors identified C&D waste management best practices for reducing C&D waste in building construction.	Spain	[121]
7.		Conceptual model for identifying the most influential factors affecting C&D waste management practices.	Iran	[83]
8.		The authors proposed an assessment tool to measure waste management performance.	Korea	[122]
9.		The authors developed a model to assess project managers’ intention and willingness in practice towards waste reduction.	China	[123]
10.		C&D waste management performance assessment model.	China	[18]

Table 4. Cont.

No	Category	Key Attributes	Region	Reference/s
11.	Environmental	The authors evaluated the environmental impacts of landfilling and recycling activities of C&D non-hazardous waste through LCA modelling.	Italy	[124]
12.		Environmental impacts assessment in relation to C&D waste through lifecycle assessment (LCA) modelling.	Denmark	[125]
13.		System dynamics model to assess the environmental performance of construction waste reduction.	China	[126]
14.		Less of Waste, More of Resource (LoWMoR) framework for diverting waste from landfills to resources.	Australia	[101]
15.		Quantification model for assessing recycling potential from demolition waste.	China	[127]
16.		Environmental management practices of C&D waste in Europe.	Europe	[60]
17.	Environmental-economic	The authors compared the economic feasibility and environmental impacts (CO ₂ emissions) between on-site and private recycling facilities.	Korea	[26]
18.		Multi-criteria optimization model for better decision making for environmental and economic benefits.	USA	[128]
19.		Quantification model for assessing ecological footprint and economic analysis.	Spain	[129]
20.	Economic	Sustainability assessment model: assess economic feasibility emphasis on project stakeholders' perspective.	Malaysia	[24,130]
21.		Cost-benefit model for effective waste management.	China	[131]
22.		C&D waste model based on the penalty and subsidy mechanism for economic aspects.	China	[110]
23.	Economic-social	The authors developed a dynamic model for assessing social, economic, and managerial system variables affecting C&D waste reduction.	China	[94]
24.		Method for evaluating economic and social impacts of the mobility of C&D waste.	Australia	[3]
25.	Social	The proposed model enhances the social performance of C&D waste management.	China	[42]

A thorough literature search on sustainable C&D waste management frameworks/models revealed that the majority of research efforts have been focused on environmental and economic impacts, mainly green construction to reduce C&D waste generation and the maximisation of reuse and recycling of C&D waste materials, economic models for cost-benefit analysis of C&D waste management, etc. However, few studies have proposed frameworks/models on social performance. Although the successful and efficient management of C&D waste management requires the collective improvement of all three dimensions of sustainability [42], there is still a lack of research efforts and collective development

of framework/model on sustainable C&D waste management. Thus, this study aims to investigate this research gap and outline prospective areas for future research.

4.4. Current Research Gaps and Future Research Direction

Globally, many studies have been conducted on various aspects of C&D waste management to reduce environmental, economic, and social barriers. Several studies demonstrated that researchers have focused on either overall C&D waste management aspects or some specific C&D waste materials (e.g., concrete, brick, etc.) recycling aspects. Furthermore, among all types of C&D waste materials, concrete and brick (recycled into aggregates) are the most researched topics for recycled product development. However, some studies emphasise other C&D waste materials like steel, wood, masonry, plastic, and glass for recycled product development [10,32,132]. Nevertheless, other C&D waste materials like soil and rock have attracted less attention, and limited research is evident on how to maximise the utilization (reuse and recycle) of such materials in order to manage C&D waste in a sustainable manner. Only a handful of studies have accentuated the importance and need for further research on legal, technical, and circularity aspects of excavated soil and rock from infrastructure constructions [11,66,133]. Thus, this area needs more explorative investigation and the outlining of solutions aligned with sustainability aspects. Researchers from various geographic locations have proposed several sustainable frameworks and models to maximise the efficiency of C&D waste management procedures. Despite several frameworks and models, there is still a lack of sustainable management of C&D waste. Furthermore, most studies on C&D waste management have focused on the building sector compared to transport infrastructure projects. Based on a review of the relevant literature, several research gaps are identified, which are discussed below in the context of seven sub-categories.

4.4.1. Limitations in Operational Aspects of C&D Waste Management

There is still lack of comprehensive C&D waste management performance measurement tools and a uniform C&D waste management guideline which can be adapted across similar geographical and economies. In addition, previous studies on C&D waste management have mostly assessed and examined the issue from an economic perspective, followed by environmental impact assessments, whereas not many investigations have been conducted to assess the social aspects. Furthermore, future research needs to assess the feasibility of establishing on-site recycling, storage, and sorting facilities in terms of sustainability aspects.

4.4.2. C&D Waste Management Legislation and Regulation Implementation and Monitoring Gaps

Researchers have widely studied this issue to minimise the illegal dumping of C&D waste. Despite imposing several types of penalties and charging fees, the effectiveness of imposing these fees is still very limited because the high level of illegal dumping is evident in both developing and developed countries [134,135]. Some researchers have discussed several barriers in the development and improvement of C&D waste landfill charging systems and have emphasised the need to consider the environmental impacts of different types of C&D waste materials [16,29,69,73]. However, there is a need for an in-depth investigation into how landfill charges can impact various transportation scenarios [136]. The lack of systematic classifications and categorisations of C&D waste types, the lack of uniform legislative and regulatory requirements, bureaucratic approval procedures, etc., hinder the effective management of C&D waste [22]. Thus, more explorative research needs to be conducted to develop a comprehensive and uniform regulatory framework and outline strategies for expediting decisions and approval processes.

4.4.3. Inefficient Stakeholder Engagement and Management

Stakeholder awareness and acceptance are vital factors for efficient C&D waste management [92]. However, several studies have indicated that stakeholder attitudes, percep-

tions, and behaviours significantly affect C&D waste management processes and performance [16,24,108,137,138]. In particular, stakeholders' behaviour towards C&D waste management is highly influenced by their perceptions, experiences, and social pressures [93]. Stakeholders' behaviour and conventional practices towards C&D waste management can be changed through training and awareness education campaigns and programs. In recent times, there have been efforts made to implement sustainable C&D waste management practices. However, a gap exists which still requires further research to build effective solutions [76,137].

4.4.4. Limitations of an Holistic Framework/Model to Assess Environmental, Economic, and Social Impacts

Many earlier studies have focused on the importance of sustainable management of C&D waste and proposed several models and frameworks. Properly managing C&D waste can bring numerous environmental benefits such as the efficient use of raw materials, minimisation of CO₂ emissions, and less waste being sent to landfills [22,139]. Economic benefits can also be realised through savings on purchasing costs, landfill charges, and revenue generated from selling scrap waste materials [14,46,140]. Additionally, sustainable C&D waste management can have social benefits such as job creation in the recycling and reuse sectors, improved working conditions and safety for waste management operators, increased awareness of waste management practices, and a reduction in illegal dumping [14,42,80,81].

Although a substantial amount of C&D waste sustainable management frameworks and models have been developed, proposed, and utilised, there is a lack of a framework to cover the critical aspects of assessing C&D waste management performance [18]. Sustainable management of C&D waste research is still in its preliminary stage, as it has yet to fully integrate environmental, economic, and social aspects. Research trends depict that the 'sustainability' and 'sustainable management' of C&D waste have mostly focused on environmental and/or economic impacts rather than a comprehensive assessment of all three components. Also, a few research studies have focused on social impacts, which are critical for understanding the overall impact of C&D waste management [42]. It has been observed from the analysis that most of the review papers emphasise developing C&D waste management practices and minimising such waste via reuse and recycling processes. However, comprehensive sustainable impact assessments of C&D waste generated from transport infrastructure projects are still very limited [141].

Many efforts have been made to assess C&D waste management performance through developing and evaluating sustainability assessment models, for instance, the waste prediction model in Spain, the waste score determination model in Singapore, the factor analysis model to assess contactors' behaviour and attitudes in Malaysia, the sustainable procurement model, and many more [24,27,140,142]. Some other studies focus on environmental aspects [13,17,21], economic aspects [111,140,143], and social aspects [42,80,81]. However, the aforementioned research focused on specific geographical locations rather than wider cross-regional mobility of C&D waste management throughout the lifecycle process [3,69]. Therefore, understanding and considering the dynamics and mobility during the lifecycle of the C&D waste procedure is still very limited [29,69,73].

Jin et al. (2019) identified research gaps and suggested some emerging research areas, such as prefabricated construction, the circular economy, and the qualification of waste generation. Additionally suggested is the development of a comprehensive evaluation framework for designing, planning, and evaluating the performance of C&D waste diversion for future investigation [9]. On the other hand, Chen et al. (2021) discussed research gaps in the lack of a systematic review of complex C&D waste sorting, transportation distance, and evaluation of its environmental impacts [64]. Globally, the illegal dumping of C&D waste is one of the most significant concerns and barriers to stopping illegal dumping practices. Du, Xu, and Zuo (2021) [75] focused on the illegal dumping of C&D waste in relation to its consequences and impacts on the environment, waste management, economics, and emerging technologies. Future research on environmental issues, such as the

identification of the migration of pollutants and treatment of illegal dumping pollutants, needs to be conducted. In addition, the development of a comprehensive framework or decision analysis model for improving stakeholders' decisions relating to sustainable C&D waste management is still a critical gap that needs to be addressed. Apart from that, there is a lack of unified economic assessment standards for evaluating the costs associated with the illegal dumping of C&D waste.

4.4.5. Inadequate Market for Recycled Products from C&D Waste

There are two emerging research areas gaining attention in the field of C&D waste management. The first is the underdeveloped market for recycled products, and the second is the disparities between the supply and demand of recycled materials. There is a need for further research to understand these issues better and develop practical solutions to create a stable market for recycled products that will provide numerous environmental, economic, and social benefits to the present and future.

4.4.6. Limited Studies on Social Performance

The limited studies on social aspects as compared to environmental and economic impact and performance assessments on C&D waste management are attributed to several factors. Key project stakeholders (clients, builders, waste management contractors) from the construction industry are concerned about the financial benefits, while other stakeholders such as regulatory authorities, local community, and environmental activists group are concerned about achieving a reduction in environmental and social impacts through managing C&D waste. Construction industry practitioners are powerful in decision making, and so it is obvious that their interest is more geared towards economic assessment [42]. Furthermore, studies related to the environmental and economic performance assessment of C&D waste management have presented mathematical/statistical modelling that is based on quantification methods. In contrast, the investigation of social aspects requires an in-depth understanding of local context, which can be better investigated through qualitative methods rather than statistics. Social impacts of C&D management such as workers' health and safety, accessibility to local areas, business, and job opportunities for remote communities, etc., could better understood through community participation and dialogues. This review study found very limited studies investigating the social factors hindering C&D waste management performance as opposed to environmental and economic dimensions. In addition, among the limited studies on social impact assessment, the majority adopted statistical/mathematical quantification methods in order to develop a social performance assessment framework/model. Collective research focused on the three dimensions of sustainability is needed to investigate the enabling factors for enhancing community involvement and awareness, and to improve C&D waste management behaviour in both numerical and descriptive perspectives.

4.4.7. Inadequate Integration of Information Technology

The integration of information technology for sustainable C&D waste management is an emerging research topic that has been discussed in several publications, and it is recommended as a future research area that needs to be explored. For example, the integration of building information modelling (BIM), big data, global positioning system (GPS) trackers, and geographic information system (GIS) applications can enhance the efficiency of C&D waste management [9,29,69,73,108]. In addition, using big data to estimate the composition of construction waste is critical for efficiently operating landfills, and for sorting plants in construction waste management [144]. The integration of information technologies (e.g., BIM, GIS, GPS) for tracking and monitoring C&D waste and assessing and analysing this information is still in the primary stage. However, the bibliometric findings identify the circular economy and machine learning as the peak research trends (shown in Figure 5) in the C&D waste management field in recent years. Therefore, more research is required with the integration of information technologies and circular economy models into the

C&D waste management industry to promote the successful implementation of sustainable C&D waste management practices.

4.4.8. Development of Conceptual Framework

The conceptual framework (illustrated in Figure 7) is developed based on the findings from the data sourced from WoS and bibliometric analysis. The C&D waste management barriers are sub-categories in seven broader themes representing critical research areas for further in-depth investigation.

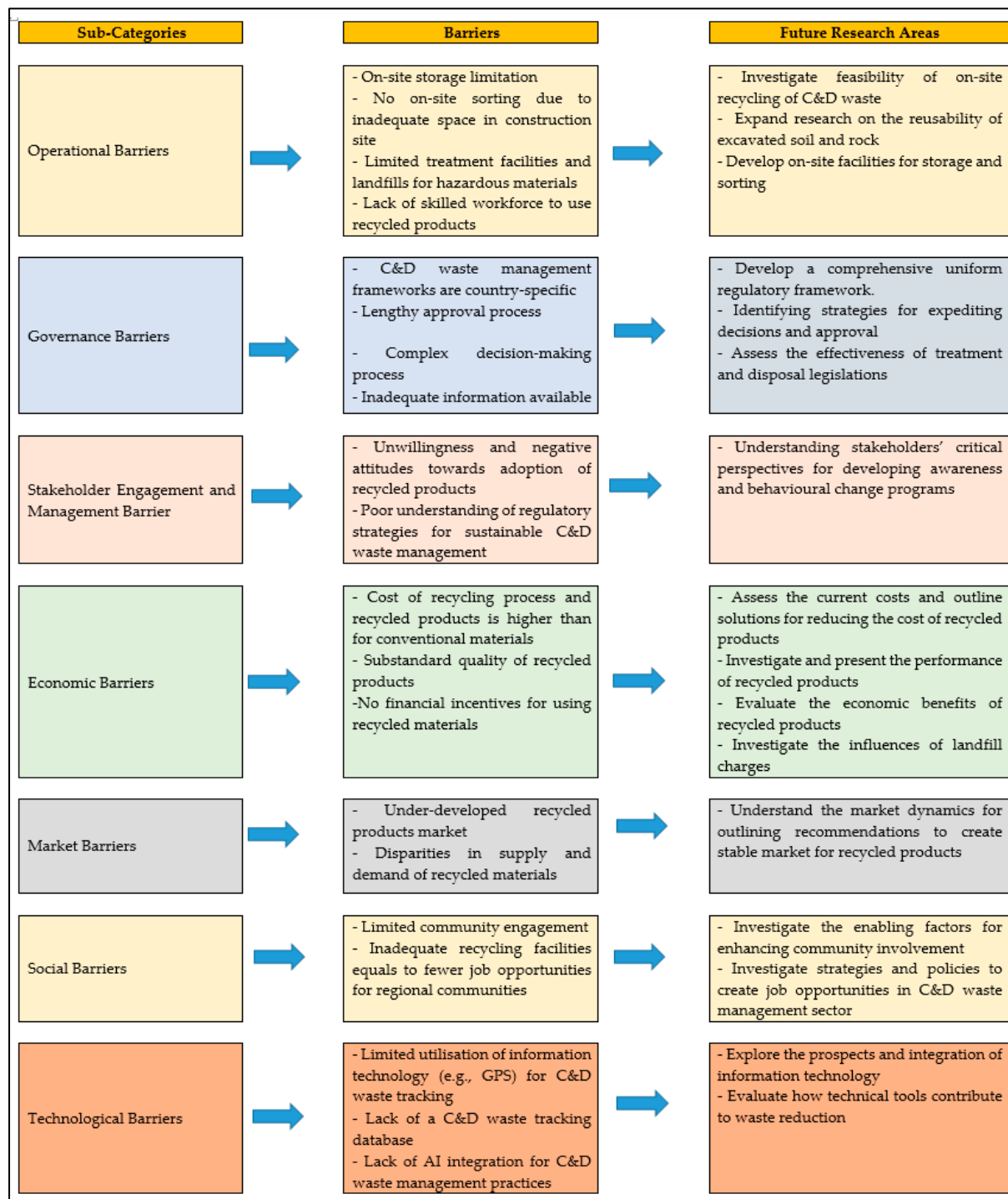


Figure 7. Identified barriers and future research areas.

This systematic literature review analysed the current situation and mapped the research gaps to develop practical solutions for minimising C&D waste generation and maximising the reuse and recyclability of C&D waste materials. Additionally, this study finding outlines emerging factors hindering sustainable C&D waste management practices in both developing and developed economies.

5. Conclusions

In this paper, a comprehensive bibliometric analysis was conducted to review C&D waste management publications using the WoS database search, and identified 1601 publications from 2002 to 2022 for further analysis. Despite many research studies having addressed the problems associated with inefficient C&D waste management, these problems are still persistent. The research related to sustainability and the circular economy has increased significantly after the introduction of global agendas like the European Union (EU)'s strategic framework in 2005 and the UN's 'Sustainable Development Goals' in 2015. The adoption of the circular economy and sustainability into C&D waste management can enhance the transition of achieving the 3R principals of waste management strategies. In the last few years, the research focus has been shifted towards the circular economy and the integration of information technologies such as the application of BIM, GIS, GPS, and big data for sustainable management of C&D waste. Researchers have outlined several barriers including stakeholders' unwillingness, inadequate skills, the high costs of recycled products, inadequate information about the quality and standards of the recycled products, etc., hindering the adoption and utilisation of recycled products from C&D waste. This situation affects the reduction in C&D waste generation and slow uptake of acceptability and usability of recycled products from C&D waste.

To conclude, this study summarises the current research gaps and future research by identifying seven categories:

- (1) Limitations in the operational aspect of C&D waste management;
- (2) C&D waste management legislation and regulation implementation and monitoring gaps;
- (3) Inadequate market for recycled products from C&D waste;
- (4) Inefficient stakeholder engagement and management;
- (5) Limitations of sustainable C&D waste management frameworks and models;
- (6) Limited studies on social performance as compared to environmental and economic performance;
- (7) Inadequate integration of information technology in sustainable management.

The aforementioned research gaps and future research areas provide valuable insights to scholars, industry experts, and policymakers to design studies by collectively addressing the three dimensions of the sustainability framework for managing C&D waste. Additionally, this study is a valuable resource for researchers in gaining a deeper understanding of C&D waste management barriers and developing practical solutions to enhance sustainable C&D waste management practices.

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