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Circular Economy Research on Building Construction and Demolition Waste: A Global Review of Current Trends and Future Research Directions

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Abstract

The circular economy (CE) paradigm has piqued public interests worldwide as a significant innovative attempt to conserve finite resources, reduce waste, and shift away from the linear economy of "take use and dispose of". An emerging shift to a CE model is unavoidable for resource conservation and efficient use of materials. Although CE is still at its early stage of managing building construction and demolition waste (BCDW), the scientific contribution of the CE agenda is significantly growing and augmenting in the construction industry. Therefore, this study aims to present the state-of-the-art research on CE adoption in BCDW management using a mixed review approach (quantitative and qualitative analysis). In addition to the existing trends and considerations, the main research themes and CE strategies adopted in BCDW management, are presented and discussed. Furthermore, CE indicators for BCDW and effective management operations for BCDW in a CE environment are put forward. Future research directions, including lifecycle assessment indicators for BCDW minimisation in a CE, application of advanced technologies for CE, and intelligent decision support tools for CE adoption in the BCDW management, are highlighted. It is believed that the analysed critical issues for CE adoption in BCDW management and identified future research directions would further help the development of CE research and help stakeholders and policymakers in advancing and adopting CE in the construction industry at large.

Keywords: Circular economy; Construction and demolition waste; Indicators; Review; Sustainability; Waste management

1. Introduction

The building construction industry (BCI) is an important sector that serves other sectors and contributes to global socio-economic growth (Olukolajo et al., 2022). The industry provides roughly 25% of the gross domestic product and job opportunities for about 7% of the global population (Norouzi et al., 2021). In Europe, the BCI provides jobs for over 18million people (Benachio et al., 2020). It has also contributed to rapid urbanisation and the provision of living and working space (Oluleye et al., 2021). It is projected that with a 60 percent increase in the management of construction resources, the industry will generate an additional $1.6 trillion annually (Pan & Zhang, 2021). These economic benefits will only continue if construction resources are consumed efficiently and sustainably (Pan & Zhang, 2021). There has been an increase in demand on the BCI because of the geometric rise in population (Joensuu et al., 2020), leading to increased resource consumption (Norouzi et al., 2021).

Moreover, the BCI consumes up to 40% of global raw materials (Darko & Chan, 2016) generates about 40% of waste (Nasir et al., 2017), and emits about 25% of carbon dioxide (Mahpour, 2018). Hence, it implies the industry is one of the highest waste generators globally (Bilal et al., 2020), a sign of unsustainability of the sector (Núñez-Cacho et al., 2018). These issues could be traced to the unsustainable economic approach of "*take, make, dispose*", otherwise known as linear economy, entrenched in the BCI (Bilal et al., 2020).

A linear economy is an approach that harnesses construction materials for building purposes and trashes them off at the end of the useful life of the building (Leising et al., 2018) since they are designed and assembled for a single time use without the advantage of injecting the used materials back into the system. The liner economy focuses on the limited life span of resources without considering the product's afterlife (Jacobsen, 2006). The cumulative problems of the linear economy created lots of concerns among the government, construction professionals, and decision-makers on the need to look for a lasting way to avert the environmental consequences of resources consumption and waste generation (López Ruiz et al., 2020). Consequentially, this led to an urgent need to promote a sustainable built environment with increased efficiency of construction resources and waste (Tserng et al., 2021).

CE paradigm has gained momentum in various sectors such as the textile and agriculture sectors (Esposito et al., 2020) but not much traction in the BCI despite the level of waste generated and the unsustainable approach to resource use (Çetin et al., 2021). As a result, various CE definitions have emerged, such as Bilal et al. (2020), which regard CE as an approach to solving linear economy problems. Ellen MacArthur (2015) defined CE as the appropriate approach to end the menace of the linear economy through treating, reusing, and recycling waste materials to promote sustainable consumption and cleaner production. Jacobsen (2006) averred that CE is a regenerative approach to a sustainable and balanced environment. In the view of Bressanelli et al. (2021), CE is an approach that reconfigures the current methods of producing and usage of resources to enhance efficiency while catering to the needs of people to attain a sustainable environment.

Moreover, CE is a concept that could offer various advantages in a close loop. This concept is still relatively new in the BCI (Leising et al., 2018). However, it is regarded as an alternative to the unsustainable linear economic model (Núñez-Cacho et al., 2018). The goal of this initiative is to reduce construction-consumption systems, linear material, and energy flow systems, and waste by incorporating materials cycles, and renewable and cascade-type energy flows into the linear system. (Antwi-Afari et al., 2021). The increasing need for CE in the BCI has drawn the attention of researchers, and studies, including reviews, have been conducted. Previous reviews (Table 1) on CE in the BCI are informative and cannot be overlooked.

Table 1: Summary of previous reviews

Paper	Research methods	Database	Findings	Research gaps
(Benachio et al., 2020)	Qualitative Review	Scopus	• Findings show that there is insufficient knowledge on standard practice for CE in the BCI.	•No detailed information on the transition from the linear economy to a CE •BCDW and CE indicators were not captured
(Antwi-Afari et al., 2021)	Scientometric Review	Scopus	• The study finds out that Circular product design and end-of-life considerations are not well covered in existing studies.	•The study did not consider BCDW, indicators, and effective management operations.
(Hossain et al., 2020)	Qualitative Review	Web of Science, Goggle scholar, and Scopus	•CE comprehensive adoption and evaluation of specific building projects is still limited	•Information on BCDW, CE indicators for BCDW and effective management operations are lacking. •Three future research trends advocated for are insufficient to promote CE in the BCI.

Paper	**Research methods**	**Database**	**Findings**	**Research gaps**
(López Ruiz et al., 2020)	Qualitative Review	Scopus and Web of Science	A conceptual integrated model for CE adoption in the construction industry was put forward	•Building materials and the CE indicators were not considered.
(Osobajo et al., 2020)	Qualitative Review	Scopus	Studies have considered resources use in a CE with limited information on building design.	•Information on the shift from a linear economy to a CE was scanty. •The study did not consider BCDW, CE indicators, and effective management operations
Current study	*Scientometric and qualitative Reviews (Mixed method)*	*Scopus*	-	-

These reviews (Table 1) have improved the current understanding of CE in the BCI, but some gaps in knowledge still exist. As a result, it is necessary to address these significant knowledge gaps by exploring and obtaining a deep understanding of CE in BCDW. Moreover, at the preliminary validation for this study, the previously published reviews were not comprehensive based on the authors' knowledge and did not deal with CE for BCDW. The studies focused on the construction industry without a thorough understanding of a particular stage of a construction project (planning and design to demolition) for the application of CE.

As an attempt to tackle the research gaps and the limitations mentioned, this study is unique. It provides a distinct understanding of the state of the art of research on CE in BCDW using a mixed review approach (scientometric and qualitative). The review becomes necessary in BCDW due to the large amount of waste generated by the construction sector. For the scientometric review, the specific objectives centred on (i) analysing the trends and structure of academic publication on CE adoption in BCDW; and (ii) determining the network of the most productive country, research outlet, and co-occurrence network keywords in CE research in BCDW. For the systematic review, the objective is to explore the suitable CE strategies for BCDW across the building life cycle; CE indicators in BCDW management, previously developed CE models, and CE effective management operations.

The fulfillment of these objectives would assist in understanding the hot research topics and the state of the art of CE adoption in BCDW. Also, the achievement of the study's aim will provide insights into the broad studies conducted in CE for BCDW. More so, it will provide information about the areas for future research. Practically this research outcome will be very useful to many CE stakeholders and will serve as a credible knowledge base for policy makers and practitioners. This will enable them in funding research efforts on the identified salient areas.

2. Research Methodology

This study was conducted using an interpretive philosophical procedure using published articles as the element of analysis. This procedure ensures the researcher's nuance and variability in their close interaction with the published articles to understand ideas and design new knowledge. This approach has been adopted in construction literature in areas like IoT research development in construction (Ghosh et al., 2021), procurement in the built environment (Yevu et al., 2021), and artificial intelligence in green buildings (Debrah et al., 2022). The operational adoption of this philosophy was attained through a mixed-method review approach (scientometric and qualitative analysis) in Figure 1.

2.1 Scientometric/quantitative analysis

A scientometric analysis is a widely used technique for exploring research development. Specifically, it provides an understanding of the research productivity of a country, academics, faculties, and journals (Wuni et al., 2019). The scientometric analysis has been widely used in revealing the development in construction-related research over the years. For example, sustainable development (Olawumi & Chan, 2018), artificial intelligence in construction (Darko et al., 2020), and building information modelling (Saka & Chan, 2019). This analysis was adopted in this research. The procedures followed in Figure 1 are also described below:

2.1.1 Preparatory investigation

A preliminary investigation of the topic was carried out simply using Google scholar. This was conducted primarily for validation to (i) examine articles' availability and suitability for review purposes and (ii) identify existing keywords and the preeminent ones. The outcome of the preliminary validation showed that there are limited reviews on the subject matter. Still, none was related to CE in BCDW. This helped in coming up with better and more robust research questions.

2.1.2 Search strategy and Database selection

Selecting a suitable search strategy and appropriate database(s) is critical before retrieving articles for a review. There are different databases, but the most popular are Web of Science and Scopus. In this study, Scopus was selected over Web of Science. The choice of Scopus is centred on four reasons (i) the majority of research articles in the construction domain are stored in Scopus (Hong & Chan, 2014); (ii) Scopus is the biggest citation database for all peerreviewed articles (Tariq et al., 2021); and (iii) in terms of precision and consistency, Scopus perform better than other databases (Darko & Chan, 2016). A basic search was conducted and then refined based on the frequent keywords from other relevant articles. The improvements in terms of the investigation were made through different rounds of refinement, the search string generated is: "Circular economy" OR "circularity" OR "circular business" AND "waste" AND "construction and demolition" OR "project life cycle" OR "building project". This search resulted in 128 articles.

2.1.3 Yardsticks for inclusion and exclusion

The criteria for inclusion and exclusion in this study were patterned in line with Tariq et al. (2021). The yardstick for inclusion adopted includes: (i) research articles focusing on CE or circularity in the construction, building, or housing sector (ii) no objection to the year of publication. Also, the yardstick for exclusion is presented as (i) research focusing on CE without considering construction/building-related issues were excluded; (ii) research articles focusing on construction without capturing CE were excluded; (iii) articles from a discipline outside the construction domain were excluded. (iv) abstract only articles, articles in another language other than English, and those without full text were screened out. The inclusion and exclusion resulted in 116 articles exported to VosViewer software for science mapping.

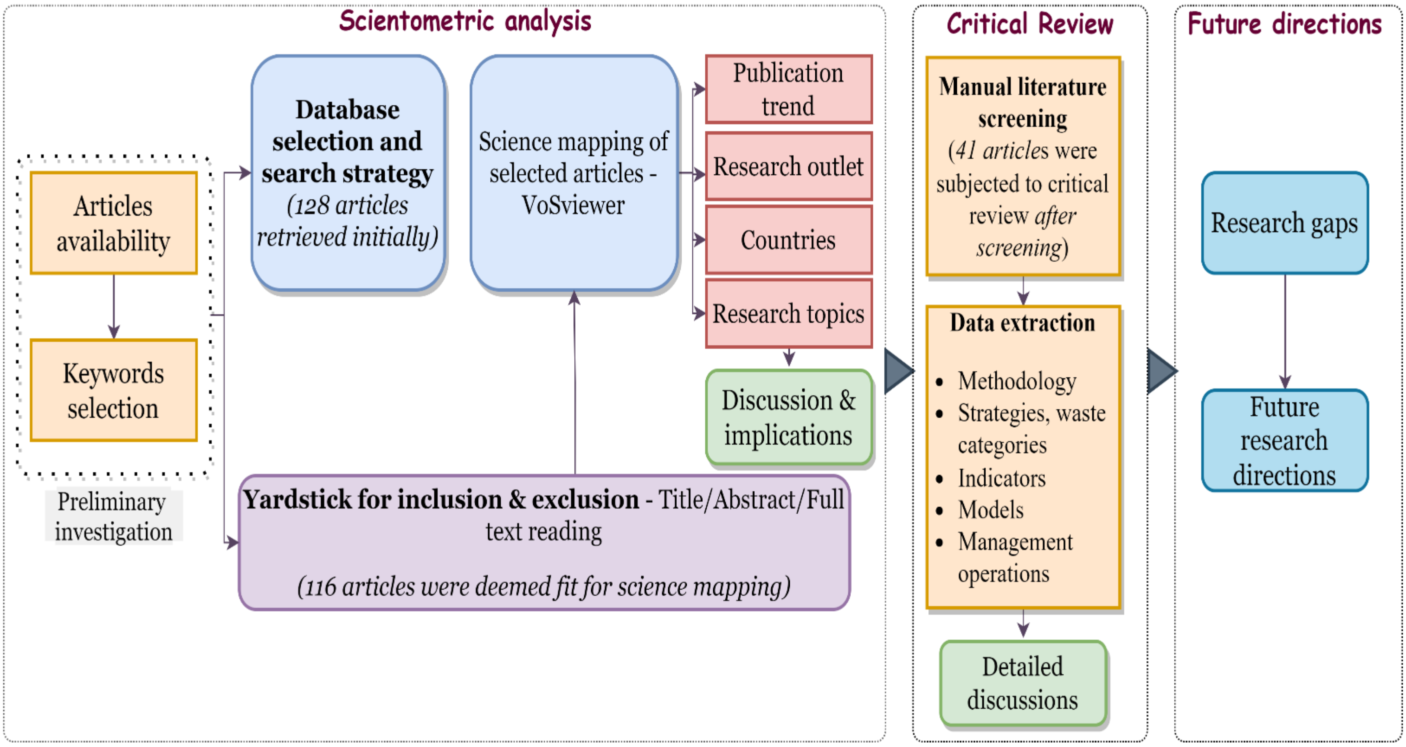

Figure 1: Research methodology process for the study

2.1.4 Mapping of selected articles

In-depth mapping of the extant literature is usually done by software tools. These software tools are numerous with their identity as some are versatile while some are special purpose. Adequate understanding of the strength and weaknesses of the tools is pivotal to its selection. Among the various mapping tools include CiteSpace, VosViewer, and BibExcel. The most popular and easy to use among these, especially in construction-related research, is VosViewer (Olawumi & Chan, 2018). VosViewer is a text-mining tool that is particularly useful for visualising massive networks. It was adopted for this analysis following these steps: (i) data set loading, visualisation, computing, and data mining, (ii) co-citation analysis, analysis of keyword, journal, and country co-occurrence.

2.1.5 Qualitative/Critical review

The 116 articles used for the scientometric analysis were later subjected to further full-text reading by the authors following the objective of the qualitative review (Figure 1). Only 41 articles met these criteria and were adopted for the critical review. The content analysis of these articles is presented in Appendix A.

3. Presentation and discussion of science mapping results

The science mapping discussion for this study was carried out under the following headings (i) trend of publication; (ii) mapping research outlets; (iii) mapping of countries; (iv) mapping of keywords co-occurrence.

3.1 Annual publication trend of CE research on construction and demolition waste

Figure 2 presents the yearly distribution of analysed CE articles that focus on BCDW. Of the 116 papers, the earliest studies were authored by (Marlet, 2014; Sansom & Avery, 2014). This implies that the CE concept for BCDW emerged in 2014 and explains while it is still a new concept in the industry; and this was followed by one, two, and three papers published in 2015, 2016, and 2017 respectively. However, the remaining papers were published between 2018 and 2021. Hence, it implies a significant interest in CE research for BCI in the last four years. This finding is in tandem with previous studies which classify CE as one of the hottest topics in the construction domain. The increase in the commitment level to a particular research domain always shows forth in the annual publication trend.

The need for a shift from a linear approach to a better sustainable system (circular economy) further explains the recent attention given to CE. It also clearly shows that CE is becoming imperative to the construction industry globally in managing waste.

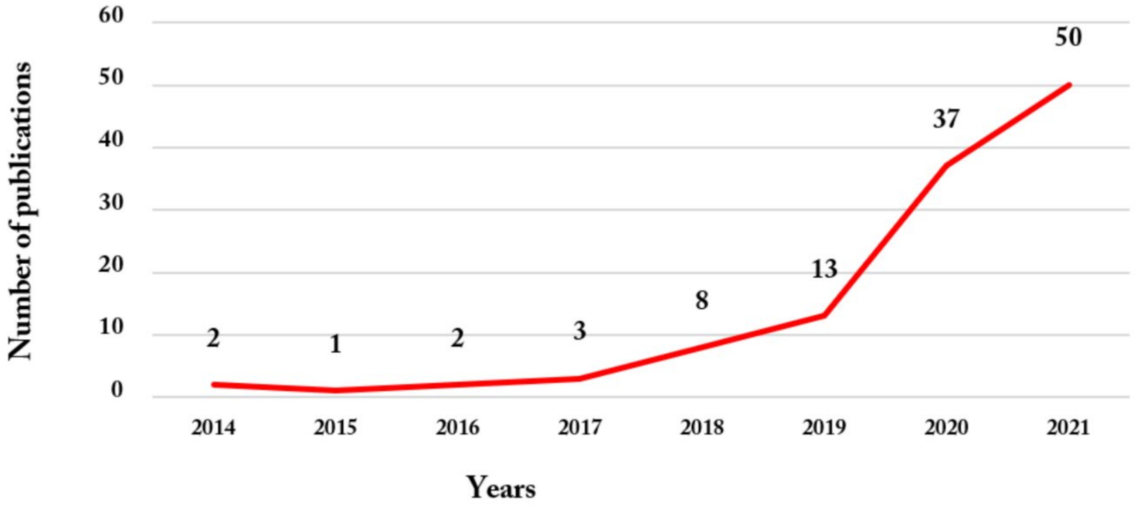

Figure 2: Annual publication chart of CE research on construction and demolition waste

3.2 Journal publication outlet analysis

The 116 articles are distributed across 47 scientific journals, as presented in Figure 3. A larger percentage of the articles (42%) are published in four academic journals, which are Journal of cleaner production (14%), Resources Conservation and Recycling (13%), Sustainability (11%), and Waste Management (4%). This implies that research lying at the junction between CE and BCDW is strongly linked to the sustainability direction. In all, the implementation of CE to the BCDW is a budding and growing topic, strongly associated with sustainability research

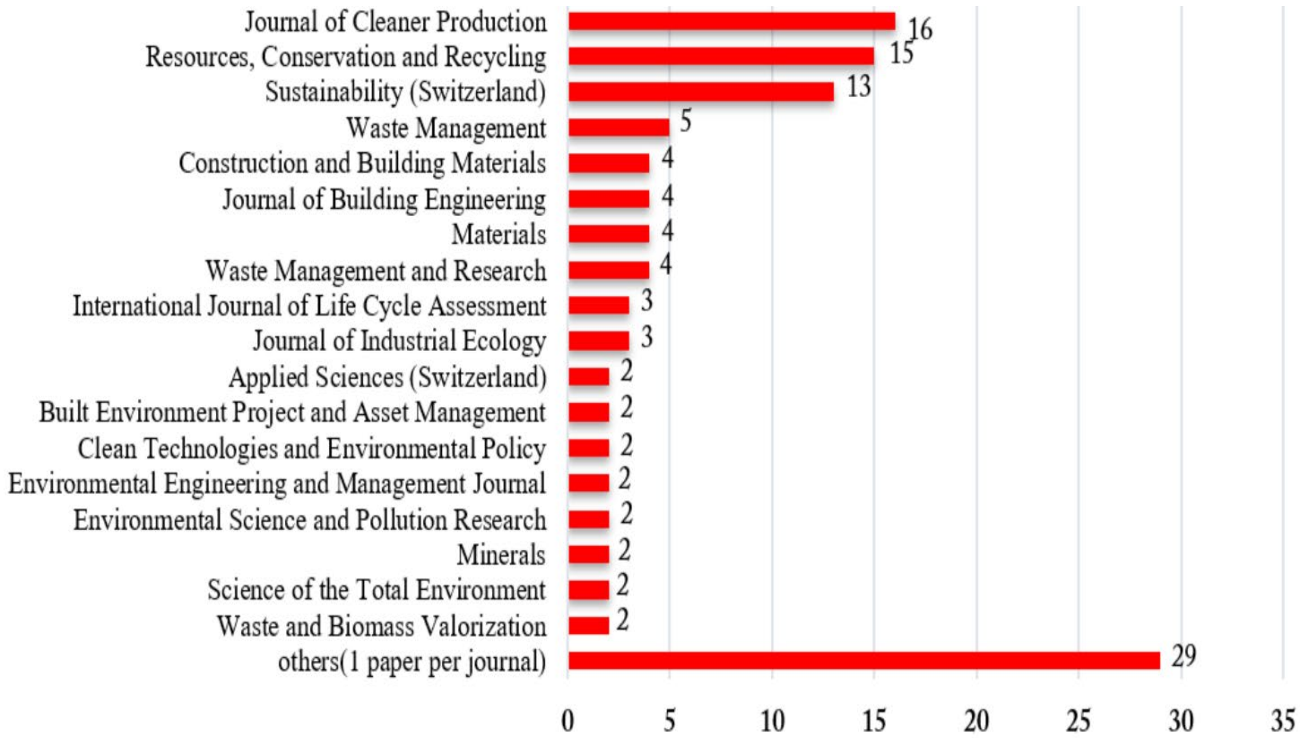

Figure 3: Article distribution per research journal

3.3 Science mapping of countries

The network collaboration of countries often enhances the proper mapping of the most productive countries in a particular research domain. However, clear knowledge of the most productive and influential countries is vital in promoting research funding and collaborations (Tariq et al., 2021). The search criteria adopted in this study include analysis type (co-authorship), analysis unit (country), while the minimum number of documents of a country and the minimum number of citations of a country were set to 3 and 5, respectively. Based on this search criteria, out of 39 countries in the CE research for BCDW, only 16 fulfill the criteria (Table 2). Equally, about 8% (16 out of 195) of all the world's nations are committed to CE research in BCDW. This is quite small and further confirmed the infancy state of CE in the BCI generally. Each country's contribution to CE research for BCDW is explained via the node size (Figure 4).

For instance, Spain has the biggest node size, connoting that it is the most productive country with 27 articles. Italy and China follow with 18 and 11 articles, respectively. The most productive countries in CE research for BCDW are Spain, Italy, and Canada. This might be because of the early adoption of CE in these countries compared to other regions. Furthermore, the developed countries are making a good effort in promoting CE in minimising BCDW. However, the effort is still not enough because countries like the United States, Canada, and

Germany are key nations that have pushed the frontiers of sustainability but have done little regarding CE issues. Nevertheless, little or nothing has been done on CE in developing countries to minimise BCDW. This could be because of their low awareness or expertise in CE to promote cleaner production in the BCI.

Moreover, Figure 4 revealed four clusters of the countries based on how often they cite one another. For instance, Australia, the United States of America, Canada, Austria, and Belgium belong to one cluster denoted by the red colour. The remaining three clusters of countries are represented in blue, green, and yellow. Similarly, countries closely placed beside each other such as Spain and Italy, cite each other frequently. The line thickness denotes greater affinity, and thicker lines between Spain and Italy, Italy and China, China and Hong Kong connote a greater connection and association among the country pairs.

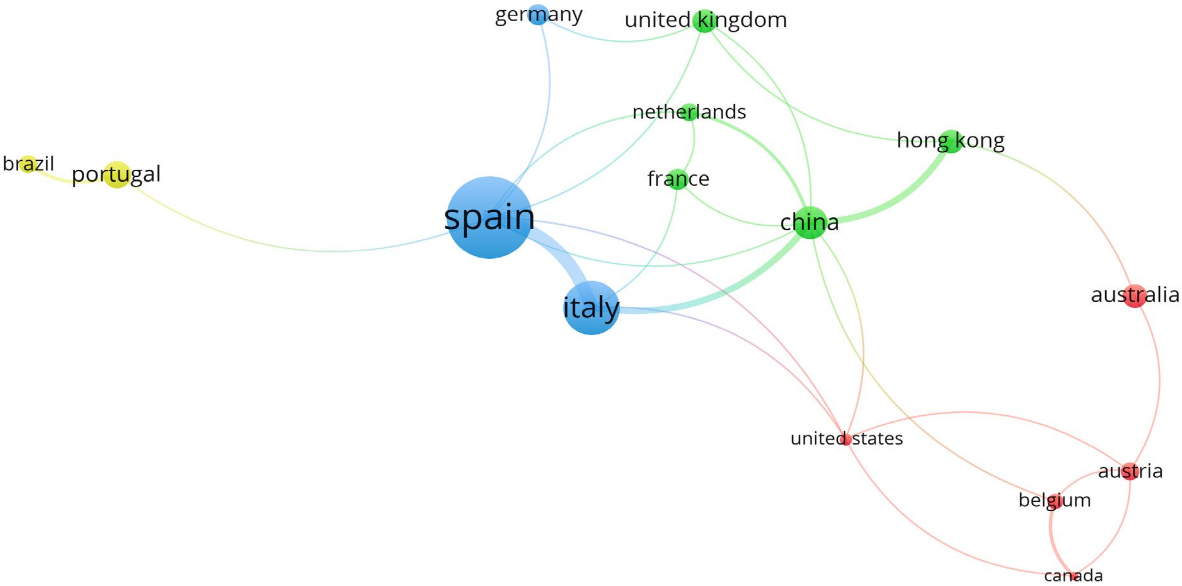

Figure 4: Most productive countries in CE research for construction and demolition waste

Table 2: Top countries in CE research on building construction and demolition waste

Countries	**Documents**	**Citations**	**Av. Citations**	**Total link strength**
China	11	544	49	15
Italy	18	267	15	14
Spain	27	523	19	14
Hong Kong	8	363	45	6
United State	4	74	19	5
Austria	6	74	12	4
Belgium	5	28	6	4
Canada	3	26	9	4
Netherland	6	37	6	4

Countries	Documents	Citations	Av. Citations	Total link strength
United Kingdom	8	553	69	4
France	7	8	1	3
Portugal	9	42	5	3
Australia	8	88	11	2
Brazil	6	22	4	2
Germany	7	283	40	2
Finland	4	14	4	0

3.4. Major research areas of CE in construction and demolition waste

The major research themes were determined using the keywords co-occurrence, and four clusters were identified (Figure 5). Information from Figure 5 enhances the development of the framework of research themes (Figure 6).

3.4.1 Co-occurrence analysis of keywords

The author's keywords often explain the key themes of an academic article. These keywords usually serve as indexation in a database for search efficiency (He et al., 2017). As a result, a keywords network has the potential of representing a knowledge domain (Su & Lee, 2010) and gives clarity into important research topics and how they are mutually organised and associated (Wuni et al., 2019). To this end, scientific mapping of all keywords within the publications set gives a credible map of various research areas and themes in a particular domain. The co-occurrence analysis was carried out using the author keyword in this study. This approach has been applied in various construction research articles (Darko & Chan, 2016; Olawumi & Chan, 2018). Therefore, this approach would better represent the different research themes regarding CE in BCDW.

The minimum benchmark of occurrence of keywords was set to three to ensure that cluster results are comprehensive and representative. This benchmark was arrived at after multiple trials on the VosViewer software. It is worthy of note that some similar keywords in the analysis exist, and some are redundant. A thesaurus file was used to combine them in the network map with attention to matching keywords. For example, "construction and demolition waste" was used to replace "construction and demolition waste(cdw)", "construction waste", "cdw", and "waste", among others.

Redundant keywords, such as China and European Union, were removed to enhance better and quality results. Based on the filtering and merging of similar words/phrases, 19 co-occurrence keywords were noted and grouped into 4 clusters. Each cluster is indicated with a distinct colour in distance-based visualisation (Figure 5). The node sizes depict the keywords co-occurrence, while the line thickness represents the affinity of the keywords. The thicker line between 'circular economy' and 'construction and demolition' shows a high link and association between the two keywords. The four clusters which are the main research themes of CE in BCDW are:

Cluster 1: Circular lifecycle assessment of building construction materials

The keywords under this cluster include 'construction', 'construction and demolition waste', 'life cycle assessment', 'mechanical properties', 'recycled concrete', and 'recycled aggregate' (Figures 5 and 6). The research effort figured out in this cluster is on the circular lifecycle assessment of building materials. Life cycle assessment of construction materials entails a dynamic cradle to cradle approach to appraise construction materials across the building lifecycle (Hossain et al., 2020). However, proper analysis of the environmental impact of building materials lies in the proper understanding of the lifecycle of the materials (production, usage, and demolition) (Guo et al., 2017). Construction and demolition waste and recycled aggregate are the most prominent in this cluster based on their node size. This shows that effort has been diverted more to these two areas than others in the cluster. Although most studies focused on the building construction materials lifecycle assessment in a CE, research on lifecycle assessment indicators in minimising building construction waste is still limited. Therefore, future study on the lifecycle assessment indicator framework for BCDW in a CE is not out of place.

Cluster 2: Building construction materials flow system

This cluster encompasses keywords such as: 'buildings', 'industrial ecology', 'material flow analysis', and 'urban metabolism'. This research theme explains the flow of building construction materials. A holistic material flow system has been an increasingly preferred method for rational decisions in BCDW management (Guo et al., 2017; Thushari et al., 2020). This system helps understand the process functions and their interconnection in BCDW management (Thushari et al., 2020). The system is very imperative in managing flows of materials and analysing them. In this cluster, the key term based on the node size in Figure 5 is material flow analysis (MFA). MFA has become a very important technique for industrial ecology to assess the metabolism of a particular material (Sendra et al., 2007). This technique quantifies stocks, inputs flow, and resource losses in building projects. Similarly, the need to understand the flow of construction resources and any loss in construction resources has attracted research efforts (Sendra et al., 2007).

Cluster 3: Circularity in construction and demolition

Substantial efforts have been tailored towards adopting CE in BCDW, resulting in the cluster with commonly used keywords such as ‘circular economy’, ‘construction and demolition’, ‘resources efficiency’, and ‘urban mining’. CE and construction and demolition are two major keywords in this cluster. This research theme intensifies the effort on the need to embrace CE during construction and demolition. Construction and demolition require proper management of resources and waste. The management of this waste must be prudent. The shift to circularity in construction and demolition has been viewed as a response to the problems of inefficiency in building resources. Waste is often generated during the construction and demolition of a building; however, discarding this waste creates more environmental issues.

Also, a regenerative system for tackling construction waste is CE, which can minimise resources, waste, and energy by keeping them in a close loop (Baldassarre et al., 2019) is critical. Achieving this is tied to implementing a circular frame based on closing loops, slowing loops, and narrowing loops (Gorgolewski et al., 2008). Although circularity in construction and demolition is gaining attention, information and research on its contextual issues and the best way to predict BCDW in a circular economy are scarce. Therefore, further research is needed to empirically examine the contextual issues and develop an intelligent approach for waste prediction.

Cluster 4: Circular economy strategies

This cluster consists of four keywords: ‘recycling’, ‘reuse’, ‘sustainability’, and ‘waste management’ (Figures 5 and 6). This research cluster denotes the various circularity approaches that will promote sustainability and reduce waste during the construction and demolition of building projects. CE strategies are the measures that reduce waste generated from natural resources (Foster, 2020). A significant aspect of CE is having a clear picture of the various CE strategies and how they can be adopted in waste management to promote sustainable and cleaner production. One of the major CE strategies in literature is recycling. Many BCDW that cannot be easily reused could be recycled. Nevertheless, the CE strategies have gained momentum but focus on the best practice, and the decision support system for its integration is still very scarce.

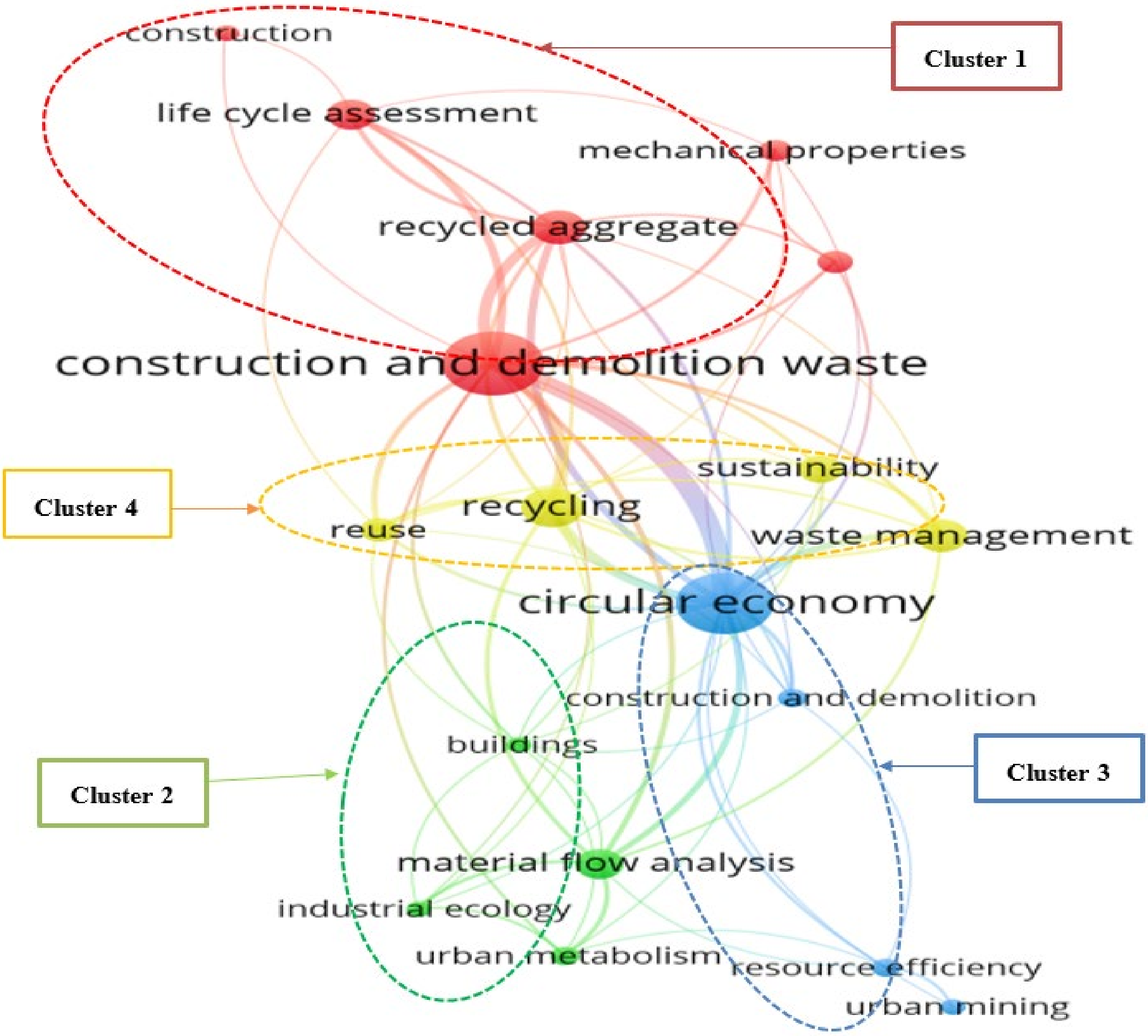

Figure 5: Major research areas of CE in construction and demolition waste

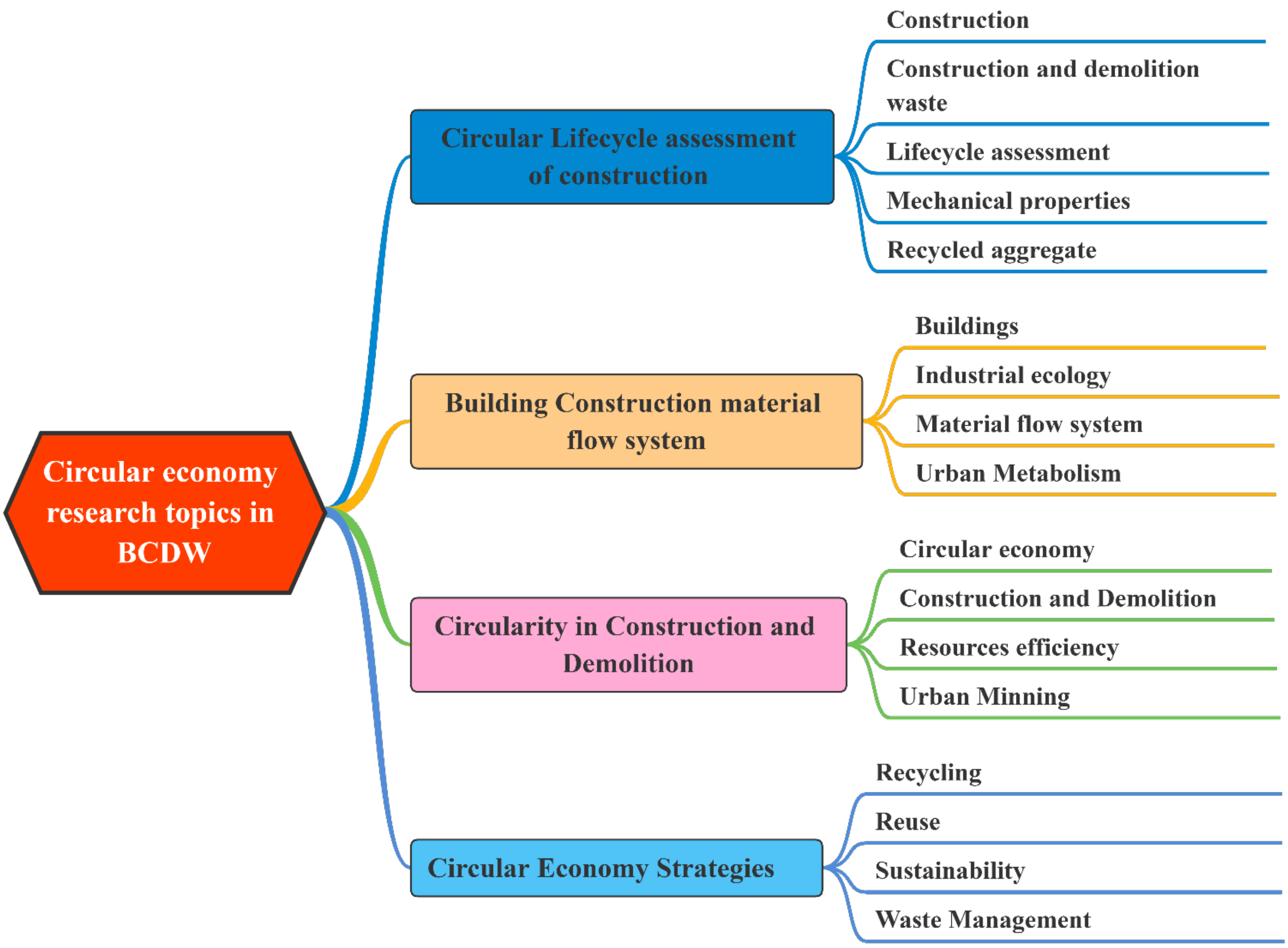

Figure 6: Framework of the major research areas on CE in BCDW

4. Critical Review and Discussion

A total of 41 research articles were used for the systematic review as they meet the study's selection criteria and thematic foci. The systematic review specifically focused on (i) the various types of circular economy strategies applicable in BCDW, (ii) the materials, the strategies are applied on or could be applied on, and (iii) the stage (construction/demolition stage) at which it is best to apply these on the various BCDW. All the articles examined are listed in Appendix A. The thematic foci for the critical review are based on the following issues: (i) CE methodologies; (ii) CE strategies, BCDW categories, and the stage of application in the building lifecycle; (iii) CE indicators in BCDW management; (iv) CE models in BCDW; (v) CE management operations for BCDW.

4.1 Methodological characteristics of the research corpus

Over the past years, research in circular economy in the domain of BCI has been developing, and various research approaches have been used to increase knowledge and promote the shift from a linear economy to CE. These methods include case study, experimental, survey, and theoretical research (Table 3). Empirical research and case studies have dominated over the past years. This is because they are more suited for research works that are still at an early stage.

Regarding survey research, it has gained credible attention over the years. Survey research is very significant in today's world because it helps measure the representativeness of individual perceptions and experiences. Survey research stands to provide hard numbers on the perception of practitioners that could help in taking critical decisions (Punch, 2003). Also, the case study research has explored various methodologies, such as thematic cartography (Mihai, 2019) and artificial neural networks (Lu et al., 2021). The experimental investigation focuses on the characteristics of materials that could be recycled, reused, recycled, remanufactured, and recovered.

Few studies have adopted the artificial intelligence (AI) approach in CE research. As a result, attention should be given to AI research in the future to promote digitalization in CE transition in the construction industry.

Table 3: Summary of methodological characteristics of the included papers

Research types	Methods adopted	Authors
Automation	Optimisation, simulation, scenario analysis	(Cal et al., 2021)
Case study	Dynamic modelling approach	(Noll et al., 2019)
	System dynamic	(Zoghi & Kim, 2020)
	Enterprise input and output analysis	(Yu et al., 2021)
	Artificial Neural Network, Decision Tree, Regression	(Lu et al., 2021)
	Content analysis	(Minunno et al., 2018; Nußholz et al., 2019; Bao & Lu, 2020; Nunes & Mahler, 2020; Iodice et al., 2021; Ping Tserng et al., 2021)
	Thematic cartography	(Mihai, 2019)
Experimental	Materials characterisation Experiment	(Rose et al., 2018; Kataguiri et al., 2019; Gebremariam et al., 2020; Caneda-martínez et al., 2021; Gebremariam et al., 2021; Moreno-Juez et al., 2021)
Empirical research	Structural Equation modelling	(Jain et al., 2020)
	ANOVA and Relative Importance index	(Ratnasabapathy et al., 2021)
	Predictive analytics	(L. Yuan et al., 2021)
	Agent-Based Modelling	(Ding et al., 2021)

Research types	Methods adopted	Authors
	Phenomenology technique	(Akinade et al., 2020)
	Fuzzy TOPSIS	(Mahpour, 2018)
	Composite indicator and scoreboard	(Foster & Saleh, 2021)
	Descriptive analysis	(Esguícero et al., 2021; Superti et al., 2021b)
	Thematic analysis	(Shooshtarian et al., 2021)
	Material flow analysis	(Arora et al., 2020; Tazi et al., 2021)
	Interpretive structural equation modelling	(Bilal et al., 2020)
	Social Network Analysis	(Liu et al., 2021)
	Deep learning	(Akanbi et al., 2018)
Theoretical	Theory development	(Jiménez Rivero et al., 2016; Gálvez-Martos et al., 2018; Huang et al., 2018; Hahladakis et al., 2020; Luciano et al., 2020; Cristiano et al., 2021; Superti et al., 2021a)
	Norm analysis	(Condotta & Zatta, 2021)

4.2 Circular economy strategies in building construction and demolition waste management

Building construction and demolition waste minimisation are possible by adopting various circular economy strategies (reuse, recycle, remanufacture, and recovery). These strategies could be applicable in the construction phase, demolition phase, or construction and demolition phase put together. Extant literature reviews showed that the strategy could be applied independently or combined with various waste generated from construction and demolition (Figure 8).

4.2.1 Independent circular economy strategies in BCDW

4.2.1.1 Recycling of BCDW

Recycling entails various activities that ensure waste materials are retrieved, sorted, and reprocessed into a new product. Waste that cannot be reused and remanufactured is often subjected to recycling. This strategy extracts materials (secondary materials) from materials that have been discarded. Recycling is an important strategy in CE as it stands as a fundamental approach to reducing BCDW (Ding et al., 2016; Chau et al., 2017). The recycling process in BCI could either be onsite recycling or treatment plant recycling. Out of these two, onsite recycling has been seen as the most efficient strategy. It gives proper consideration to the environmental dimension of sustainability (Bovea & Powell, 2016). The adoption of recycling in BCI is based on various parameters such as properties of materials, impurities related to the recycling, and prices (Liu et al., 2021).

BCDW during recycling pass through several processes such as (i) Primary recycling (upcycling) – which involves the transformation of BCDW into products with similar properties or higher quality. (ii) Secondary recycling (downcycling) – this entails the conversion of BCDW into lower quality relative to the original quality at new; and (iii) Tertiary recycling - this is the breakdown of BCDW into its previous raw components and later transform them into a product with comparable properties to the original materials.

The potential of recycling is vast during the construction and demolition of buildings (Ruiz et al., 2020). This strategy is the most used in the industry. Common building materials usually recycled include concrete, glass, clay, cement plasterboard, prefabricated materials, plastic, bricks, masonry mortar, recycled aggregates, cement mortar, glass, and gypsum (Gebremariam et al., 2021; Tazi et al., 2021). Recycling has been used more on concrete at the construction and demolition stages (Gebremariam et al., 2020). This could be because of concrete's intrinsic feature, making it very easy to recycle compared to other waste.

Recycling concrete reduces construction waste, reduces the need for landfills, and saves waste disposal fees. In the same way, it has the potential of reducing the costs of transportation as concrete can easily be recycled in a location near construction or demolition site. Recycling in building projects helps in processing materials to obtain the same grade of quality from the material (Marzouk & Azab, 2014). The extension of the useful life of materials through recycling has a cumulative advantage that spans beyond the building itself to the externalities, thus contributing to socio-economic and environmental development (Díaz-López et al., 2021). The recyclability of BCDW is often dependent on numerous factors such as the external environment, construction and design of the materials to be recycled, and management factors. Research has argued the possibilities of recycling as a circular strategy to reduce building environmental impacts instead of new natural resources during the production phase.

Nevertheless, recycling of construction and demolition destroys the integrity of a product and degrades the quality and value (Domínguez et al., 2016). Additionally, the process is very tedious and not convenient, especially for metals and composite materials that are very expensive to recycle and prone to corrosion (Akhund et al., 2019). Recycling glass is very expensive, especially when the waste is broken and contaminated in different colours. Although recycling is less attractive than other strategies, it remains the most important and widely used strategy in construction and demolition waste management(Nunes & Mahler, 2020).

However, despite the potential of recycling, the recycling rate of resources in the BCI is still very low. This low recycling rate could be attributed to factors such as inadequate recycling infrastructures(Noll et al., 2019), lack of incentive for recycling building construction and demolition waste (Huang et al., 2018), inadequate suitable treatment plants for recycling (Lockrey et al., 2016), inadequate codes, and regulations for recycling, high cost of recycled materials relative to original materials, inadequate finance for recycling, unfavourable economies and intrinsic features of the resources (Gaustad et al., 2018). The low recycling rate in the construction industry could also be because of the newness of the circular economy in the sector. Although recycling is the most used strategy, its adoption is only peculiar to a few developed countries, and many developing countries are yet to understand the potential of the strategy (Mahpour, 2018). Therefore, more research effort is expected to unveil more potential of recycling in the future.

4.2.1.2 Reuse of BCDW

BCDW can be kept in a close loop by reusing them (Díaz-López et al., 2021). This approach involves using BCDW to meet the aforementioned purpose of the material. Reuse is the first strategy that comes before every other in construction and demolition waste management (Arora et al., 2020). Reuse is a common practice globally, but targets for reuse in BCI are very scarce. Few construction and demolition materials usually reused include excavated soil, façade panels, heritage building materials, and prefabricated materials (Kataguiri et al., 2019). Many of these wastes generated can be reused for a similar purpose, or lesser purposes, or the materials might need reprocessing to retain their quality through repair and refurbishment (Díaz-López et al., 2021).

Reuse, although it needs the highest quality at the end of the life of the materials, provides the quickest and fastest secondary products with the least energy consumption and cost (Gaustad et al., 2018; Condotta & Zatta, 2021). Therefore, reuse is a CE-suitable strategy for managing waste at the construction and demolition stages. In the same way, reuse is better than recycling because it has little or no negative environmental impact. It has been established that the reuse of BCDW can save energy (40%) and carbon footprint (60%), respectively (Akanbi et al., 2018).

Despite the advantages of reuse as a CE strategy, its adoption and implementation are not free from barriers (Mahpour, 2018). For instance, many secondary materials in construction and demolition waste are usually not marketable due to lack of demand from customers, fear of low quality, inadequate standards for secondary materials, and lack of awareness of the best way to reuse construction materials (Huang et al., 2018). Lately, one of the critical factors affecting the reuse of materials in construction and demolition waste includes lack of appropriate information on the quality of the secondary materials and lacks regulations for reuse of construction and demolition waste (Ghisellini et al., 2018). This has affected the provision of these materials in the market as many are not certain of the quality of the secondary material and the best way to identify them (Ghisellini et al., 2018). Therefore, investigating the dynamism of issues in reusing BCDW could be a hotspot for future research direction.

4.2.1.3 Remanufacturing of BCDW

At the end of the useful life of construction materials, any waste that cannot be reused directly is often subjected to remanufacturing— otherwise, known as second-life production is, the use of discarded materials in a new product with a similar function (Ghisellini & Ulgiati, 2020). A remanufactured BCDW should possess brand-new quality even when reclaimed from other components. Remanufacturing covers rebuilding the material by integrating old, new, and repaired parts. This strategy applies to prefabricated geopolymer and façade cladding panels (Cal et al., 2021). This strategy has many environmental benefits, such as lower use of construction materials and lower ecological impact.

Nevertheless, at the global level, remanufacturing is the least used approach in the management of BCDW due to numerous factors such as inappropriate planning system for materials requirements, inadequate information for remanufacturing, inadequate spare parts materials, cumbersome remanufacturing process, an imbalance between supply and demand (Kurilova-Palisaitiene et al., 2018). Other factors responsible for its lack of full recognition BCI include inadequate technical know-how, inadequate sales channels, high cost of labour, and legislation restriction. Therefore, efforts still need to be integrated to ensure that remanufacturing as a CE strategy comes to the limelight in the BCI.

4.2.2 Combined circular economy strategies in BCDW

As a BCDW could be processed via a single circular economy strategy, it could also be refined where a percentage of the material would be involved in one strategy while some would be interested in other strategies based on the composition and the nature of the waste generated.

To this end, multiple strategies could apply to a particular waste at both construction and demolition phases (Figure 8).

4.2.2.1 Reuse and recycling of BCDW

Reuse and recycling could be used together to minimise construction and demolition waste. Materials that are often subjected to these two strategies at the same time include wood at both the construction and demolition stages (Rose et al., 2018), prefabricated materials at both construction and demolition stages (Minunno et al., 2018), concrete and plasterboard at both construction and demolition stage (Gálvez-Martos et al., 2018). Interestingly, the combination seems very complicated but much applicable in BCDW. For instance, some parts of concrete could be reused while those that cannot be reused would be recycled to avoid waste of materials. Gálvez-Martos et al. (2018) argued that adopting reuse and recycling for a particular waste is the best approach to ensure no materials loss and promote sustainable consumption of resources.

4.2.2.2 Reuse and recovery of BCDW

Reuse and recovery could be applied as a CE strategy to a particular BCDW, such as concrete and marble (Luciano et al., 2020). Recovery as a circularity strategy encompasses product collection at the end of the useful life, dismemberment, sorting, cleaning, and usage in the successive lifecycle of the material (Ghisellini & Ulgiati, 2020). Products that cannot be directly reused in a close loop are subjected to recovery; the sorted and cleaned waste products become part of an entirely new system that is different from the previous system (Luciano et al., 2020). However, putting these two strategies together might be complex; therefore, a decision support system might need to be developed in this situation so to guide the process.

4.2.2.3 Recovery, reuse, and recycling of BCDW

The combination of recovery, reuse, and recycling CE strategies is also applicable to managing a BCDW. For instance, (Oliveira et al., 2021) noted that this combination could be applied to different materials. The integration of these strategies is the most efficient approach toward waste minimisation and will promote zero waste as some would go for reuse, others will be recycled or recovered (Huang et al., 2013). The aggregation of these three strategies is the backbone of a CE whereby waste generated in economic activities is passed back to the consumption loop (Cristiano et al., 2021). Combining these strategies forms the 3R strategy for waste minimisation, which is becoming a guiding factor in the BCI. The adoption of the three strategies is expected to reduce environmental risk and promote public health (Memon, 2010). Nevertheless, the usage of the three strategies is still very rare in the BCI. This is because attention has always been on using just a single strategy on material, and part of such materials that could not fit into such strategy would be discarded. Therefore, it is imperative to create an enabling environment and a system to facilitate its implementation and predict the level of waste and the quantity that can be reused, recovered, and recycled.

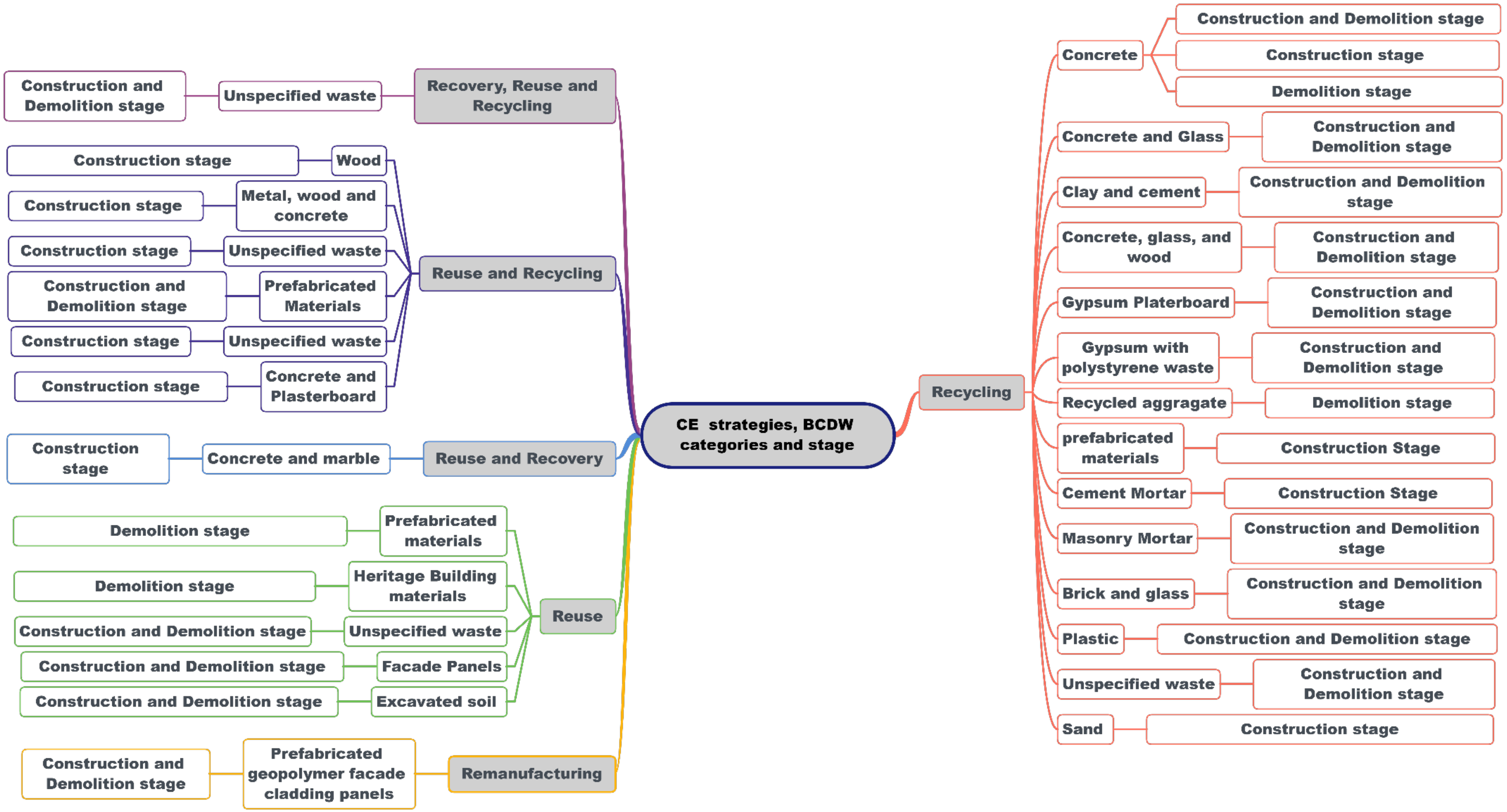

Figure 8: CE strategies, BCDW categories, and stage operational framework

4.3 Common indicators for BCDW management

Indicators are necessary to track progress and domain for action on the transition towards CE in the BCDW. The promotion of CE in any sector requires the deployment of monitoring and evaluation tools (indicators) to measure and assess progress. Indicators are usually adopted to measure construction industry performance towards circularity in waste management. Table 4 presents the common indicators for BCDW used in existing studies.

Table 4: Summary of indicators for BCDW in existing research studies

Categories	Indicators	References
Process	Volume of BCDW generated	(Jiménez Rivero et al., 2016; Akanbi et al., 2020; Luciano et al., 2020)
	Rate of recovery of BCDW	(Cottafava & Ritzen, 2021)
	The volume of BCDW disposed to the landfill	(Superti et al., 2021a)
	Frequency of recycling and quantity of BCDW recycled	(Bilal et al., 2020)
	Frequency of reuse and quantity of BCDW reused	(Gálvez-Martos et al., 2018; Foster & Saleh, 2021)
	The degree to which CE infrastructures are in place	(Mahpour, 2018)
	Amount of unrecoverable BCDW.	(Cottafava & Ritzen, 2021)
Government Initiatives	Number of construction industries receiving financial support towards BCDW circularity	(Superti et al., 2021a)
	Available design support tools	(Akanbi et al., 2020)
	Available roadmaps for BCDW management	(Mahpour, 2018)
	Degree of voluntary collaboration towards CE for BCDW	(Superti et al., 2021a)
	Degree of collaboration with other industries	(Superti et al., 2021a)
	Number of seminars and workshops organised on Circularity of BCDW by public institutions	(Superti et al., 2021a)
	Number of innovative schemes for CE developed by the government for BCDW management	(Gebremariam et al., 2020; Hahladakis et al., 2020)
	Available fines on landfilling	(Gálvez-Martos et al., 2018)
Market, investment, and platforms	Courses available on CE in the universities	(Mahpour, 2018)
	Number of construction sectors using innovative technologies for CE	(Bao & Lu, 2020; Ratnasabapathy et al., 2021; Superti et al., 2021a)
	Degree of adoption of circular business model	(Superti et al., 2021a)
	Awareness level of CE among the public	(Mahpour, 2018; Jain et al., 2020; Guerra & Leite, 2021)
	Number of capacities developed and trained in CE for BCDW management	(Cal et al., 2021; Superti et al., 2021a)
	Number of employees in CE oriented organisations	(Guerra & Leite, 2021)
	Number of development programs put in place for CE in the construction sector	(Caneda-martínez et al., 2021; Superti et al., 2021a)
	Number of academic construction laboratories involved in CE research	(Bilal et al., 2020)

Categories	Indicators	References
	Number of construction organisations and associations working on promoting CE	(Bilal et al., 2020)
	Available online platforms to promote CE among construction experts	(Gálvez-Martos et al., 2018)
Industrial symbiosis and sharing economy	Number of construction industries involved in industrial symbiosis	(Borbon-Galvez et al., 2021; Yu et al., 2021)
	Expected impact of industrial symbiosis and sharing economy	(Borbon-Galvez et al., 2021; Yu et al., 2021)

4.4 BCDW management circularity models

Circular business models are considered essential to promoting the sustainable management of waste in the construction industry (Wuni & Shen, 2022). Adequate understanding of existing models on BCDW management in a CE is imperative in shifting from waste to wealth (treating BCDW as viable resources) in the construction industry. Also, various models related to CE developed in literature may be a veritable pathway to developing a circular business model. This is essential towards closing the circularity gap in the construction industry. Therefore, proper integration and understanding of various existing models in literature may be useful to create and capture value while achieving sustainable production and consumption. This may eventually support the development of a holistic circular business model for the construction industry. Models in extant studies related to BCDW circularity are presented in Table 5.

Table 5: Summary of models developed in previous research studies on BCDW management

Models	Description	References
Demolition waste generation model	This model was developed to determine the quantity of salvage waste obtainable from a building at the demolition and end-of-life.	(Akanbi et al., 2020; Cal et al., 2021; Lu et al., 2021)
Waste evaluation model and management	This model was developed to determine the quantity of construction waste generated and the management process suitable.	(Ding et al., 2021; Esguícero et al., 2021)
Demolition cost prediction and lifecycle cost model	This model was developed to analyse the economic dimensions of construction and demolition (C&D) waste in a CE	(Zoghi & Kim, 2020)
BCDW composition model	This model was developed for easy recognition of the composition of construction and demolition waste.	(L. Yuan et al., 2021)

4.5 BCDW effective management operations in a CE in existing research studies

Management operations must be necessary for BCDW circularity in the construction industry. These operations are required to promote effective management (Gálvez-Martos et al., 2018). Understanding these operations may be useful in establishing an innovative best management framework (Iodice et al., 2021) for BCDW circularity and flow in a close loop. This may enhance sustainable development in the consumption of resources in the construction sector. The BCDW management operations in a CE in existing studies are presented in Table 6.

Table 6: BCDW effective management operations in a CE

BCDW effective management operations in a CE	Description	Potential leading actors	References
Identification, sorting, and processing of BCDW	Identifying the composition of the BCDW using an image recognition approach, e.g computer vision or existing dataset on demolition records. It will facilitate proper sorting and invariably enhance better quality of recycled and secondary materials.	AC, GD, DC	(Gálvez-Martos et al., 2018; Akanbi et al., 2020)
BCDW site management plan	This operation encompasses managing BCDW by establishing a standard or controlled site waste management plan that specifies activities for each category of BCDW, the estimated generated quantity, management alternatives, resource allocation, cost estimation, and responsibility definition for actors.	GD, CE	(Gálvez-Martos et al., 2018; Mahpour, 2018; Iodice et al., 2021)
Quality assurance plan for secondary materials	The quality assurance plan for secondary materials entails designing standards for recovered and recycled BCDW to enhance the demand and segregation of BCDW.	GD, AC	(Gálvez-Martos et al., 2018)
Efficient BCDW handling	BCDW must be handled properly to avoid material loss. This could be possible via adequate storage of BCDW and the adoption of an innovative approach while handling BCDW towards CE.	AC, GD	(Akanbi et al., 2020; Shooshtarian et al., 2021)
Designing out BCDW	Effective CE at the end of life is connected to every stage in the building lifecycle. The 3R potentials in a close loop must be properly designed during materials design. If this is properly done, the circularity at the demolition stage would be feasible.	AC, CE	(Minunno et al., 2018; Akinade et al., 2020; Tazi et al., 2021; Superti et al., 2021a)
BCDW management scheme and principles	In formulating an effective management framework, effective strategies must be put in place for various categories of BCDW. Action is needed to understand the quantity of BCDW, applicable CE principles that could be adopted, and opportunities that could be maximised in a CE.	GD, CE	(Mahpour, 2018; Bilal et al., 2020; Tserng et al., 2021; Superti et al., 2021a)
Economic tools integration	This entails the development of an instrument that promotes higher tax for dumping at the landfill, and sanctions on lack of CE promotion at the demolition	GD, PL	(Gálvez-Martos et al., 2018;

BCDW effective management operations in a CE	Description	Potential leading actors	References
	site. It also involves rewards for BCDW management in a CE in the form of tax reduction and subsidised secondary materials		Shooshtarian et al., 2021)

Key: AC= Academia; GD= Government departments; DC= Demolition contractors; CE= Construction experts; PL= Policymakers

Table 7: Summary of key issues retrieved from the literature

Thematic foci	Key findings	How knowledge could be enhanced
CE strategies, BCDW categories, and the stage of application in the building lifecycle	CE strategies have been manually identified and apportioned to various BCDW.	Innovative segmentation of BCDW based on CE strategies (reuse, recycle, and landfill), e.g., robotic system. Extending research in this direction would promote smart circularity.
CE methodology adopted over the years	Experimental research has dominated CE research over time. Few empirical studies were carried out.	Promotion of more empirical studies on CE in developing and developed economies.
CE indicators in BCDW management	Indicators for BCDW have been manually identified in this study.	• Effective knowledge management on CE indicators. • Knowledge-based decision support based on the indicator • Lifecycle assessment indicators.
CE models in BCDW	• Demolition waste generation model • Waste quantification, evaluation, and management • Demolition cost prediction and lifecycle cost model • Waste composition model	Intelligent circular business model, e.g., using AI. Extending knowledge in this area would lead to AI enable CE.
CE operational management	CE effective operational management have been identified in the literature	Holistic operational framework for BCDW management CE.

5 Future salient research areas

These reviews show that CE adoption in construction projects is still emerging. Very few specific topics in CE adoption in construction have gained attention. More studies (Table 7) should be conducted to harvest CE's full opportunities and potential in the construction industry. As numerous technicalities and processes exist for a successful CE adoption, hence, the research directions highlighted and discussed in the subsection are imperative for a successful CE in BCDW management.

5.1 Implementation of CE strategies in the construction sector

CE is regarded as the pathway to cleaner and more efficient resources consumption with numerous potentials in the construction industry (Bilal et al., 2020). Realising these potentials of CE is pegged to understanding the various issues surrounding its implementation, especially in developing economies. Therefore, there are still many unanswered questions in adopting and implementing CE in the industry. CE adoption and its strategies cannot happen in isolation without considering the contextual issues, measures, and dynamism of factors surrounding it. Previous studies place more emphasis on the experimental aspect of CE. To date, several aspects of CE implementation have not been empirically evaluated, such as the – (i) dynamism of factors affecting CE strategies, (ii) measures for integrating CE strategies across the building lifecycle, and (iii) contextual parameters for implementing CE-based on the economy (developing/developed) and stakeholders. Investigating these issues critically by verifying the degree of the influence of the individual or combined would enhance CE adoption.

5.2 Best practice framework for CE adoption

Implementing CE strategies is usually possible by paying attention to the management practice to achieve success (Antwi-Afari et al., 2021; Hossain et al., 2020). The management practices help in designing a comprehensive framework for implementing CE on a global scale. But it is worrisome that till now, there is still a dearth of agreement on the appropriate CE framework that would guide construction and demolition waste management (Bilal et al., 2020). As construction practitioners in the construction industry rely more on an effective framework for better implementation of a process, future studies could consider developing best practice frameworks (tools, guidance, and standards) for CE adoption and implementation.

5.3 Circular lifecycle assessment indicators for building construction

Studies on the lifecycle assessment of building construction waste are prominent in the literature. However, research efforts linking the lifecycle assessment indicators for buildings in a CE are still scarce. Understanding these indicators may be a pointer for evaluating the circularity performance of every construction material at different levels in their respective lifecycle. Therefore, it is essential to conduct an exploratory study on the various lifecycle assessment indicators at the material extraction stage, manufacturing stage, logistics stage, and construction operation and demolition phase for building construction and demolition waste in CE.

5.4 Application of technologies for CE in building construction and demolition waste

The application of industry 4.0 technologies such as (artificial intelligence, deep neural networks, blockchain, internet of Things, digital twin, additive manufacturing) in CE for construction and demolition waste minimisation is still limited as well as the research efforts (Rajput & Singh, 2019). Without innovative technologies, a smooth circularity in the industry would be truncated. Recently, industry 4.0 technologies have emerged as a key roadmap to facilitate a shift from a wasteful economy (linear economy) to a sustainable economy (circular economy) in the industrial sector (Norouzi et al., 2021). Furthermore, one of the best ways to promote sustainable development goals is to embed CE and industry 4.0, especially in the construction industry, across the building lifecycle (Chauhan et al., 2021; Dantas et al., 2021). With industry 4.0 having the capability to lessen resources consumption in the industrial system (Rajput & Singh, 2019), more innovative research is needed to explore how these technologies can be coupled with CE and the parameters that must be considered to achieve *smart circularity* and *circular 4.0* in the BCI.

5.5 Circular business models for building construction and demolition waste

The existing business models in the construction and demolition sector still have their foundation firmly standing on the linear economy. There is a dearth of a coherent and suitable business model for circularity in construction and demolition (Govindan & Hasanagic, 2018). Many studies suggested adopting a cradle-to-cradle model as a replacement for the business model for CE in construction (Hossain et al., 2020). This model has failed with myriads of challenges such as inadequate standards on product refurbishment, weak economic incentives, an inappropriate trade back system, and life cycle cost. There is a pressing need to expedite research on CE by developing a comprehensive and sustainable business model for managing construction and demolition waste. This could be modification to the existing model, development of a holistic new business model, and a hybrid CE business model. Therefore, future research could develop a new model or improve existing models towards circularity of BCDW.

5.6 Circular economy knowledge management systems

Knowledge is a great weapon that could bring about innovative change in any organisation (Ghasemi & Valmohammadi, 2021). Creating, sharing, and managing knowledge is imperative to attain this change. However, there has not been comprehensive knowledge management of CE in the construction industry over the years. There has been limited active research linking knowledge management to a CE. More so, many construction industries in the developing and developed economies are still in the dark about what could be done to promote CE (Mahpour, 2018). This is because of their lack of awareness and ineffective knowledge management practice for CE. Therefore, with knowledge management being a veritable tool to create awareness and improve understanding (Ghasemi & Valmohammadi, 2021), more research is needed to investigate the best way knowledge management could help improve CE with attention to the people, process, content, and strategies across the building lifecycle stages.

5.7 Intelligent decision support systems for circular economy in minimising building construction and demolition waste

Research on intelligent decision support systems (DSS) for circularity in construction and demolition waste management is scanty. The need for a DSS is imperative in a CE as it will ascertain the best alternative solutions to any given problem in a close loop. A DSS could be designed for predicting waste generated and procurement in a circular economy. With the significance of the DSS to motivate the construction practitioners to opt for circularity decisions, this could be a fertile area for future research on the development of an intelligent decision support system for CE in construction and demolition waste minimisation.

Figure 9: Future research hot spots and opportunities on CE

6. Conclusions

Circular economy is poised to make a tremendous impact in facilitating sustainable production and consumption and waste management in the construction industry. To unravel the trend of CE research in BCDW, a mixed-method review was adopted. This review approach was important to overcome the loopholes in adopting qualitative and quantitative studies. Extant literature on CE in BCDW was analysed to reveal the research pattern and existing pulsating arguments. This helps in creating the knowledge gap for future research. This study presents key research topics, CE indicators in BCDW management, BCDW and CE management strategies, challenges of BCDW management in a CE, and the knowledge gaps to guide future studies. It was found that previous studies adopted the experimental research type as the most used in CE research for BCDW management. Moreover, the CE strategies adoption have gained attention in the literature as the best way to minimise BCDW.

This study has provided valuable insight into CE adoption in the management of BCDW by analysing the recent literature to promote CE practicability and sustainable consumption in the construction industry. The findings of this study have set the path for future studies by providing future research directions in CE for BCDW management. This study explored the various BCDW from extant literature and the appropriate circularity strategies. This would be a valuable reference for practitioners to understand the categories of BCDW and the suitability of CE strategies. Practitioners and policymakers may use the identified CE indicators and effective BCDW management operations to monitor progress and action towards CE transition in BCDW management. The identified probable challenges may be used by practitioners to understand the bottlenecks on the road to CE. Hence, potential solutions can be understood. The existing models for BCDW in a CE revealed in this study may be useful in extending knowledge towards developing the CE business model for the construction industry. For all construction stakeholders, the implementation of CE in BCDW management would represent key progress towards sustainable consumption. Based on the findings and analysis of the study, future research should consider smart circularity of BCDW management, intelligent decision support system for CE in BCDW management, and circular business model development for BCDW. Also, with the role of knowledge in promoting CE, knowledge management in a CE needs to be investigated. Best-practice framework for CE adoption and lifecycle assessment indicators are the grey areas that may be considered for further investigation.

Despite its substantial contributions, this study has limitations that should be considered when interpreting the findings. Only papers obtained from the Scopus database were used in the analysis, which may have influenced the coverage of publications in the subject topic. Furthermore, the scope of this study was restricted to academic papers. In the future, studies may integrate different databases and document sources. The terms used for the search may be biased, and so may not provide a complete view of the study field. In future investigations, these keywords may be modified.

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Appendix A: Content analysis of the reviewed journal articles on CE research

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
(Shooshtarian et al., 2021)	Australia	Construction and demolition(C&D) waste management in Australia: challenges and possibilities	Data from relevant stakeholders through an online survey	• There is a lack of a local market for secondary materials • There is a lack of knowledge and acceptability for CE	• Providing guidelines on the requirement for reusing secondary materials	A comprehensive picture of how Australian C&D waste management stakeholders feel about the present waste management system was provided.
(Hahladakis et al., 2020)	Qatar	The role of recycled aggregates in the long-term management of C&D waste	Government documents and interviews with stakeholders	• Absence of proper regulations for BCDW management in a CE • Lack of in-situ waste sorting. • No substantial research has been carried out on BCDW management in a CE in the country.	• Government support towards the development of regulations for BCDW management • Development of BCDW management infrastructure system • Development of CE based research	There are numerous opportunities and strengths in using recycled aggregate which must be maximized to enhance C&D waste circularity
(Superti et al., 2021a)	Switzerland	CE interventions categorisation framework	Content analysis and Data from relevant stakeholders	• Interventions to promote CE in BCD sectors are not well structured. • Current circularity indicators for BCDW management have a narrow focus.	• Indicators for CE transition in the C&D sector must be developed	Significant CE interventions in the C&D sector are Research and Realize, Enable, and Support
(Caneda-martínez et al., 2021)	Spain	Behaviour and Properties of materials from C&D Wastes	C&D waste materials	• Research is still in its early stage in C&D waste circularity	• Funding and development of CE based research	Fine concrete wastes are viable for valorization as supplemental cementitious materials.
(Arora et al., 2020)	Singapore	A systematic framework for estimating the potential for urban mining, recovery, and reuse of construction materials and components	Floor plans and survey plans of various dwellings	• The systemic reuse of building components and urban mining is still far from reality • Inability to different waste from reusable products • Lack of effective CE policy of trust	• Additional effort should be put in place for the adoption of urban mining for a CE • Trade regulations should be put in place in a circular business model to determine waste from reusable materials • Development of policies of trust and practice among stakeholders	Reusing secondary resources would need more detailed information on outflows.

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
(Kataguiri et al., 2019)	Brazil	Reuse strategies for excavated soil with	Soil samples from construction and demolition waste landfill	Lack of information on the reuse strategies for excavation soils from construction works are	Funding and development of CE based research	CDW-soil mixes can strengthen the subgrades and subbases of low-volume road pavements.
(Nußholz et al., 2019)	Sweden and Denmark	Understanding of the importance of secondary materials for decarbonization of the building industry together with the interplay of business model and policy instruments	Interviews with relevant stakeholders	• Limited access to enough quantity and quality secondary materials • Lack of recovery infrastructures • A low incentive for recovery at higher material value.	• Increase in the number of companies involved in waste recovery and sales of secondary materials • The building design for circularity and development of recovery infrastructures • Introduction of an obligatory BCDW management plan	Secondary construction materials represent a considerable opportunity to reduce carbon emissions at the product and industry levels.
(Nunes & Mahler, 2020)	Brazil, European Union, and the USA	BCDW management comparison in a CE.	Interviews with relevant stakeholders	• Low quality of recycled materials • Inadequate policies that oblige the public to use secondary materials • Lack of market knowledge on the supply of recycled aggregate.	• Quality certifying organization • Enactment of binding CE polices	Brazil's performance in BCDW is below the USA and European Union
(Gebremariam et al., 2021)	Netherlands	Sustainable concrete formulation from C&D waste	Varieties of products from C&D waste	-	-	Possibilities of designing the greenest and most sustainable concrete from C&D waste
(Gálvez-Martos et al., 2018)	Europe	Suitable practices for C&D waste management	Literature and European experts	• Lack of effective market Lack of effective management practice in a CE.	• Development of the effective market for secondary materials • Establishment of best management practices for BCDW in a CE.	Appropriate best management practice was developed across the supply chain in Europe
(Mihai, 2019)	Romania	C&D waste issues	Literature review, environmental reports, and field observations	Poor monitoring of BCDW flow	Adequate monitoring of BCDW flow for total circularity.	Various stages related to the C&D waste were identified, among which are illegal dumping, collection, and disposal to landfills, treatment and reuse in construction projects,

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
						regional waste management system, and recycling
(Cristiano et al., 2021)	Italy	Experts perceptive on CE transition in Italy construction industry	Interviews with relevant stakeholders	• Inadequate demand for recycled materials • Lack of data in the end-of-life stage towards CE.	• Mandating the use of recycled materials • Development of an effective database for enhancing circularity at end of life	The framework of public data on BCDW and i-Tree canopy tool for identifying the general picture of BCDW and its composition were developed
(Huang et al., 2018)	China	C&D waste management in China in a CE	Interviews with relevant stakeholders	• Lack of standards and knowledge for reducing, reusing, and recycling BCDW • The infancy of recycling technology • Lack of market for recycled and reused materials	• Development of appropriate CE model and standards • Adoption of innovative technologies in BCDW management • Development of secondary market	There is a big challenge to CE adoption in China due to numerous militating factors
(Jain et al., 2020)	India	The attitude of construction experts towards waste circularity	Questionnaire survey and interview with an expert	Lackadaisical attitude towards waste circularity	Creation of awareness for CE at various levels	Behaviour towards construction and demolition waste circularity is triggered by driven by personal motivation, institutional pressures, and environmental consciousness.
(Akinade et al., 2020)	United Kingdom	Design for deconstruction in a CE	Focused group interview	• Inadequate design for deconstruction tools • Lack of policies to support design for deconstruction	• Development of standards and best practices for design for deconstruction • Development of stringent legislation to support design for deconstruction	There is an urgent need to bring design for deconstruction to the limelight in the construction industry to promote CE
(Bao & Lu, 2020)	China	Efficient circularity C&D waste	Site investigation and interview with experts	Lack of technologies for CE	Development of advanced circularity technologies	Success in China is attributed to the implementation of veritable governmental intervention towards circularity

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
(Lu et al., 2021)	China	Construction waste generation using machine learning	Databases	Lack of reliable data in developing economies	Development of databank for BCDW towards CE	This study also reveals that the 11 cities in China produced a total of about 364 million m^3 of construction waste in 2018
(Ratnasabapathy et al., 2021)	Australia	Exploring barriers to adopting waste trade practices in the BCI	Interviews with experts.	• Lack of technology for effective waste trade • Lack of waste data reporting system	• Development of advanced circularity technologies • Development of databank for BCDW towards CE	Technical barriers are the most significant among others
(Gebremariam et al., 2020)	Netherland	Technologies for recycling concrete waste	C&D waste	• Quality issues of recycled aggregate • Emission related due to the transportation of waste	Development of advanced technologies to enhance quality and waste transportation	Advanced Dry Recovery technology is suitable for sorting out clean coarse aggregate while Heating Air Classification System (HAS is used to produce clean fine aggregates
(Moreno-Juez et al., 2021)	Spain	Viability of inorganic CDW fine fractions as SCMs in blended cement.	C&D waste	Lack of research on the use of Glass waste from building	Improved experimental study on the use of C&D waste	The presence of the filler effect in inorganic waste induces the neoformation of hydrated phases
(Jiménez Rivero et al., 2016)	Spain	Plasterboard recycling energy and climate impact	C&D waste	Inadequate information on material flow of construction waste	Development of an analytical approach to quantify the flow of construction waste	Lifecycle greenhouse gas is lowered, and recycling of construction waste increases
(Yu et al., 2021)	Netherlands	Industrial symbiosis towards CE in the construction industry	Databases	Lack of motivation for industrial symbiosis from actors	Development of motivation for industrial symbiosis in the construction industry	Industrial symbiosis is not properly established in the construction industry due to a lack of collaboration among actors
(Tazi et al., 2021)	France	Ability to attain CE in residential building materials	C&D waste generated and recycled materials	• Overdesign of residential buildings • Technological challenges	• Promotion of design for disassembly and industrial ecology practices • Development of technological innovations	Natural aggregate extraction of 20% is generated when using stock and flows of recycled aggregates from C&D waste

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
(Ping Tserng et al., 2021)	Taiwan	Strategies for adopting CE in building projects	Interviews with relevant stakeholders	Lack of information on the strategies to promote CE	Adoption of the 5R (rethink, reuse, recycle, reduce and repair) CE principles	A framework for implementing CE practice was developed
(Noll et al., 2019)	Greece	C&D waste generated and EU CE target.	Interviews with relevant stakeholders	Limited C&D waste treatment options	Enhancement of various CE principles in C&D waste management	The recycling rate of C&D waste in Greece is far from meeting the recycling target of the EU.
(Foster & Saleh, 2021)	Europe	Circular cities and the reuse of heritage cities	Databases	Lack of systematic ways to measure the reusability of heritage building materials	Establishment of CE measurement index	A modern composite indicator known as the Circular City Adaptive Reuse of Cultural Heritage Index was developed
(Iodice et al., 2021)	Italy	Sustainability of C &D waste management in a CE.	Databases	High cost of managing C &D waste in a CE.	The incentive to support C &D waste management in a CE.	The environmental benefits of managing C&D waste in a CE is significant
(Condotta & Zatta, 2021)	Europe	Reuse of building elements in a CE.	Interview with construction stakeholders	• Uncertainties about the application of CE • Increased management cost • Legal barriers and inconsistent framework	• Promotion of innovative approaches by academics to improve CE applications • Government support for CE • Development of a consistent legal framework	The scarce application of CE initiatives is largely affected by the management view
(Akanbi et al., 2020)	United Kingdom	Demolition waste prediction using deep learning	Databases	Difficulty in estimating the end-of-life value of building materials	Development of a predictive model for estimating the value of demolition waste	It is possible to determine with high accuracy the circularity potential of materials from the building after demolition
(Superti et al., 2021b)	Switzerland	Factors affecting the recycled concrete recommendation	Questionnaire	A wrong attitude towards CE	Promoting awareness of the benefits inherent in CE	The reduced environmental impact of Recycled concrete is a major reason for its recommendation
(Bilal et al., 2020)	-	Barriers to CE adoption in the Building sector	Questionnaire	• Lack of regulations and laws towards CE	• Government support and penalties for non-compliance, incentives for compliance	The current state of CE implementation in the building sector is not good enough

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
				• Inadequate support from government and research organizations	• Funding for CE research and initiatives to improve public awareness	
(Mahpour, 2018)	Iran	Barriers to CE adoption in C &D waste management	Questionnaire	• Ineffective BCDW dismantling and sorting approach • Uncertainty of the result of moving towards CE.	• Promotion of design for disassembly in the construction industry • Sensitization on the benefits of moving towards CE	The barriers to CE adoption are too critical and must be removed for effective transition
(Liu et al., 2021)	China	Barriers to applying CE in construction waste recycling	Questionnaire	• Inadequate incentive from the government towards CE. • Insufficient education for CE	• Government provision of incentives for CE uptake and improve market acceptance of secondary materials • Knowledge management towards CE	There is no management mechanism in place to control the CE barriers
(Liang Yuan et al., 2021)	Hong Kong	Recognition model for the composition of waste	Database	• Lack of databank • Lack of innovative technologies	• Development of construction waste databank • Development of technological innovations for CE	The composition of construction waste was determined, and a model was proposed
(Zoghi & Kim, 2020).	Iran	Analysis of the economic dimensions of C&D waste	Published articles	• Lack of numerical economic matric	• Development of a benchmarking system for CE transition	The profit and the cost implication of construction and demolition waste management was modelled
(Ding et al., 2021)	China	Construction waste quantification	Database	• Insufficient waste data • Bad attitude of demolition contractors	• Development of databank for BCDW towards CE • Using economic tools on demolition contractors	A quantification model for construction waste was developed
(Esguícero et al., 2021)	Brazil	Construction waste management process model	Interview with experts	• Lack of financial commitment towards CE	• Government provision of incentive for CE uptake	Construction waste management model in a CE was developed
(Rose et al., 2018)	United Kingdom	A novel concept for reusing Timber in a CE	Timber materials	• Lack of information on the potential of CE	• Awareness promotion towards CE.	Combination and secondary and primary timber

Paper	Location	Study scope	Data source	Challenges	Solutions	Major Findings
						materials in building construction would enhance reuse.
(Cal et al., 2021)	Greece, Italy, and Romania	Estimating the waste generated from construction waste.	Monitoring data from case studies	• Lack of CE confidence among stakeholders	• Promotion CE worship and training	CE can trigger further innovations in the construction industry if financially enhanced by the government
(Minunno et al., 2018)	Australia	Strategies for applying CE in prefabricated building	Published articles	• Inadequate standard measures, and an underdeveloped closed-loop supply chain	• Development of standard architectural measures to promote CE and adoption of tracking technology with embedded information in building components.	Prefabricated buildings are imperative to material savings and waste reduction construction sector
(Luciano et al., 2020)	Italy	Resources optimization via framework development	Waste materials	• Lack of proper accounting for resources used in the construction industry	• Keeping account of the resource inputs, extraction, and consumption, as well as of the output	Waste production in construction projects is high and should be sustainably managed.

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