frontiers | Frontiers in Built Environment

TYPE Review
PUBLISHED 20 January 2025
DOI 10.3389/fbuil.2025.1519219

Adopting circular economy in construction: a review

Preethi Amrut Rao*, Md Motiar Rahman and Saiful Baharin Duraman

Civil Engineering Programme Area, Faculty of Engineering, Universiti Teknologi Brunei, Bandar Seri Begawan, Brunei Darussalam

Check for updates

OPEN ACCESS

EDITED BY
Xianhai Meng,
Queen's University Belfast, United Kingdom

REVIEWED BY
Mohammad Afrazi,
Tarbiat Modares University, Iran
Khurram Iqbal Ahmad Khan,
National University of Sciences and Technology, Pakistan

*CORRESPONDENCE
Preethi Amrut Rao,
p20230007@student.utb.edu.bn

RECEIVED 29 October 2024
ACCEPTED 06 January 2025
PUBLISHED 20 January 2025

CITATION
Rao PA, Rahman MM and Duraman SB (2025) Adopting circular economy in construction: a review.
Front. Built Environ. 11:1519219.
doi: 10.3389/fbuil.2025.1519219

Global development is integral to construction activities that consume enormous amounts of natural resources, of which a considerable part is wasted during the construction and demolition phases. Only a small part of such construction and demolition waste is recovered and recycled, and the rest goes to landfills and dumpsites, containing a high volume of recoverable and reusable materials and components, causing environmental hazards and depleting natural resources. This occurs due to the practice of linear economic model in construction. By contrast, the circular economy (CE) approach can potentially offer an effective solution for this issue, through its long-lasting and standardized design with reduced resource input; and extensive reuse and recycling of resources, products and components. However, CE is not being widely practiced. As such, this study was designed to investigate why CE is not being widely practiced, and what needs to be done for its wider adoption. As the beginning, a systematic literature review extracted 32 motivators, 35 challenges and 31 strategies. Further analysis clustered these three groups of factors into eight focus areas of: legal and regulatory framework; knowledge, education and training; infrastructure, technology and innovation; awareness promotion and support; collaboration and information sharing; standardization; circular business model and positive finance and economics. Finally, a conceptual framework is presented, for wider adoption of CE and sustainability assessment and reporting, in construction. The outcomes are expected to provide guidance and indication to policy and decision-makers on what needs to be done for wider adoption of CE in construction.

KEYWORDS

circular economy, construction, built environment, building information modeling (BIM), industry development, sustainable construction

1 Introduction

The construction sector contributes substantially to the global GDP and employment opportunities (Kenny, 2007; Khan, 2008), representing 10% of the workforce (Becqué et al., 2016) and is estimated to account for 14.7% of GDP in the year 2030 (Global Construction Perspectives and Oxford Economics, 2015). Growing GDP raises the need for construction and the consumption of materials (Petrović and Thomas, 2024), to over half of the world's raw materials (World Economic Forum, 2016), 40% of energy (Becqué et al., 2016), and one-sixth of freshwater withdrawals (Sandanayake, 2022), all of which are not sustainable. This is also causing a rise in investments in energy-efficient buildings, global resource consumption, and associated emissions (UNEP, 2022). Nevertheless, a significant portion of these resources are wasted during construction and demolition of structures/buildings (i.e., CDW–construction and demolition waste), forming 30–40 percent of the world's solid waste generation, and containing 50% recoverable and recyclable materials and components (Jin et al., 2019). Only 20%–30% of such materials and components are recovered and recycled (World Economic Forum, 2016; Shao et al., 2023), and the remaining goes to landfills and dumpsites. This results from the prevailing linear economic model characterized by a 'take-make-use-dispose' approach, which mainly focuses on the production and consumption stages of structures and components lifecycle, while neglecting what happens after consumption (Çimen, 2021). The necessity for a change to a more sustainable and circular economy model is highlighted by numerous studies that fault the prevailing model for its negative impacts, which include increased strain on finite natural resources, carbon emissions, environmental pollution, and generation of waste (Ellen MacArthur Foundation, 2015b; Bocken et al., 2016; Ness and Xing, 2017; Pomponi and Moncaster, 2017; Akanbi et al., 2018; Ghisellini et al., 2018; Çetin et al., 2022).

Circular economy (CE) is an innovative approach to moving away from the fundamental linear model and promoting sustainability systematically (Rahla et al., 2021). It is a regenerative and restorative system to untie economic development from resource depletion (Bocken et al., 2016), by reducing the raw material inputs and protecting natural resources by relying on renewable sources, eliminating waste, and reducing carbon footprint (Smol et al., 2015; Adams et al., 2017; Kirchherr et al., 2017). The community as a whole views CE favorably on the basis of technological concepts that have the potential to both decrease environmental impact and yield economic benefits, promoting game-changing developments in product-service delivery, social and economic innovations, resource efficiency, and responsible consumerism (Su et al., 2013; Velenturf and Purnell, 2021). CE in construction can be termed as a closed-loop system that seeks to improve resource efficiency, reduce waste, and encourage perpetual refurbishment, reuse, and recycling of construction materials and components (Geissdoerfer et al., 2017). It employs the principles of conservation (i.e., 3R–reduce, reuse, and recycle) to reduce consumption of resources and materials, increase durability by optimizing the lifespan of materials as well as components (World Green Building Council, 2023); design easy connections for disassembly as well as adaptability for reuse at the end of their function and reuse the components and parts through prefabrication at the end of life (Cruz Rios and Grau, 2020); and eventual recycling with the remainder returning to the nature. CE focuses on decreasing the effect of construction activities on the environment by aiming to transform the traditional linear model that is primarily used in construction activities. When construction materials, components, and resources reach their end of useful life, CE turns them into valuable economic resources (Ness and Xing, 2017).

CE is widely argued to be adopted in construction to aid in the realization of the UN Sustainable Development Goals (SDGs) (Geng et al., 2012; Mahpour, 2018). CE can address environmental issues (Zhuang et al., 2023), especially those on clean water (SDG 6), affordable and clean energy (SDG 7), economic growth (SDG 8), infrastructure and industrialization (SDG 9), sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), and climate change (SDG 13), by using cost-effective and sustainable modern methods of construction (MMC), with assistance of building information modeling (United Nations, 2015; Schroeder et al., 2019; Schöggl et al., 2020; Awan and Sroufe, 2022).

MMC includes offsite construction, prefabrication, and modular/volumetric construction (Rahman, 2014) and embodies concepts that can assist in adopting CE practices when applied. For example, MMC takes construction off the site, thus ensuring cost savings, reduced maintenance, and more scope of reuse and recycling through offsite manufacturing of standardized modular components and panels that are prefabricated and transported to construction sites and installed (Pan et al., 2007; World Economic Forum, 2016). By using demountable components and panels, MMC allows deconstruction enabling faster construction and resource efficiency (Geldermans, 2016; Hamida et al., 2022).

MMC can be applied using assistance of building information modeling (BIM). Better visualization, multidisciplinary data integration, sustainable design options, documentation and cost savings in construction projects are all made possible by BIM, which is a computer-aided technology that creates and manages data about the digitally represented building model throughout its lifecycle for real-time collaboration (Azhar, 2011; Eastman et al., 2011; Mesároš and Mandičák, 2017; Montiel-Santiago et al., 2020). BIM models could be utilized to analyze the design accuracy and precision at various phases of the design process allowing for design optimization (Xiao and Bhola, 2022). BIM avoids the waste of surplus materials through correct material quantity calculations (Nadeem et al., 2018) and can enable comparison and selection of the greenest and most energy-efficient options for new and renovation projects. Additionally, it enables the assessment of eco-building attributes and consumption of energy (Ustinovichius et al., 2018) as well as the analysis of how design and material selection impact the building's performance at the end of its life concerning waste production (Akanbi et al., 2019). BIM-based systems can store instructions on components and their association to the structure, enabling methodical deconstruction (Minunno et al., 2018) and effectively manage the recycling and reuse of resources (Jayasinghe and Waldmann, 2020), by tracking maintenance and repair activities, planning for refurbishments, and making informed decisions about the end-of-life options for each component, whether to be reused or recycled (Charef and Emmitt, 2021).

A SUN-sponsored study suggested that a CE would have the potential to cut primary material usage by 32 percent by the year 2030 and 53 percent by the year 2050 (Ellen MacArthur Foundation, 2015a). CE principles if adopted in the construction sector, are predicted to increase productivity by USD 100 billion annually (World Economic Forum, 2016) and Europe will save 600 million annually in primary resources input by 2030 (Morgan and Mitchell, 2015). Implementing CE in construction can assist in sustainability assessment and reporting as the CE framework features methods and tools to help organizations meet the criteria and thus report clear ESG (environmental, social, governmental) targets, strategies, policies, and measures. Despite such wider benefits, CE is not being widely practiced in construction. CE concepts are hardly implemented in construction (Guerra and Leite, 2021). In developed countries, the implementation is not satisfactory. For example, the limited number of research that is conducted on the applications of CE in construction are practical case studies (Eberhardt et al., 2019; Çetin et al., 2022) in developed countries (Kirchherr and van Santen, 2019; Mhatre et al., 2023), there are limited studies related to the CE state of practice in construction in the United States (Guerra and Leite, 2021) and small-medium enterprises (SME) in Europe's construction sector still face obstacles to the transition to CE (Marino and Pariso, 2021). According to a Slovakian study, only 46% of medium-sized businesses use three to five fundamental CE activities, such as minimizing and reusing energy, water, waste, and materials, and 26% of SMEs do not apply CE principles in their operations (Levický et al., 2022). The situation in developing countries is worse. These countries need to develop infrastructure at a quick rate, which implies large-scale construction. Therefore, most future construction will occur in developing nations for their development needs and to provide infrastructure to their growing population. It is these countries that need to adopt CE more than the developed countries. There have been several sporadic studies on individual items in developing countries. For example, studies indicated that "Optimize" and "Loop" were the most critical of the six-dimensions of the CE implementation framework for the construction sector's successful circularity transition in developing countries (Koc et al., 2023), that there are numerous barriers to CE adoption in developing nations, resulting in a limited shift from linear to CE (Ngan et al., 2019; Patwa et al., 2021; Ali et al., 2022; Zuofa et al., 2023) that is due to lack of knowledge, technological awareness, economic aid, acceptance of secondary materials, etc (Tleuken et al., 2022; Mhatre et al., 2023),and barriers faced by developing nations are significantly different from those faced by developed countries in the adoption of CE in construction industry (Oluleye et al., 2023) due to differences in regulatory and socio-economic contexts of the countries (Alotaibi et al., 2024). Furthermore, understanding how digital technologies associated with CE are used in practice and if they are beneficial to businesses is lacking, while businesses also struggle with how they can practically use the principles of CE. However, there has been no comprehensive study with specific focus on developing countries, as to why CE is not being adopted, at least to the extent it is happening in developed countries. Therefore, it is required to look back and review for global purposes why the adoption momentum of CE in construction is not happening in developing countries which need the adoption more than the developed countries.

As such, an extensive literature review was conducted to understand what needs to be done to set the research agenda, as well as to develop a conceptual framework, based on relevant motivators, challenges and strategies. The outcomes will allow a better understanding of the need, generate awareness for practitioners, and provide direction to policymakers to craft guidelines for wider adoption, such as to revise building codes. The subsequent sections discuss the research methodology, the eight common focus areas, and a conceptual framework for wider adoption of CE in construction, and how it could assist in sustainability assessment and reporting in the CE context. Finally, the paper summarizes the concluding observations and future scope.

2 Methodology

One significant research method that has been widely applied in built environment studies is the Systematic literature review (SLR) (Chelliah et al., 2021). To permit reasonably clear conclusions about what is and is not known, this particular methodology finds existing studies, chooses and evaluates contributions, analyzes and synthesizes data, and presents the evidence (Denyer and Tranfield, 2009). With thorough searching techniques, predefined search strings, and standardized criteria for inclusion and exclusion, SLR enables scientists to hunt for research beyond their particular subject fields and connections (Robinson and Lowe, 2015).

This study utilized the PRISMA ("Preferred Reporting Items for Systematic Reviews and Meta-Analyses") statement as the method for literature search, selection, and reporting for the SLR. The PRISMA statement is a guideline consisting of a checklist of items devised to address poor reporting in SLR (Moher et al., 2007). It was developed to help researchers executing systematic reviews to communicate the purpose of the article, the authors' approach, and their conclusions (Page et al., 2021). Many review writers, reviewers, and editors from journals have endorsed the statement and referenced it (Swartz, 2011). Considering the complexity of the current field of study, the SLR accordingly adopted this method for reporting as CE in construction is a new field with a rich scientific body of knowledge, and PRISMA has the ability to appraise the articles comprehensively and present transparent, complete and clear data (Sohrabi et al., 2021). Therefore, the study started with the aim of outlining the motivators, challenges, and strategies for adopting CE in construction using studies in the literature.

The search for relevant studies was conducted in four databases for scientific literature, namely, Scopus, Taylor and Francis, Science Direct, and Emerald Insight. Utilizing multiple databases helps narrow the reference list and identification of core references that can be utilized for a systematic literature review. The specific strings that were utilized for searching the literature were: circular economy, circular economy and construction, circular buildings, circular economy and built environment, and building information modeling. These search strings are used to determine the attributes of CE principles and cover the scope of their implementation in the construction industry. Figure 1 presents the PRISMA flow diagram for article search and reporting.

All keywords were provided in one search for every database mentioned above, which resulted in about 13451 articles. The number of publications that were identified with each keyword on different databases is seen in Table 1. As the number of articles published after the first step was very high, in the second step the articles were filtered based on the study period from 2001–2023, as it was during these last 2 decades that the CE concepts emerged and developed. The screening step involved eliminating articles not specifically concerned with the construction industry, reducing the number of articles to 283. This was followed by removing articles with the same title and duplication caused for the keywords used, resulting in 262 articles: Science Direct 192, Scopus 8, Taylor & Francis 44, and Emerald Insight 18. In the subsequent steps, the abstracts and contents of the articles were comprehensively examined to ensure that they used the concepts and developments of CE in construction industry, resulting in 125 for the review from all four databases. These 125 articles thus selected were based on the criteria that they included at least one or more of the concepts like dealing with CE, BIM, MMC, benefits of CE, and the keywords are included and somehow relevant with these articles. Figure 2 shows these 125 articles arranged by their year of publication from 2012

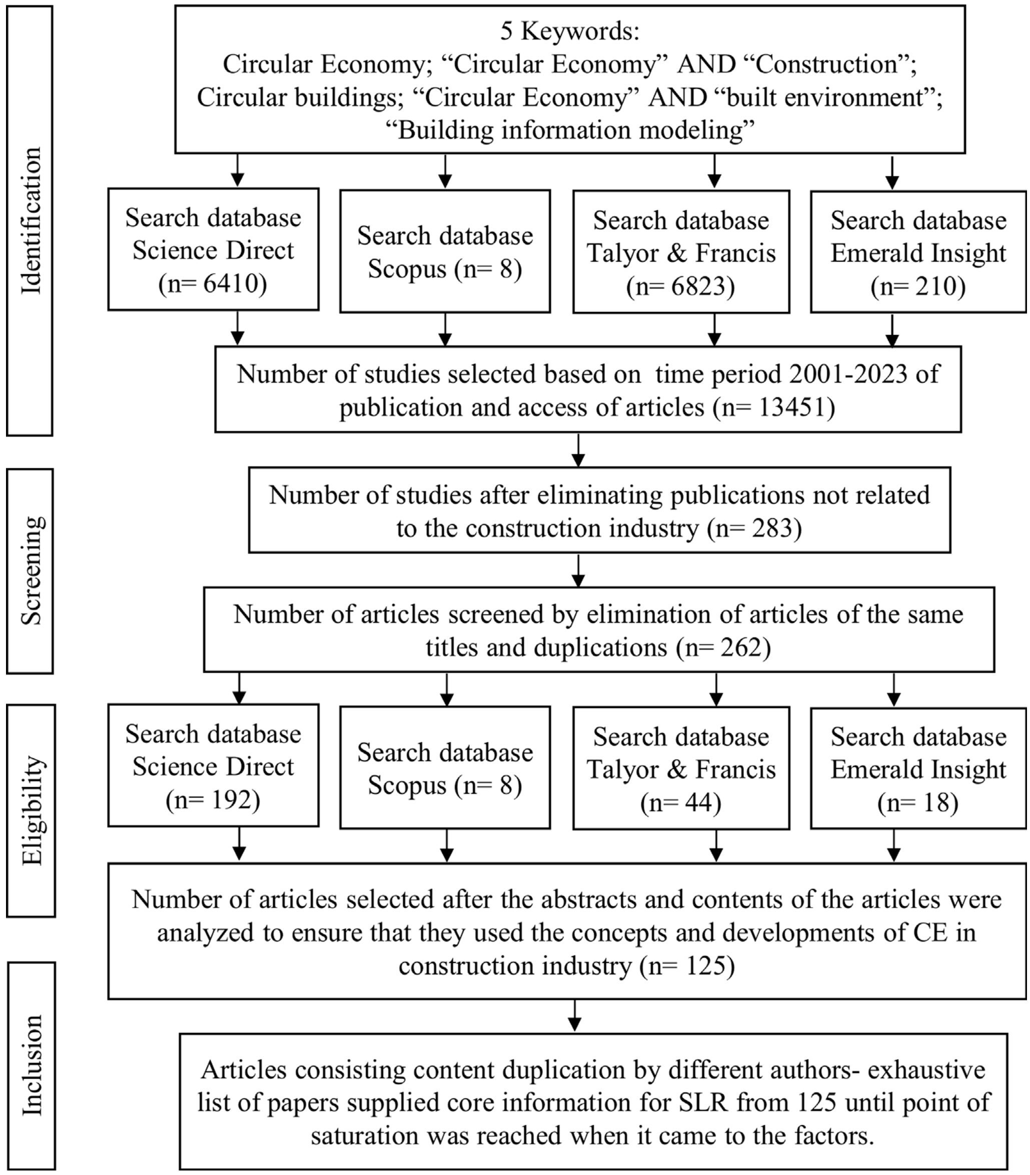

FIGURE 1
PRISMA flow diagram for article search and reporting.

to June 2023, as no eligible articles were found from 2001 to 2011. There is a steady rise in the growth starting with only one article in the beginning year and reaching a peak with 32 articles in 2021 and 24 articles each in 2022 and 2023. The articles originated from the countries as shown in Figure 3 with United Kingdom (26) at the top, followed by Netherlands (23), China (6), Austria (5), Sweden (5), Hongkong (5), India (5), Australia (4), Finland (3), Italy (3), Spain (3), Brazil (3), and many countries with 2 and 1 articles. The content analysis included gradual reading of the articles for more explanation where the key areas were identified and tallied followed by the systematic refinement of the broad factors into the eventual number of motivators, challenges, and strategies. Further thematic analysis grouped them into eight combined focus areas. These are discussed in further subsections.

Since there were articles consisting of plenty of content duplication by different authors, an exhaustive list of papers supplied the core information for the SLR from the 125 publications until a point of saturation was reached when it came to the broad factors, meaning that the researcher could not come across any new motivators, challenges, and strategies in the papers. Additional references were added to substantiate some arguments using relevant papers that were not included in the database search.

3 Results and discussions

3.1 Focus areas

The SLR identified the motivators, challenges, and strategies for adopting CE in construction. Content analysis by further investigation and scrutiny into the list of the three factor groups led to the identification of additional points within each factor

TABLE 1 Number of publications from search results.

Keywords	Science direct	Scopus	Taylor and francis	Emerald insight
"Circular Economy"	66501	15127	29104	855
"Circular Economy" AND "Construction"	12156	916	467	213
Circular buildings	157823	1704	37328	720
"Circular Economy" AND "built environment"	1,396	131	207	52
"Building information modeling"	5,505	6,956	91818	205
All keywords in one search	6,410	8	6,823	210
Total	13451			
After elimination process	192	8	44	18
Final number	125			

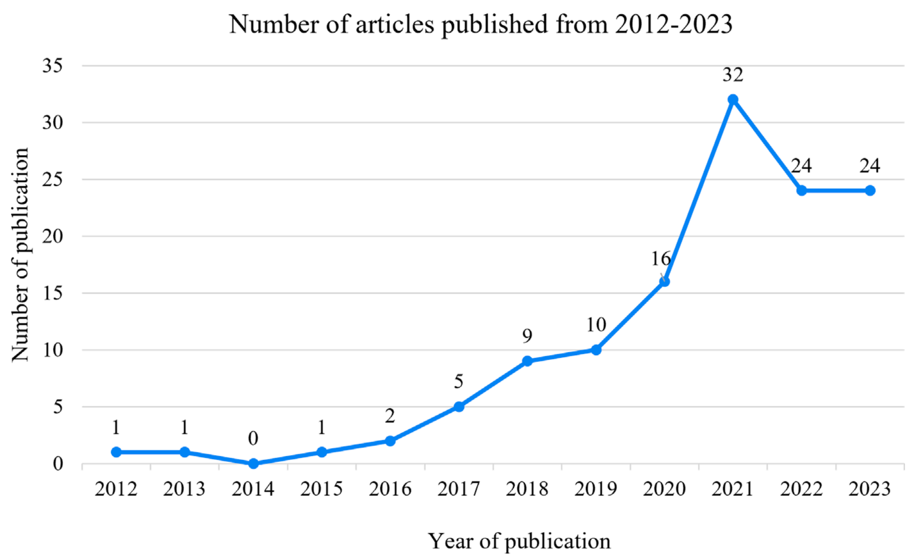

FIGURE 2
Number of articles published from 2012 until June 2023.

group, resulting in 32 motivators (M01-M32), 35 challenges (C01-C35), and 31 strategies (S01-S31). The key motivators, challenges, and strategies are summarized in Table 2. However, it was observed that certain factors were being preferred more than others. For example, in motivators, technical, infrastructure and operational support seem to be more beneficial and the emphasized challenges are lack of technical, technological and financial support. Policy and regulatory framework seem to be emphasized in strategies, to apply the measures and overcome the challenges. The long list of factors was then analyzed thematically and cross-examined to identify eight combined focus areas for wider adoption of CE in construction as shown in Figure 4. The focus areas reiterate the list of factors into appropriate areas. The following sub-sections discuss the eight focus areas. The refined factor lists grouped into the suitable focus areas are reported in Table 3.

3.1.1 Legal and regulatory framework

Regulations by the EU push the idea of a CE. In developing countries, there is little focus on implementing appropriate legal and regulatory interventions to promote the idea of circularity (C01). If policymakers wish to generate support for CE, they should intensify their efforts to remove obstacles such as inconsistencies in policies, rules and regulations (C02). There is ample opportunity for government involvement concerning market barriers (C03). A few examples are, allowing entrepreneurs to operate on the market and creating the potential for price signals, property rights, and easing subsidies that support linear products (Grafström and Aasma, 2021) (S01). Institutional and regulatory forces are frequently mentioned as enabling elements for a CE (M01). Emphasis is placed on public policy solutions (such as taxation, legal frameworks, and incentives) that alleviate market imperfections (S02). Typically, these are

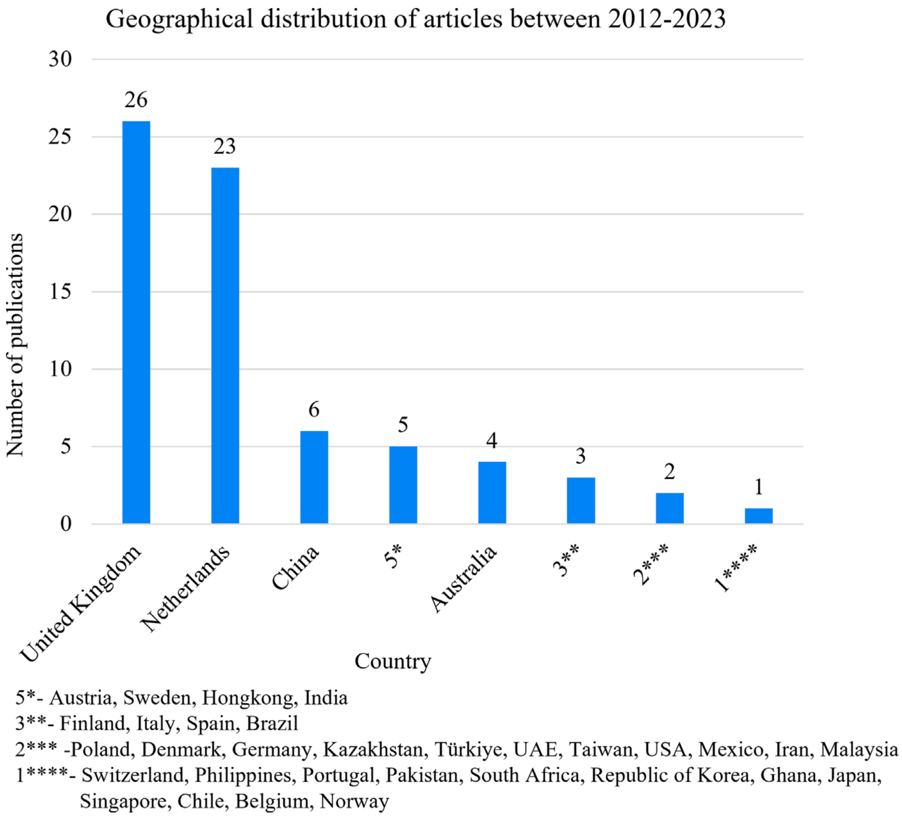

FIGURE 3
Geographical distribution of articles between 2012–2023.

changes to a national policy intended to provide financial incentives for a CE (Superti et al., 2021). Regulations with an emphasis on CE can provide guidelines for the planning, construction, and operation of buildings. This covers lifecycle costing (LCC) analysis, specifications for using recycled or repurposed materials, whole life carbon reporting, energy efficiency through life cycle assessment (LCA) for comprehensive environmental impact assessment (EIA) (Hossain and Ng, 2018), waste minimization techniques, and applying circular ideas to construction methods (AlJaber et al., 2023b) (S03) (S04) (S05). Based on their objectives and descriptions, the EU and Portuguese policies and legislation aimed at promoting this paradigm change (from linear to circular economy) were broadly categorized as resource and waste management, SDGs and green public procurement dedicated to CE (S02). The development of policies and regulations, new and innovative digital tools as well as platforms, education and capacity building, and a governance model that meets demands were the main opportunities and challenges of these laws and regulations that were recognized (Pedroso and Tavares, 2024) (C01) (C02). Regarding digital transformation, policymakers have been proactive in updating construction contracts to include BIM protocol (Charef and Lu, 2021). For example, the UK government has standardized BIM level 2 implementation by providing the PAS series which lays out a framework for collaborative working and information exchange (Charef, 2022). In addition to people and technology, obtaining CE in construction calls on policy and regulatory expertise. Policymakers should create incentive programs promoting circular material flow in the design, operation, and end-of-life phases. It is also important to quickly establish new certification programs, such as green building rating systems, to acknowledge and promote CE in construction (M02) (S04). Determining the circularity of structures requires the definition of circularity criteria. To boost the market and convince consumers about the efficacy and value of recovered materials, certification programs within them are also deficient and need to be controlled (Charef and Lu, 2021) (C04) (S06). There are diverse policies and regulations with respect to construction, planning and infrastructure in developed and developing countries. While developed countries generally have an already set infrastructure and focus mainly on maintaining and upgrading, developing countries are fertile for newer constructions and are in an expansion phase for growth spurt. Thus, the challenges encountered and solutions for these are varied (Patwa et al., 2021; Alotaibi et al., 2024). Developed countries prioritize sustainability, safety and preservation whereas developing countries focus on basic infrastructure development. Moreover, developed countries would already have a robust legal system and a well-defined regulatory framework, including building codes and laws which are strictly enforced. With limited regulatory frameworks which may still be evolving and lack of enforcement, developing countries find it harder to ensure that buildings are compliant with CE. For example, there are lack of standards and regulations for using secondary/used materials and components

TABLE 2 Summary of key motivators, challenges and strategies.

Factor group	Category	Factors
Motivators	Policy implementation	M01, M02, M25, M26, M29, M30
	Knowledge and workforce development	M03, M04, M05, M06, M07
	Technical, infrastructure and operational support	M11, M12, M19, M20, M21, M22, M23, M24, M27
	Sustainability awareness	M13, M14, M15, M17, M18
	Research and development	M08, M09, M10, M16
	Incentives	M28, M31, M32
Challenges	Lack of policy and regulatory framework	C01, C02, C03, C04, C25, C26
	Knowledge and academic gaps	C05, C06, C07, C08, C09, C10
	Lack of technical, technological and financial support	C11, C12, C13, C14, C24, C31, C32, C33
	Lack of awareness measures and outreach	C15, C16, C17, C20
	Lack of collaboration and organizational backing	C18, C19, C21, C22, C34, C35
	Market limitations	C23, C27, C28, C29, C30
Strategies	Policy and regulatory framework	S01, S02, S03, S04, S05, S06, S16, S17, S18, S19, S20
	Education, skill development and training	S07, S08, S09, S10, S14
	Technological and financial aids	S11, S12, S13, S26 S27, S28, S29
	Organizational collaboration	S15, S30, S31
	Market mechanisms	S21, S22, S23, S24, S25

(Mhatre et al., 2023), lack of relevant policies, regulations, and construction codes for MMC (Tleuken et al., 2022), and inadequate enforcement of environmental regulations to manage CDW (Bao, 2023; Mhatre et al., 2023). Some ways of curtailing these problems would be to develop building codes that would incorporate safety, structural integrity and technological advancements within them. It is important to establish regulatory bodies that would provide policymakers opportunities to implement CE through taxes, laws, and regulatory framework within the construction industry (Pomponi and Moncaster, 2017) and be responsible for monitoring compliance to these newer codes and practices (Hjaltadóttir and Hild, 2021). Depending on the climate, cultural and geographical demands of the nation, international standards often serve as a guide for developing ideas and integrating newer construction methods. This can be done by reforming and aligning existing policies and regulations in line with CE principles to facilitate adoption of CE practices (Bao, 2023) like revising policies to facilitate waste management practices for material reuse and upcycling (Gallego-Schmid et al., 2020) and making whole-life carbon estimates mandatory (Gillott et al., 2022). There is also a need to develop standard practices for the reuse of building materials (Benachio et al., 2020) and quality certifications for secondary materials (Mhatre et al., 2023). Other than these, education and training in MMC and BIM are also critical in achieving a sustainable system in developing countries.

3.1.2 Knowledge, education and training

Technical training and knowledge of CE are crucial aspects of the effective adoption of CE principles in construction practices. The need for experts in the sector to implement CE effectively is rising as there is a growing interest to achieve a sustainable and financially viable future (Guerreschi et al., 2023) (M05) (M06) (M07). Good education, technical training, knowledge sharing, and competencies by academia and industry are essential in this regard to facilitate use of CE construction practices and concepts (Kanters, 2018; Guerreschi et al., 2023) (M03) (M04). Every generation benefits equally from this bidirectional exchange of knowledge, which considers different perspectives and experiences. Research and instruction on CE strategies help put into practice sustainable development that considers the social, economic, and environmental domains (M09). It is significant in developing economies as the number of experts is usually low in such countries (Guerreschi et al., 2023) (C05) (C06). The current deficiency in industry-wide comprehension is anticipated to impede the acceptance of circularity in the short run (C09) (C10). It is suggested that certain stakeholders within the supply chain, such

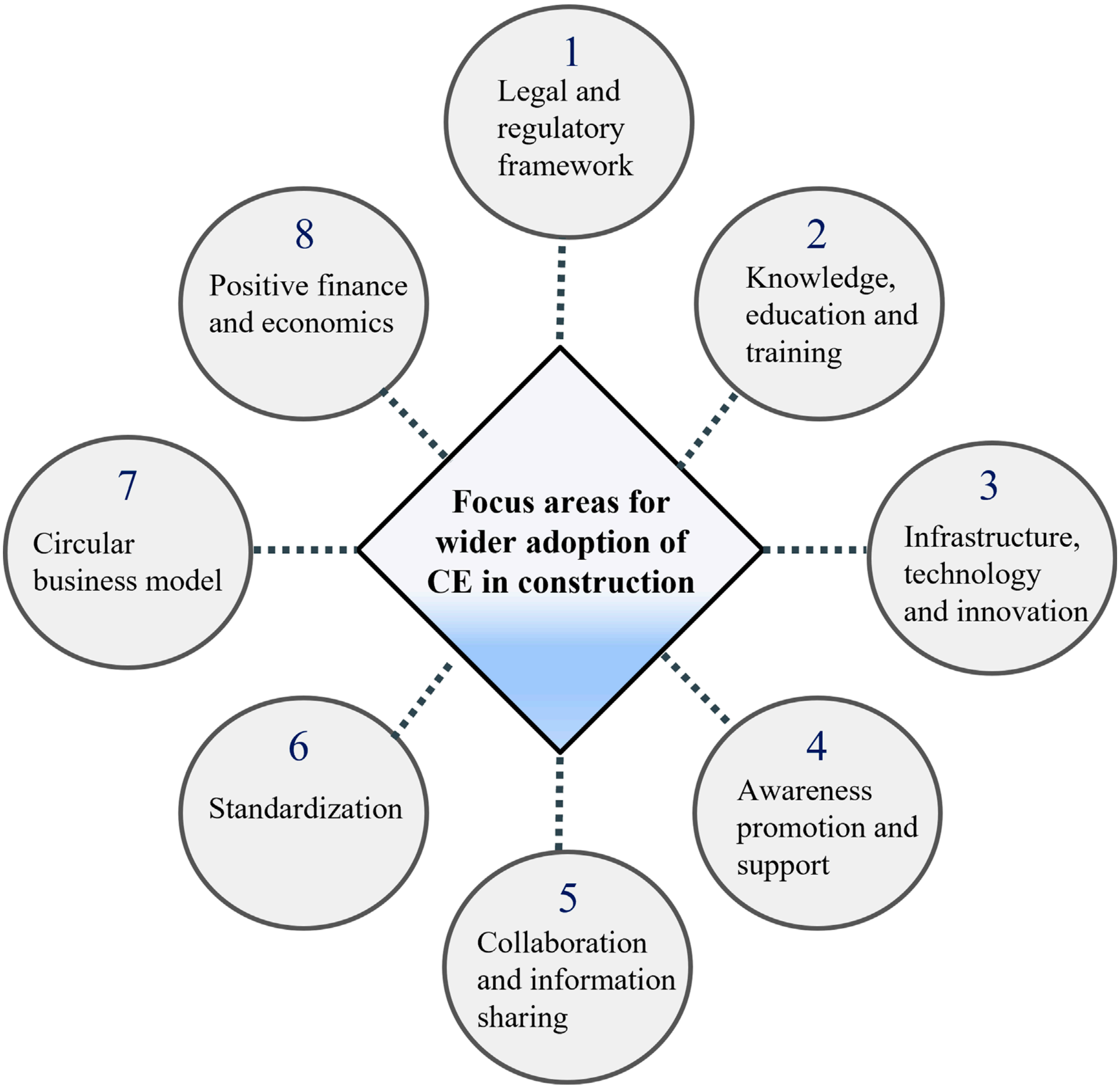

FIGURE 4
Focus areas for wider adoption of CE in construction.

as consumers and designers, possess a limited understanding of how to effectively implement CE concepts (Adams et al., 2017) (C07) (C08). A cohesive set of CE design abilities is becoming increasingly necessary in both business and academia since it may direct the creation of specialized training courses and curricula (M10). Building competencies is essential to design practice such as designing with BIM (S08). An emphasis on these competencies in the curriculum might facilitate a drive to shift to a CE in higher design education (Sumter et al., 2020) (M08). Utilizing BIM technology and optimization techniques in the early design process enables environmentally friendly and ecologically conscious construction and infrastructure design while tacking the effects on the environment (Afzal et al., 2023). Individual courses aimed at improving one's knowledge and skills are mostly run by educational institutions and businesses, providing chances for professional advancement, experience acquisition, and on-the-job training (M10). To effectively design educational and training initiatives, it is crucial to comprehend the spatial distribution of economic activity concerning local and global economies, considering the various CE techniques. CE education must cover both fundamental and supporting circular occupations, spanning vocational training and skill development to postsecondary education (S07). For example, knowledge and skills on MMC (S09). The demand for education and training will change when the CE takes effect, as will the jobs that meet those requirements (Burger et al., 2019).

3.1.3 Infrastructure, technology and innovation

Technology and innovation are the backbone of the entire concept of CE, as without them, the concept would not seem feasible on a large scale. Lack of technical support for the professionals hampers CE adoption (Mhatre et al., 2023) (C12). Information and communication technologies (ICT) are possible remedies for CE

TABLE 3 Focus areas for wider adoption of CE in construction.

Focus area	ID	Factors
Legal and regulatory framework	M01	Developing supporting policies and regulatory framework
	M02	Incorporating CE principles in sustainability assessment tools, e.g., in LEED
	C01	Lack of policy and regulatory framework
	C02	Inconsistencies in policies, rules and regulations
	C03	Lack of policy focus on lower supply chain members (e.g., suppliers)
	C04	Non-inclusion of CE aspects in sustainability assessment systems
	S01	Establish suitable policy and regulatory framework
	S02	Enforcement and monitoring of rules and regulations
	S03	Mandatory whole-life carbon estimating/reporting
	S04	Mandatory environmental impact assessment (EIA)/life cycle assessment (LCA)
	S05	Mandatory lifecycle costing (LCC) analysis
	S06	Inclusion of demolition techniques, waste reduction and salvaging in planning
Knowledge, education and training	M03	Providing suitable education and training in academia
	M04	Relevant education and training in industry
	M05	Availability of technical specialist: design team
	M06	Availability of contractor/subcontractor teams
	M07	Availability of material/component suppliers
	M08	Extended academic research
	M09	Focused research in the industry
	M10	Joint research and development by industry and academia
	C05	Insufficient/lack of education and training in academia
	C06	Lack of relevant training and education in the industry
	C07	Lack of knowledge on CE practices: clients
	C08	Lack of knowledge on CE practices: designers
	C09	Lack of knowledge on CE practices: contractors/subcontractors
	C10	Lack of knowledge on CE practices: suppliers
	S07	Joint industry-academia education and training programs
	S08	Skill development for designing with BIM
	S09	Skill development on MMC, i.e., prefabrication, off-site/modular construction, etc.

(Continued on the following page)

TABLE 3 (*Continued*) Focus areas for wider adoption of CE in construction.

Focus area	ID	Factors
Infrastructure, technology and innovation	M11	Availability/access of CE related data and data sharing facilities
	M12	Use of digital technologies/BIM in design
	C11	Lack of suitable inventory management of salvaged/recycled materials and components
	C12	Lack of technical assistance/support for construction industry professionals
	C13	Insufficient technological integration in design (e.g., carbon/waste estimation)
	C14	Lack of use of technology in demolition/salvage process
	S10	Establish information support and dissemination center
	S11	Introduce material passport (i.e., tag/barcode) system for inventory management
	S12	Set up common data exchange platforms between construction organizations
	S13	Develop suitable technology for salvaged material/component segregation
Awareness promotion and support	M13	Concerns for environmental issues, e.g., pollution or waste generation and disposal
	M14	Concerns for climate change, e.g., from energy use and CO2 emissions
	M15	CE approaches allow easier maintenance of structures/facilities
	M16	Demonstration projects/case studies highlighting benefits of CE practices
	M17	Awareness generation through workshops, seminars, and conferences
	M18	Awareness generating activities through digital media (e.g., on TV)
	M19	Commitment and management support of client
	M20	Commitment and management support of government
	M21	Commitment and management support of construction organizations
	C15	Lack of awareness generating activities: demonstration projects
	C16	Lack of awareness generating activities: digital media
	C17	Lack of awareness generating activities: seminars, workshops, conferences
	C18	Lack of commitment and support at government level
	C19	Lack of commitment and support of construction organizations
	C20	Lack of commitment/interest of clients/users on CE practices (e.g., on used materials)
	S14	Awareness generation through pilot projects

(Continued on the following page)

TABLE 3 (*Continued*) Focus areas for wider adoption of CE in construction.

Focus area	ID	Factors
Collaboration and information sharing	M22	Organizational collaboration, e.g., between contractors, subcontractors/suppliers
	M23	Collaboration in project delivery, e.g., contractor/supplier involvement in design
	M24	Accountability of individual supply chain members, e.g., on CE approach
	C21	Lack of organizational collaboration, e.g., between contractors, subcontractors/suppliers
	C22	Lack of collaboration in project delivery between contract parties
	C23	Lack of accountability of individual supply chain members
	C24	Lack of data transparency, e.g., of quality of recycled materials/components
	S15	Clients to initiate collaboration between contract parties
Standardization	M25	Quality certification systems for used/recycled materials or components
	M26	Standardized manufacturing of materials and components (e.g., shape, size, etc.)
	C25	Lack of standard design manuals (supporting CE practices)
	C26	Lack of standardization of recycled/reusable materials or components
	S16	Certification/environmental assessment system incorporating CE practices
	S17	Introduce audits before demolition (e.g., for salvaging)
	S18	Develop design manuals incorporating CE practices
	S19	Standardization of recycled/reusable materials or components
	S20	Third-party certification of used/recycled materials for quality assurance
Circular business models	M27	Flexible business models, e.g., purchase materials on credit, buy-back unused items, etc.
	C27	Lack of flexible business models, e.g., buy-back unused items, etc.
	C28	Lack of adequate quantity and quality of used and recycled materials/components
	C29	Lack of market demand for salvaged/recycled materials and components
	C30	Virgin/new materials are cheaper than recycled and reused materials
	S21	Enforce flexible business models, e.g., buy-back unused items
	S22	Update procurement methods to include salvaged/recycled materials/components
	S23	Introduce marketplace for used and recycled materials/components
	S24	Create market demand for salvaged/recycled materials, e.g., aligning with incentives
	S25	Introduce innovative/alternative materials using recycled content

(Continued on the following page)

TABLE 3 (*Continued*) Focus areas for wider adoption of CE in construction.

Focus area	ID	Factors
Positive finance and economics	M28	Financial incentives (e.g., low-interest loans, tax reduction) for used/recycled materials
	M29	Increased taxes on virgin raw materials
	M30	Increased tax on (construction and demolition) waste disposal
	M31	Non-financial incentives to design professionals, e.g., preference in bidding or ranking
	M32	Non-financial incentives to constructors, e.g., preference in bidding or ranking
	C31	Lack of funding for relevant research and development
	C32	Lack of financial incentives from government, e.g., tax reductions, subsidies, and loans
	C33	Lack of financial incentives from financial organizations, e.g., loans, reduced interest
	C34	Lack of non-financial incentives, e.g., in preferential bidding or ranking
	C35	Lack of non-financial incentives, e.g., awards, public recognition for firms/projects
	S26	Provision of funding for research and development
	S27	Provision for alternate project investment/financing, e.g., PPP or PFI
	S28	Financial incentives by the government, e.g., tax adjustments, subsidies, loans, etc.
	S29	Financial incentives by private institutions, e.g., loans, and reduced interest
	S30	Non-financial incentives by clients, e.g., preferential bidding or ranking
	S31	Non-financial incentives in the industry, e.g., awards/accolades for recognition

problems because they can aid in CE-oriented decision-making (Yu et al., 2022) (M11). How digital technology can help reduce building waste during the design stage has not received much attention (C13) (C14). Digital technologies like BIM can help the industry adopt circular design principles, increasing material recycling rates and decreasing wasteful building waste (Talla and McIlwaine, 2022) (M12). There is a call for the creation of cost-efficient technology and adequate infrastructure for CE materials and processes to address the lack of suitable technology and inventory management for salvaged material/component and their segregation (Charef and Lu, 2021; Gedam et al., 2021; Mhatre et al., 2023) (C11) (S13). Performance, expansion, and innovations in CE go together. Organizations that implemented CE innovations saw a marked increase in revenue and employment growth when compared to other organizations in their industry and exhibited a markedly improved financial situation with no discernible effect on labor productivity. Instruments that mandate the adoption of CE practices by construction organizations can increase the benefits of CE developments at the corporate level. Policymakers can establish a Porter-hypothesis-type win-win scenario by promoting technologies that advance the concepts of CE, provided that the market responds to these advances by increasing the willingness or inclination to purchase CE-based products. Therefore, it is crucial to combine policies that educate consumers about the long-term advantages of a shift toward CE with legislation focused on the CE (Horbach and Rammer, 2020). Establishing an information support and dissemination center may aid in achieving this (S10). Once materials are tagged in material passports, BIM can be used to track components and import them into design software at the design stage (Gallego-Schmid et al., 2020) (S11). Common data repository facilities and exchange platforms through BIM and Blockchain technology can provide project information from inception to end of life and enable material and energy traceability, allowing users to predict the recycling and reuse of materials/components (Charef and Lu, 2021; Shojaei et al., 2021) (S12). BIM tools can assist in selective disassembly and disassembly planning by providing a disassembly model with complete information in an automated and efficient way (Sanchez et al., 2021).

3.1.4 Awareness promotion and support

All relevant stakeholders must be aware of the CE principles and practices, which might stimulate economic growth, create employment, and lessen environmental effects like carbon emissions while addressing the growing resource-related issues that companies and economies face (Ellen MacArthur Foundation, 2015b) (M13) (M14). To encourage stakeholders to embrace CE practices, raising awareness of CE, and demonstrating its advantages for the environment and economy through extended workshops, seminars, and conferences is imperative (Leising et al., 2018) (M15) (M17). Without such information, stakeholders risk ignoring the potential economic and environmental benefits and the chance to produce more profitable and circular results. The most important awareness hurdles identified in the literature are the following: "a lack of case studies; inadequate information in building design; a fragmented supply chain; a lack of skills and engagement in the supply and value chains; and a limited understanding of CE" (AlJaber et al., 2023b) (C15) (C17). Implementing pilot projects based on the best practice case studies of circular buildings, awareness through electronic media, events and advertisements and land, temporary planning permissions, and support for the circular activities by governments are necessary to promote CE (Bilal et al., 2020; Dokter et al., 2021; Williams, 2023) (M16) (M18) (M20). Moreover, there existed a noticeable lack of awareness within the sector. This could be attributed to the absence of widespread consensus on the manifestation of CE principles in the construction industry (Adams et al., 2017). Budget and upfront expenditures, awareness and CE education gaps, a lack of legislation, and the need for modifications to the present building company structures are the biggest obstacles that have been found (Guerra and Leite, 2021) (C18) (C19). The obstacles that must be addressed to proceed with construction waste management are improving rules, changing people's awareness and perspectives, and providing resources to gather pertinent data on construction waste (Esa et al., 2017) (M19) (M20) (M21). There is a knowledge gap about the insufficient data on the qualities of recovered and recycled building materials, which is the cause of the lack of confidence and acceptability for recovered and recycled materials (C20). To encourage the use of recovered materials, it is necessary to raise knowledge awareness and educate all stakeholders on the 3R (Reduce, Reuse, and Recycle) strategy (Osei-Tutu et al., 2023). Pilot projects demonstrating use of deconstruction practices and incorporation of recovered and recycled materials will raise awareness (López Ruiz et al., 2020) (S14). Organizations can benefit from increasing the level of awareness of utilizing BIM technology as a resource saving technique for delivering waste efficient projects by recruiting new BIM specialists and conducting training and certification programs (Ganiyu et al., 2020).

3.1.5 Collaboration and information sharing

Collaboration and information sharing are very significant due to the complexities of CE. Lack of platforms for organizational collaboration and stakeholder participation in project delivery (Munaro and Tavares, 2023) (C21) (C22), and lack of accountability of individual supply chain members, for example, producer/suppliers' responsibility for product liability (Gerding et al., 2021) due to segmentation and lack of disclosure are barriers to the sector's adoption of circular practices (Hjaltadóttir and Hild, 2021) (C23). Stakeholders' understanding and awareness of CE need to be increased. If the shift to CE is to take place, then all stakeholders must work to modify their strategies and collaborate to share experiences for the next cross-sectional working processes (Moscati et al., 2023) (M22). To attain circularity in a project, cooperation between project stakeholders in both vertical and horizontal supply chains is essential. This kind of cooperation is necessary to create a shared platform for finding potential business partners, exchanging information, and creating business plans for material flow or sharing (M22) (M23). Used materials are considered inferior, and knowledge and comprehension of CE procedures are absent. These hurdles result from the lack of confidence in and embrace of reused materials and the lack of care for recovered materials (Osei-Tutu et al., 2023) (C24). Regarding material flows, the requirement to monitor material reuse, maintain track of material origins, and facilitate the transfer of material ownership are also pressing for the cooperation of large-scale value chain actors on a common platform (Senaratne et al., 2021) (M24). In supply chain cooperation, developing a vision is the first step for CE. To integrate new collaborative techniques among the supply chain collaborators, higher level actor knowledge is necessary. Stakeholders must be able to expand their horizons to encompass a building's end-of-life alternatives. They must also adopt a new, interdisciplinary approach to problem-solving in which others can hold participants accountable for their assignments and outputs (M24). Facilitating supply-chain cooperation by bringing together all partners, from suppliers to designers, demolishers, and waste management companies is crucial in network mechanics (Leising et al., 2018). A CE is largely made possible by information exchange between contract parties (S15). Firms can maintain product and material awareness by having information about the treated items as well as the activities of other stakeholders. The primary means by which product makers get lifecycle data and expertise from repair, refurbishment, and recycling is through enhanced feedback. Using this data, they may improve their designs and production processes, resulting in more environmentally friendly products, such as recyclable or more long-lasting items with more efficient, dependable maintenance. As a result, the product's lifespan is extended. To further the CE, inter-organizational information exchange should adhere to transdisciplinary standards (Jäger-Roschko and Petersen, 2022). A central repository facility consisting of BIM models, the BIM dimensions, projects' databases, and information about the asset from its inception to its end of life can assist in data management at the asset and material level (Charef and Lu, 2021).

3.1.6 Standardization

Based on the growth of CE in construction, professionals argue, citing a lack of uniform procedures and practices to assist them in implementing their building endeavors (Benachio et al., 2020) (C25). There is a lack of standardization of recycled and reusable materials and components preventing their demand and use freely for new and repurposed constructions (Hart et al., 2019). By creating frameworks, design guidelines, supporting materials, and standards for the sustainable utilization of resources and energy while preserving the value and quality of materials throughout the cycle, standardization measures help to implement CE policies (M25) (S18) (S19). Examples include improving recycling quality and quantity and ensuring waste prevention and management by introducing audits before demolition (Mhatre et al., 2021) (M25) (S17). A manufacturing-style approach to the durability and reuse of standardized components and materials, as well as simplicity, standardization, modularity in design, sustainably sourced materials, and transparent and accessible mechanical connections, all facilitate circular building (Dams et al., 2021). Most standards are imposed from an economic perspective instead of an environmental one. Environmental assessment systems must incorporate CE practices like having regionalized tools and databases for LCA (Hossain and Ng, 2018) and tracking and monitoring protocols for assessment methods (Pomponi and Moncaster, 2017; Gallego-Schmid et al., 2020) (S16). Combining digital technologies like BIM, MP, and environmental sustainability tools like LCA and LCC are not yet promoted by policy framework. Hence, standardizing them will help with decision-making related to design process and end of life management (Giorgi et al., 2022). Once standardized, policies can encourage their application. Furthermore, ISO 20887 appears to be the first real standard that addresses the concept of building component reuse. There has to be more morphological uniformity. It is not appropriate to limit this morphological standardization to profile sections alone. Broader emphasis should be placed on standardizing the heights and lengths of architectural components (Anastasiades et al., 2021) (M26) (S19). There needs to be a framework for standardizing CE, proposing it as a sustainable paradigm that can facilitate uniform organization of diverse regulatory components, allowing various standardizing organizations to assess them (S20). This CE standardization system can involve employing specific tools, guidelines, Key Enabling Technologies (KETs), and Key Performance Indicators (KPIs) that can present a company as a representation of a circular business, serving as the most consolidated analytical unit for the circular value chain (Ávila-Gutiérrez et al., 2019) (S18) (S20). As the industry grows closer to a closed-loop supply chain, studies on standardizing material types and dimensions may be useful for MMC and can offer a list of the materials that make up a structure (Minunno et al., 2018) (M26).

3.1.7 Circular business model

A clear business case is necessary to implement any new model. Although less obvious, applying CE in the construction sector is feasible from a business case standpoint. However, as often thought in today's markets and with today's rules, CE business models for the construction sector are significantly less obvious. As far as research indicates, the primary obstacles and hurdles to providing CE services in the construction industry are not recognized by partners in the sector and are rarely, if ever, discussed in CE literature (Van Den Brink et al., 2017) (C27). The creation, distribution, and collection of value within and with closed material loops by an organization serve as the foundation for a circular business model (Linder and Williander, 2017). For circular business models to be effective, other facets of sustainability such as social and environmental concerns must be considered (Haggège et al., 2017). Hence, implementing circular business models that redefine profitability and use product-service systems as ownership models is vital to transition to CE (Pomponi and Moncaster, 2017) (M27) (S21). The requirement for a systems-thinking-based new economic model is becoming increasingly apparent, and today's unparalleled convergence of social and technical advancements may make the shift to a CE possible (Ellen MacArthur Foundation, 2015b). An organization through a circular business model generates, collects, and distributes value by utilizing the value creation logic centered on prolonging the useful life of products and parts and closing material loops through long-life design, repair, and remanufacture. The preceding value chain, which replaces primary material input with secondary materials and components, and the following value chain, which makes them available for further use to maximize the original set value, are two examples of extending the lifespan and closing material loops. It is ideal to extend their useable life and close the production loop when a product attains its irreversible end of life (Nußholz, 2017). Businesses run higher risks if they use reused supplies instead of virgin materials because there is less market interest in products made from recycled materials (Grafström and Aasma, 2021) (C29). Lack of adequate quality and quantity of salvaged/recycled materials is due lack of standards and quality certifications and market demand (Mhatre et al., 2023) (C28). Also, cost of virgin/new materials is cheaper than processing and recycling cost to produce secondary/recycled materials (Favot and Massarutto, 2019) (C30). Updating procurement methods such as government procurement, and circular tendering (Williams, 2023), leasing or buy-back schemes (Leising et al., 2018) and establishing digital marketplaces for salvaged/recycled materials can increase supply and generate market demand (Çetin et al., 2022) (S22) (S23) (S24). These salvaged/recycled materials can be tagged in the material bank using MP and BIM can be used to track and import them when it comes to the design stage of a project (Gallego-Schmid et al., 2020). Discussing business model circularity is crucial in light of the financial practices that society is currently embracing. Increasing the number of circular firms would aid in mitigating many of the drawbacks of linear enterprises in the past, present, and perhaps future. In an attempt to develop environmentally friendly solutions, circular business models often consider the environmental and economic dimensions in that order, paying potential neglect to the social component (Salvador et al., 2020). Utilization of innovative alternate materials using recycled content will reduce dependency on certain materials that are used in every construction project and improve the availability of materials (Norouzi et al., 2021) (S25). Furthermore, organizations can include contracting methods adapted to CE approach in their business models like assigning higher weightage to contractors using such alternate materials and BIM in their projects than the overall cost in the tender selection process (Minunno et al., 2018).

3.1.8 Positive finance and economics

A well-designed and focused financial initiative program is lacking for CE practices. By offsetting the upfront expenses of switching to more circular processes, these initiatives might increase the financial appeal of these approaches. If these initiatives are not provided, firms may view CE practices as an expense, lowering their incentive to adopt them (AlJaber et al., 2023b) (C31) (C32) (C33). Financial instruments should be developed to lower business risk, monitor external taxes, raise environmental accounting, and set the appropriate price (Govindan and Hasanagic, 2018) such as imposing taxes on disposing of CDW and increasing taxes on the mining of virgin raw materials (Mhatre et al., 2023) (M29) (M30). The government can support financial initiatives to assist CE by making the initial financial commitment to implement it (Smol et al., 2015) (S28) by devoting specific budget for CE approach in construction, launch platforms for CE investments, and tax rebates and subsidies for circular applications and materials (Bilal et al., 2020; López Ruiz et al., 2020; Charef and Lu, 2021) (M28). Promoting CE will be MMC based where BIM is needed, which causes considerable upfront costs although savings are superior in the long run. Contractors and consultants work on profit-based setups and are driven by it. Hence, without incentives they may not adopt newer and costlier construction processes. With clear guidelines, policies, and regulations drawn by the government for construction industry, compliance to CE based practices will be achievable. Economic incentives in the form of either tax reductions or low-interest loans encourage private sectors to take up sustainable work practices in construction. One might think of it as a direct internal loss for the government by giving these incentives, however, in the longer period, these investments can be recovered as the efficiency in the industry will improve with a sustainable sector in place. While economic incentives are crucial in promoting CE, government should lay down strict policies and regulations to provide these incentives. For example, incentives may be offered initially for 5–10 years, after which CE practices will become the new norm. Once the time-bound incentive period is crossed, it should be mandated to continue to adhere to CE principles for all upcoming constructions. This way sustainable construction practices will be achieved in an efficient manner. The growing fascination with the financial elements of CE enterprises results from the technological shift toward sustainability and CE shaping investments and company operations. The financing sources, both public and private, evaluate various financing subjects, including supply chains, cooperative projects, and the circular business of individual companies, using various criteria like "valuation and profitability of circular business models, their type, investment costs, and their business potential". Many variables that may operate as drivers have also been thought to behave as inhibitors (Saarinen and Aarikka-Stenroos, 2023). This is because the CE is still relatively new and not recognizable as a linear standard system. The absence of institutional, financial, and non-financial metrics to evaluate the growth of various circular enterprises is another significant issue impeding the adoption of the CE (C32) (C33) (C34) (C35). Financial insights can be given into design alternatives while using BIM during design stage (Çetin et al., 2022), and project cost optimization can be achieved during construction and maintenance as BIM can yield useful data for future deconstruction and remodeling tasks (AlJaber et al., 2023a). It is crucial to emphasize that assets from many sources (reuse, recycling, product design, etc.) must be considered in evaluating the product's expenses throughout all manufacturing stages before it can be considered financially successful which can be enabled by funding for CE research and development (S26). Thus, monetary incentives, program subsidies, and public awareness among governments, industries, and clients are critical variables for the development of the CE (Gonçalves et al., 2022) (S28). Non-financial incentives from industry and clients include awards for recognition and preference in bidding or ranking to design professionals and constructors that employ CE practices (Minunno et al., 2018; Bilal et al., 2020) (M31) (M32) (S30) (S31). The extent to which businesses attain CE is correlated with the investment amount. The degree to which investments are made in CE is also influenced by the availability of money and, more specifically, the level of financial backing that could come from loans with reduced interest from private institutions (Górecki et al., 2019) (S29). The expansion of diverse circular activities carried out by corporations appears notably influenced by the availability of resources, particularly at an affordable cost. Emphasizing the quality of these resources is crucial, given that corporations often require greater guarantees to finance operations within the CE framework compared to other initiatives (Aranda-Usón et al., 2019). Providing alternate investment/financing like PPP or PPF to these corporations could be of assistance in such a scenario (Bilal et al., 2020; Munaro and Tavares, 2023) (S27).

3.2 Conceptual framework

The conceptual framework for the present study is shown in Figure 5. The conceptual framework proposed presents a solution for the wider adoption of CE in construction. It consists of four sub-frameworks.

The first sub-framework comprises the motivators, challenges and strategies extracted from literature that were analyzed based on CE principles that informed the development of the framework leading to the placement of the identified eight focus areas in the second sub-framework with the third and fourth sub-framework on either side of it. The third sub-framework is the CE applications and techniques comprising components such as design for reuse, optimized use of resources, waste management, design for disassembly, closing resource loops, waste minimization by design, collaboration among stakeholders, modern methods of construction, use of secondary material, material bank, design for adaptability and flexibility, substitute material, standardization of resources and take-back schemes. The fourth sub-framework is the client and project preferences composed of components like cost optimization, client's requirements, time and quality, risk and compliance, and procurement models.

BIM allows these frameworks to be self-contained and also interact with other sub-frameworks to collaborate and suggest options. For example, throughout the focus areas sub-framework, BIM can lead to broader adoption of CE by allowing its interaction with the required components of the CE applications and techniques sub-framework like design for reuse and disassembly, modern methods of construction for knowledge, education and training, material bank for infrastructure, technology and innovation, take-back schemes for positive finance and economics, etc. While considering client's preferences such as cost, quality, procurement, etc. All these sub-frameworks will be analyzed and collated to decide and develop the specific building information model which will be used for wider adoption of CE in construction.

Building a sustainable structure is the top priority. This means employing sustainable methods to carry out the work with the maximum number of sustainable materials as well as procedures, that would lessen the environmental impact and support the circular economy's objectives. In this regard, BIM offers benefits in many ways. BIM can help in regulatory compliance. A procedure can be developed to automatically analyze individual BIM models to determine and assess if they comply with local urban regulations, specifically focusing on building code and urban plan compliance from municipalities (Villaschi et al., 2022). BIM can also be used for knowledge management (KM). Despite years of application of different IT tools and knowledge management methodologies, KM in construction is still insufficiently effective. Unique properties of BIM help KM in the industry (Wang and Meng, 2021). The application of the BIM technique in infrastructure lifecycle management has rapidly grown in order to bolster the efficacy of infrastructure management systems (Jang et al., 2021). Utilizing BIM in 3D visualization of the construction resources'

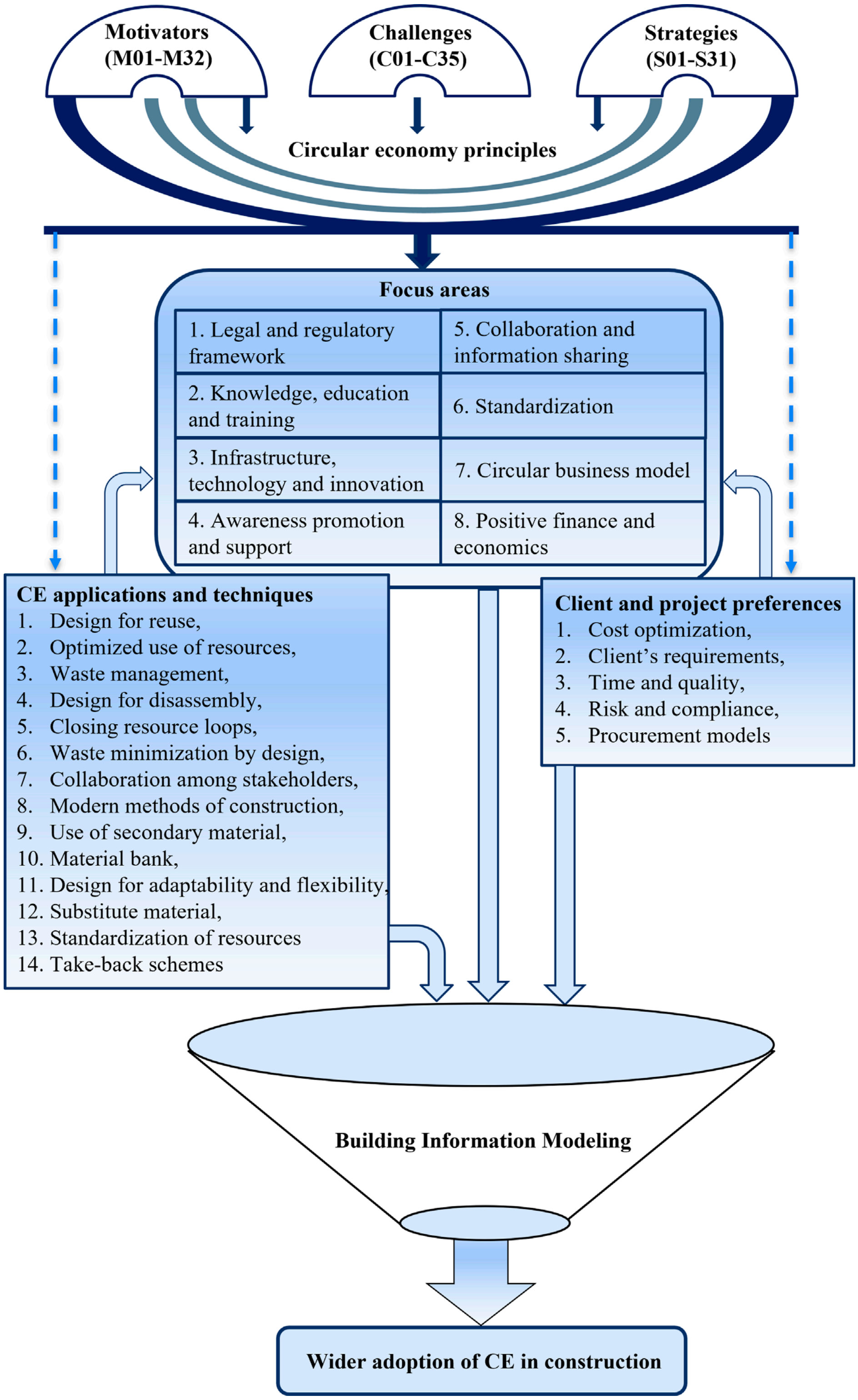

FIGURE 5
Conceptual framework for wider adoption.

indoor placement (workers, materials, and equipment) enables visual management based on situation awareness of the project's construction activities. By employing BIM visualization to improve situational awareness of construction resources on-site, waste can be detected and eliminated along with the identification of disruptions in workflow, thereby improving planning and increasing productivity (Reinbold et al., 2019). The main tenets of BIM in the construction sector are facilitating collaboration among project stakeholders (Poirier et al., 2017). ICT-based tool's interface with BIM encourages improved stakeholder cooperation (Rane et al., 2023). Recycled secondary raw materials will replace traditional, natural raw materials within specific constructions and elements. The architecture of the BIM library of sustainable elements will be useful in selecting appropriate raw materials. The BIM library will be a conduit between real building items and components and producers using BIM digital reproductions (Behún and Behúnová, 2023). BIM-based frameworks can also assess circular business models (Di Biccari et al., 2019). Lastly, project cost management specialists have many opportunities to significantly increase their cost management services' quality, speed, value, accuracy, and sophistication thanks to BIM and related digital technologies and tools (Smith, 2016).

The present framework is for the industry level. If adoption of CE at the industry level is being considered, firstly sets of motivators and challenges need to be identified to know what benefits they can gain and what problems they will face if they adopt CE. Accordingly, certain strategies must be used to balance these motivators and overcome challenges. These collated motivators, challenges, and strategies have to be analyzed using the eight focus areas in the second sub-framework. For example, under 1. Legal and regulatory framework, inclusion of material passports (MP) in building codes by standardizing MP and developing regulations to encourage its application. This is at the nationwide level as it is at policy level. Under 2. Knowledge, education and training, setting up a construction industry development board at the national level to provide a knowledge-sharing platform for training and skill development on BIM, MMC and other circular practices. Under 3. Infrastructure, technology and innovation, installation of factories for modular structure/components production for MMC, technological integration in design, digital advancement such as industry wide adoption of BIM that the UK government set up by mandating all public sector projects to use BIM by 2016. Under 4. Awareness promotion and support, a platform at the industry level for disseminating information through demonstration projects/case studies highlighting the benefits of CE practices and awareness generation through workshops, seminars, and conferences. Under 5. Collaboration and information sharing, for the successful delivery of the project the client needs to share information with consultants and contractors, and thus initiate collaboration between the contract parties. Under 6. Standardization, standardization not only in terms of quality but also involving maintaining consistent sizes and specifications for rooms, walls, and structural elements like beams and columns ensures uniformity in quality, quantity and dimensions. These can be tagged with a unique code and included in the MP. All these enable MMC, facilitate reusing or recycling, limit different types of components, and prolong lifespan. Under 7. Circular business model, to ensure effectiveness of this approach, organizations through circular business models can mandate that contractors use standardized practices and MPs in their projects. Under 8. Positive finance and economics, funding for projects using CE practices, and tax deduction for using certain percentage of secondary or recycled materials in projects. This way the set of motivators, challenges, and strategies are analyzed using the eight focus areas.

Considering a hypothetical project of a building complex for 100 houses, the client here will consider the third and fourth sub-frameworks, CE applications and techniques, and client and project preferences together. If the client is considering design for reuse and MMC, for design for reuse, standardization can be used for designing similar sizes of components and elements. This will be made possible by MMC with mass production. For optimized use of resources, using MMC, i.e., prefabricated/modular components will minimize the use of resources. For waste management, MMC will reduce waste generation by making reusing easier. But for some projects, it may be expensive. The client needs to consider which option gives cost optimization. If the client is going to consider design for reuse, MMC will be better suited. If the client considers waste management, then it will be MMC and design for reuse. Similarly, for design for disassembly, it will be MMC. But in the fourth sub-framework, the client can go for the extent to which he would like to use the CE applications and techniques, i.e., design for reuse or MMC. It can be employed for the whole project or only for partial parts such as the main components or peripheral works like parapet walls, all the while considering the time and quality, risk and compliance, and procurement models. All these will give an array of options and solutions where building information can help efficiently and BIM can precisely suggest cost involvement for multiple options from where the client then can choose which option to opt for. This model not only facilitates implementation of CE but also supports adoption of CE on a wider scale by allowing some projects to fully or minimally adopt CE, based on the client's preferences. This enables informed decision-making for every option/project. Once the decision is made, the model will be stored as a structure-specific model that will be used for designing, constructing and maintaining the structure for refurbishment, repair, and end of life management. After the structure has reached its end of purpose after n years of use, the model can help with deconstruction rather than demolition such as sequential material recovery for reuse and recycling.

3.3 Sustainability assessment and reporting

Sustainability assessment is a more contemporary definition of impact assessment that places an emphasis on developing net sustainability benefits both now, and in the future. It is pluralistic, can be used for decision-making, and can take many different forms (Bond et al., 2012). Waste has accumulated for decades due to population expansion, consumerism, and linear (take-make-dispose) economic structures. The positive aspect is that the majority of waste in the construction sector can be recycled or repurposed, although linear economy concepts also form their foundation. Rarely do the current methods for evaluating sustainability consider sustainability's economic, environmental, and social facets. However, most models rely on statistical records of CDW volumes, which frequently underestimate the actual rates of CDW formation (Nadazdi et al., 2022).

BIM is among the most exciting breakthroughs in the architectural, engineering and construction (AEC) sector that has the potential to assist in sustainability assessment and reporting in the context of CE. New design-centric techniques and procedures are needed to maximize structures' potential for recycling and the makeup of materials. Material Passports (MPs) would allow the construction sector to adopt CE and optimize design (Kovacic et al., 2019). MP serves as a tool listing all the components used in a structure, and a visual representation of the environmental effect and possibilities for recycling a building (Honic et al., 2019b). In-depth information on components utilized in a building, together with their location, state, and possibility for recycling or reuse, may be obtained using BIM and inventory management. Systems for managing stock can be connected with BIM to monitor materials. The system provides accurate data on resources available by updating the inventory when items are added or removed. Moreover, BIM can include comprehensive data sheets on certain materials' characteristics, circular potential, and environmental performance. Every material utilized in a project can have a distinct identifying number or tag issued to it by integrating material passports into BIM (AlJaber et al., 2023a). When an asset is utilized with BIM throughout its lifecycle, a digital "as-maintained" record including all asset histories after usage can be obtained. If the MP is standardized and laws encourage its application, specifically, by requiring producers to provide some openness regarding the contents of their products in terms of dependability and quality of data gathered, BIM usage for materials passports will be successful (Charef and Emmitt, 2021). A BIM-based MP functions as an optimization tool during the early phases of design and as documentation and inventory of construction supplies during the latter stages (Honic et al., 2019a). Material data can be arranged with Artificial Intelligence's (AI) assistance into digital MPs or structured databases (Çetin et al., 2023). Integrating AI with BIM and MP can effectively manage and optimize building materials and their lifecycle. AI can be leveraged to enhance data management, improve decision-making, and ensure compliance, improving efficiency and overall success of construction projects.

Facilities Management (FM) may benefit from effective Information Management (IM) thanks to BIM. When BIM is used in FM, people, location, processes, and technology are integrated to ensure greater functioning of the built environment, leading to increased quality of life at work (Aziz et al., 2016). FM teams gather and analyze data from various sources, which frequently require proper consideration when making choices in the future. AI-based statistical models might be fed by this data, enhancing FM decision-making. In this setting, BIM emerges, utilizing data and information systematization to enable structured information and its application (Pedral Sampaio et al., 2022). Adopting AI has several benefits, including enhanced energy management, efficiency and transparency, remote reading of energy meters, and better planning, operation, and control of facilities (Oluwapelumi et al., 2021).

Future developments in AEC, and FM include automatization and informatics. While AI approaches enable automation, BIM is an efficient tool for digitizing building information (Zhang et al., 2022). With the increasing relevance of BIM workflows for various project lifecycle stages, more data is generated and handled across them. The information and data gathered in BIM-based projects provide the potential to analyze and extract project knowledge from the conception to the operation phase. Machine learning (ML) is a successful strategy for process automation and for gleaning valuable insights from various data sources. It can be used alongside BIM (Zabin et al., 2022). The combination of generated AI and BIM enables a wide range of applications in the AEC space, radically altering conventional workflows. Most notably, it transforms design optimization by enabling designers and architects to quickly consider various design possibilities. The brainstorming process is streamlined, and alternatives are generated based on predetermined criteria using AI's generative capabilities. Architects, engineers, and construction experts can easily communicate and comprehend each other because of real-time language-based interactions thus encouraging a comprehensive approach to project development, reducing mistakes and improving decision-making effectiveness (Rane et al., 2023).

As it has been for decades, technology will be essential to many aspects of asset management. Increasingly, use cases for AI and ML in asset management are developing. Tools that can assist in minimizing risk, cutting expenses, improving returns, and providing products and services to customers more effectively are currently on the market (Novick et al., 2019). The asset owner can gain anything from efficiently administrating asset information. Building automation systems, Asset Information Models (AIM), and BIM systems can do a wide range of assessments for asset optimization, and the value is found after the process (Munir et al., 2020). By identifying trends and anomalies in operating data, AI may help AIM enhance predictive maintenance, maximize asset performance, and increase equipment lifespan. As a result, there can be less downtime, money can be saved, and resource allocation can be improved.

By integrating AI with FM, BIM, and AIM, stakeholders can unlock numerous opportunities to enhance efficiency, improve decision-making, and optimize performance across the building lifecycle. This integrated approach enables sustainable and efficient building practices, ensuring the long-term success of construction projects.

4 Conclusion

This study's objective was to identify why CE is not being widely practiced and what can be done to ensure its wider adoption in construction. A systematic literature review (SLR) was conducted to get a deeper insight into this issue, where 125 articles were finalized for review based on different inclusion and exclusion criteria. Through extensive context analysis of these articles, the study identified 32 motivators, 35 challenges and 31 strategies for wider adoption. Further thematic analysis classified these into eight focus areas. These factors will be further refined, if necessary, and will be used in a questionnaire survey. This paper has comprehensively discussed these areas and developed a conceptual framework that outlined the significance of BIM with the focus areas and other aspects for the wider adoption of CE in construction. The three sub-frameworks of focus areas, CE applications and techniques, and client and project preferences will be analyzed and collated to decide and develop the specific building information model that will allow resource efficiency, waste management and reduction, material selection, use of recovered and recycled materials, lifecycle management and cost management, ensuring adoption of CE principles while considering client and project specific constraints and lifecycle aspects. The conceptual framework using BIM as a strategy can help organizations transition to CE to meet the environmental, social, and governmental (ESG) criteria and thus contribute to sustainability assessment and better reporting by integrating BIM, Material Passports and Artificial Intelligence, enabling documentation, optimization of materials and processes, environmental impact, strategies, resource use, business models and decision making. This paper will make a significant contribution to organizing the literature on CE in construction, has synthesized useful knowledge to generate awareness for practitioners and academicians, and will guide policymakers on what steps need to be taken for wider adoption such as devising regulations and building codes accordingly. This study mostly adhered to buildings but can be applied to other areas of infrastructure construction such as drainage, and roads. From this comprehensive review, it is identified that a majority of the studies in this field are conceptual, hence it is suggested that future studies should focus on implementing and validating the efficiency of different CE principles. Another important gap is the lack of studies in developing nations, and therefore, this study suggests that more practical studies should be conducted in developing countries.

Author contributions

PAR: Data curation, Methodology, Visualization, Writing–original draft. MMR: Conceptualization, Methodology, Visualization, Writing–review and editing. SBD: Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article. The Universiti Teknologi Brunei (UTB) sponsored partial publication charge.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Adams, K. T., Osmani, M., Thorpe, T., and Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers. *Proc. Institution Civ. Eng. Waste Resour. Manag.* 170, 15–24. doi:10.1680/jwarm.16.00011

Afzal, M., Li, R. Y. M., Ayyub, M. F., Shoaib, M., and Bilal, M. (2023). Towards BIM-based sustainable structural design optimization: a systematic review and industry perspective. *Sustainability* 15, 15117. doi:10.3390/su152015117

Akanbi, L. A., Oyedele, L. O., Akinade, O. O., Ajayi, A. O., Davila Delgado, M., Bilal, M., et al. (2018). Salvaging building materials in a circular economy: a BIM-based whole-life performance estimator. *Resour. Conserv. Recycl* 129, 175–186. doi:10.1016/j.resconrec.2017.10.026

Akanbi, L. A., Oyedele, L. O., Omoteso, K., Bilal, M., Akinade, O. O., Ajayi, A. O., et al. (2019). Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *J. Clean. Prod.* 223, 386–396. doi:10.1016/j.jclepro.2019.03.172

Ali, Y., Jokhio, D. H., Dojki, A. A., Rehman, O. ur, Khan, F., and Salman, A. (2022). Adoption of circular economy for food waste management in the context of a developing country. *Waste Manag. and Res.* 40, 676–684. doi:10.1177/0734242X211038198

AlJaber, A., Alasmari, E., Martinez-Vazquez, P., and Baniotopoulos, C. (2023a). Life cycle cost in circular economy of buildings by applying building information modeling (BIM): a state of the art. *Buildings* 13, 1858. doi:10.3390/buildings13071858

AlJaber, A., Martinez-Vazquez, P., and Baniotopoulos, C. (2023b). Barriers and enablers to the adoption of circular economy concept in the building sector: a systematic literature review. *Buildings* 13, 2778. doi:10.3390/buildings13112778

Alotaibi, S., Martinez-Vazquez, P., and Baniotopoulos, C. (2024). Advancing circular economy in construction mega-projects: awareness, key enablers, and benefits—case study of the kingdom of Saudi arabia. *Buildings* 14, 2215. doi:10.3390/buildings14072215

Anastasiades, K., Goffin, J., Rinke, M., Buyle, M., Audenaert, A., and Blom, J. (2021). Standardisation: an essential enabler for the circular reuse of construction components? A trajectory for a cleaner European construction industry. *J. Clean. Prod.* 298, 126864. doi:10.1016/j.jclepro.2021.126864

Aranda-Usón, A., Portillo-Tarragona, P., Marín-Vinuesa, L. M., and Scarpellini, S. (2019). Financial resources for the circular economy: a perspective from businesses. *Sustain. Switz.* 11, 888. doi:10.3390/su11030888

Ávila-Gutiérrez, M. J., Martín-Gómez, A., Aguayo-González, F., and Córdoba-Roldán, A. (2019). Standardization framework for sustainability from circular economy 4.0. *Sustain. Switz.* 11, 6490. doi:10.3390/su11226490

Awan, U., and Sroufe, R. (2022). Sustainability in the circular economy: insights and dynamics of designing circular business models. *Appl. Sci. Switz.* 12, 1521. doi:10.3390/app12031521

Azhar, S. (2011). Building information modeling (BIM): trends, benefits, risks, and challenges for the AEC industry. *Leadersh. Manage. Eng.* 11, 241–252. doi:10.1061/(ASCE)LM.1943-5630.0000127

Aziz, N. D., Nawawi, A. H., and Ariff, N. R. M. (2016). Building information modelling (BIM) in facilities management: opportunities to be considered by facility managers. *Procedia Soc. Behav. Sci.* 234, 353–362. doi:10.1016/j.sbspro.2016.10.252

Bao, Z. (2023). Developing circularity of construction waste for a sustainable built environment in emerging economies: new insights from China. *Dev. Built Environ.* 13, 100107. doi:10.1016/j.dibe.2022.100107

Becqué, R., Mackres, E., Layke, J., Aden, N., Liu, S., Managan, K., et al. (2016). *Accelerating building efficiency: eight actions for urban leaders*. Washington, DC. Available at: https://publications.wri.org/buildingefficiency/(Accessed August 30, 2023).

Behún, M., and Behúnová, A. (2023). Advanced innovation technology of BIM in a circular economy. *Appl. Sci. Switz.* 13, 7989. doi:10.3390/app13137989

Benachio, G. L. F., Freitas, M. do C. D., and Tavares, S. F. (2020). Circular economy in the construction industry: a systematic literature review. *J. Clean. Prod.* 260, 121046. doi:10.1016/j.jclepro.2020.121046

Bilal, M., Khan, K. I. A., Thaheem, M. J., and Nasir, A. R. (2020). Current state and barriers to the circular economy in the building sector: towards a mitigation framework. *J. Clean. Prod.* 276, 123250. doi:10.1016/j.jclepro.2020.123250

Bocken, N. M. P., de Pauw, I., Bakker, C., and van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *J. Industrial Prod. Eng.* 33, 308–320. doi:10.1080/21681015.2016.1172124

Bond, A., Morrison-Saunders, A., and Pope, J. (2012). Sustainability assessment: the state of the art. *Impact Assess. Proj. Apprais.* 30, 53–62. doi:10.1080/14615517.2012.661974

Burger, M., Stavropoulos, S., Ramkumar, S., Dufourmont, J., and van Oort, F. (2019). The heterogeneous skill-base of circular economy employment. *Res. Policy* 48, 248–261. doi:10.1016/j.respol.2018.08.015

Çetin, S., Gruis, V., and Straub, A. (2022). Digitalization for a circular economy in the building industry: multiple-case study of Dutch social housing organizations. *Resour. Conservation Recycl. Adv.* 15, 200110. doi:10.1016/j.rcradv.2022.200110

Çetin, S., Raghu, D., Honic, M., Straub, A., and Gruis, V. (2023). Data requirements and availabilities for material passports: a digitally enabled framework for improving the circularity of existing buildings. *Sustain Prod. Consum.* 40, 422–437. doi:10.1016/j.spc.2023.07.011

Charef, R. (2022). The use of Building Information Modelling in the circular economy context: several models and a new dimension of BIM (8D). *Clean. Eng. Technol.* 7, 100414. doi:10.1016/j.clet.2022.100414

Charef, R., and Emmitt, S. (2021). Uses of building information modelling for overcoming barriers to a circular economy. *J. Clean. Prod.* 285, 124854. doi:10.1016/j.jclepro.2020.124854

Charef, R., and Lu, W. (2021). Factor dynamics to facilitate circular economy adoption in construction. *J. Clean. Prod.* 319, 128639. doi:10.1016/j.jclepro.2021.128639

Chelliah, V., Thounaojam, N., Devkar, G., and Laishram, B. (2021). "Evaluation of systematic literature reviews in built environment research," in *Secondary research methods in the built environment* (London, United Kingdom: Routledge), 55–68. doi:10.1201/9781003000532-5

Çimen, Ö. (2021). Construction and built environment in circular economy: a comprehensive literature review. *J. Clean. Prod.* 305, 127180. doi:10.1016/j.jclepro.2021.127180

Cruz Rios, F., and Grau, D. (2020). Circular economy in the built environment: designing, deconstructing, and leasing reusable products. *Encycl. Renew. Sustain. Mater.* (1–5), 338–343. doi:10.1016/B978-0-12-803581-8.11494-8

Dams, B., Maskell, D., Shea, A., Allen, S., Driesser, M., Kretschmann, T., et al. (2021). A circular construction evaluation framework to promote designing for disassembly and adaptability. *J. Clean. Prod.* 316, 128122. doi:10.1016/j.jclepro.2021.128122

Denyer, D., and Tranfield, D. (2009). "Denyer-Tranfield-Producing-a-Systematic-Review," in *The sage handbook of organizational research methods*. Editors D. Buchanan, and A. Bryman (London: Sage Publications Ltd.), 671–689.

Di Biccari, C., Abualdenien, J., Borrmann, A., and Corallo, A. (2019). "A BIM-based framework to visually evaluate circularity and life cycle cost of buildings," in *IOP conference series: earth and environmental science* (Prague: Institute of Physics Publishing). doi:10.1088/1755-1315/290/1/012043

Dokter, G., Thuvander, L., and Rahe, U. (2021). How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy. *Sustain Prod. Consum.* 26, 692–708. doi:10.1016/j.spc.2020.12.032

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2011). *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors*. Second. Hoboken, New Jersey: John Wiley and Sons.

Eberhardt, L. C. M., Birgisdottir, H., and Birkved, M. (2019). Potential of circular economy in sustainable buildings. *IOP Conf. Ser. Mater Sci. Eng.* 471, 092051. doi:10.1088/1757-899X/471/9/092051

Ellen MacArthur Foundation (2015a). Growth within: a circular economy vision for a competitive Europe. Available at: https://www.ellenmacarthurfoundation.org/growth-within-a-circular-economy-vision-for-a-competitive-europe (Accessed September 7, 2024).

Ellen MacArthur Foundation (2015b). Towards a circular economy: business rationale for an accelerated transition. Available at: https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition (Accessed August 29, 2023).

Esa, M. R., Halog, A., and Rigamonti, L. (2017). Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *J. Mater Cycles Waste Manag.* 19, 1144–1154. doi:10.1007/s10163-016-0516-x

Favot, M., and Massarutto, A. (2019). Rare-earth elements in the circular economy: the case of yttrium. *J. Environ. Manage* 240, 504–510. doi:10.1016/j.jenvman.2019.04.002

Gallego-Schmid, A., Chen, H. M., Sharmina, M., and Mendoza, J. M. F. (2020). Links between circular economy and climate change mitigation in the built environment. *J. Clean. Prod.* 260, 121115. doi:10.1016/j.jclepro.2020.121115

Ganiyu, S. A., Oyedele, L. O., Akinade, O., Owolabi, H., Akanbi, L., and Gbadamosi, A. (2020). BIM competencies for delivering waste-efficient building projects in a circular economy. *Dev. Built Environ.* 4, 100036. doi:10.1016/j.dibe.2020.100036

Gedam, V. V., Raut, R. D., Lopes de Sousa Jabbour, A. B., Tanksale, A. N., and Narkhede, B. E. (2021). Circular economy practices in a developing economy: barriers to be defeated. *J. Clean. Prod.* 311, 127670. doi:10.1016/j.jclepro.2021.127670

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., and Hultink, E. J. (2017). The Circular Economy – a new sustainability paradigm? *J. Clean. Prod.* 143, 757–768. doi:10.1016/j.jclepro.2016.12.048

Geldermans, R. J. (2016). "Design for change and circularity - accommodating circular material and product flows in construction," in *Energy procedia* (Elsevier Ltd), 301–311. doi:10.1016/j.egypro.2016.09.153

Geng, Y., Jia, F., Sarkis, J., and Xue, B. (2012). Towards a national circular economy indicator system in China: an evaluation and critical analysis. *J. Clean. Prod.* 23, 216–224. doi:10.1016/j.jclepro.2011.07.005

Gerding, D. P., Wamelink, H., and Leclercq, E. M. (2021). Implementing circularity in the construction process: a case study examining the reorganization of multi-actor environment and the decision-making process. *Constr. Manag. Econ.* 39, 617–635. doi:10.1080/01446193.2021.1934885

Ghisellini, P., Ripa, M., and Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *J. Clean. Prod.* 178, 618–643. doi:10.1016/j.jclepro.2017.11.207

Gillott, C., Davison, B., and Densley Tingley, D. (2022). Drivers, barriers and enablers: construction sector views on vertical extensions. *Build. Res. Inf.* 50, 909–923. doi:10.1080/09613218.2022.2087173

Giorgi, S., Lavagna, M., Wang, K., Osmani, M., Liu, G., and Campioli, A. (2022). Drivers and barriers towards circular economy in the building sector: stakeholder interviews and analysis of five european countries policies and practices. *J. Clean. Prod.* 336, 130395. doi:10.1016/j.jclepro.2022.130395

Global Construction Perspectives and Oxford Economics (2015). *Global Construction 2030: a global focus for the construction industry to 2030*. London. Available at: www.globalconstruction2030.com (Accessed September 10, 2024).

Gonçalves, B. de S. M., de Carvalho, F. L., and Fiorini, P. de C. (2022). Circular economy and financial aspects: a systematic review of the literature. *Sustain. Switz.* 14, 3023. doi:10.3390/su14053023

Górecki, J., Núñez-Cacho, P., Corpas-Iglesias, F. A., and Molina, V. (2019). How to convince players in construction market? Strategies for effective implementation of circular economy in construction sector. *Cogent Eng.* 6. doi:10.1080/23311916.2019.1690760

Govindan, K., and Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *Int. J. Prod. Res.* 56, 278–311. doi:10.1080/00207543.2017.1402141

Grafström, J., and Aasma, S. (2021). Breaking circular economy barriers. *J. Clean. Prod.* 292, 126002. doi:10.1016/j.jclepro.2021.126002

Guerra, B. C., and Leite, F. (2021). Circular economy in the construction industry: an overview of United States stakeholders' awareness, major challenges, and enablers. *Resour. Conserv. Recycl* 170, 105617. doi:10.1016/j.resconrec.2021.105617

Guerreschi, A., Piras, L., and Heck, F. (2023). Barriers to efficient knowledge transfer for a holistic circular economy: insights towards green job developments and training for young professionals. *Youth* 3, 553–578. doi:10.3390/youth3020038

Haggège, M., Gauthier, C., and Rüling, C. C. (2017). Business model performance: five key drivers. *J. Bus. Strategy* 38, 6–15. doi:10.1108/JBS-09-2016-0093

Hamida, M. B., Jylhä, T., Remøy, H., and Gruis, V. (2022). Circular building adaptability and its determinants – a literature review. *Int. J. Build. Pathology Adapt.* 41, 47–69. doi:10.1108/IJBPA-11-2021-0150

Hart, J., Adams, K., Giesekam, J., Tingley, D. D., and Pomponi, F. (2019). "Barriers and drivers in a circular economy: the case of the built environment," in *Procedia CIRP* (Elsevier B.V.), 619–624. doi:10.1016/j.procir.2018.12.015

Hjaltadóttir, R. E., and Hild, P. (2021). Circular Economy in the building industry European policy and local practices. *Eur. Plan. Stud.* 29, 2226–2251. doi:10.1080/09654313.2021.1904838

Honic, M., Kovacic, I., and Rechberger, H. (2019a). "Concept for a BIM-based material passport for buildings," in *IOP conference series: earth and environmental science* (Brussels, Belgium: Institute of Physics Publishing). doi:10.1088/1755-1315/225/1/012073

Honic, M., Kovacic, I., and Rechberger, H. (2019b). Improving the recycling potential of buildings through Material Passports (MP): an Austrian case study. *J. Clean. Prod.* 217, 787–797. doi:10.1016/j.jclepro.2019.01.212

Horbach, J., and Rammer, C. (2020). Circular economy innovations, growth and employment at the firm level: empirical evidence from Germany. *J. Ind. Ecol.* 24, 615–625. doi:10.1111/jiec.12977

Hossain, M. U., and Ng, S. T. (2018). Critical consideration of buildings' environmental impact assessment towards adoption of circular economy: an analytical review. *J. Clean. Prod.* 205, 763–780. doi:10.1016/j.jclepro.2018.09.120

Jäger-Roschko, M., and Petersen, M. (2022). Advancing the circular economy through information sharing: a systematic literature review. *J. Clean. Prod.* 369, 133210. doi:10.1016/j.jclepro.2022.133210

Jang, K., Kim, J. W., Ju, K. B., and An, Y. K. (2021). Infrastructure BIM platform for lifecycle management. *Appl. Sci. Switz.* 11, 10310. doi:10.3390/app112110310

Jayasinghe, L. B., and Waldmann, D. (2020). Development of a bim-based web tool as a material and component bank for a sustainable construction industry. *Sustain. Switz.* 12, 1766–1815. doi:10.3390/su12051766

Jin, R., Yuan, H., and Chen, Q. (2019). Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018. *Resour. Conserv. Recycl* 140, 175–188. doi:10.1016/j.resconrec.2018.09.029

Kanters, J. (2018). Design for deconstruction in the design process: state of the art. *Buildings* 8, 150. doi:10.3390/buildings8110150

Kenny, C. (2007). Construction, corruption, and developing countries. Available at: http://econ.worldbank.org.

Khan, R. A. (2008). Advancing and integrating construction education, research and practice., in *First international conference on construction in developing countries (iccidc–I) "advancing and integrating construction education, research and practice"*. Available at: https://www.researchgate.net/publication/283007781_Role_of_Construction_Sector_in_Economic_Growth_Empirical_Evidence_from_Pakistan_Economy (Accessed August 5, 2024).

Kirchherr, J., Reike, D., and Hekkert, M. (2017). Conceptualizing the circular economy: an analysis of 114 definitions. *Resour. Conserv. Recycl* 127, 221–232. doi:10.1016/j.resconrec.2017.09.005

Kirchherr, J., and van Santen, R. (2019). Research on the circular economy: a critique of the field. *Resour. Conserv. Recycl* 151, 104480. doi:10.1016/j.resconrec.2019.104480

Koc, K., Durdyev, S., Tleuken, A., Ekmekcioglu, O., Mbachu, J., and Karaca, F. (2023). Critical success factors for construction industry transition to circular economy: developing countries' perspectives. *Eng. Constr. Archit. Manag.* 31, 4955–4974. doi:10.1108/ECAM-02-2023-0129

Kovacic, I., Honic, M., and Rechberger, H. (2019). "Proof of concept for a BIM-based material passport," in *Advances in informatics and computing in Civil and construction engineering*. Editors I. Mutis, and T. Hartmann (Cham: Springer), 741–747. doi:10.1007/978-3-030-00220-6_89

Leising, E., Quist, J., and Bocken, N. (2018). Circular Economy in the building sector: three cases and a collaboration tool. *J. Clean. Prod.* 176, 976–989. doi:10.1016/j.jclepro.2017.12.010

Levický, M., Fiľa, M., Maroš, M., and Korenková, M. (2022). Barriers to the development of the circular economy in small and medium-sized enterprises in Slovakia. *Entrepreneursh. Sustain. Issues* 9 (5), 76–87. doi:10.9770/jesi.2022.9.3(5)

Linder, M., and Williander, M. (2017). Circular business model innovation: inherent uncertainties. *Bus. Strategy Environ.* 26, 182–196. doi:10.1002/bse.1906

López Ruiz, L. A., Roca Ramón, X., and Gassó Domingo, S. (2020). The circular economy in the construction and demolition waste sector – a review and an integrative model approach. *J. Clean. Prod.* 248, 119238. doi:10.1016/j.jclepro.2019.119238

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resour. Conserv. Recycl* 134, 216–227. doi:10.1016/j.resconrec.2018.01.026

Marino, A., and Pariso, P. (2021). The transition towards to the circular economy: European SMEs' trajectories. *Entrepreneursh. Sustain. Issues* 8 (26), 431–455. doi:10.9770/jesi.2021.8.4(26)

Mesároš, P., and Mandičák, T. (2017). "Exploitation and benefits of BIM in construction project management," in *IOP conference series: materials science and engineering* (Prague: Institute of Physics Publishing). doi:10.1088/1757-899X/245/6/062056

Mhatre, P., Gedam, V., Unnikrishnan, S., and Verma, S. (2021). Circular economy in built environment – literature review and theory development. *J. Build. Eng.* 35, 101995. doi:10.1016/j.jobe.2020.101995

Mhatre, P., Gedam, V. V., Unnikrishnan, S., and Raut, R. D. (2023). Circular economy adoption barriers in built environment-a case of emerging economy. *J. Clean. Prod.* 392, 136201. doi:10.1016/j.jclepro.2023.136201

Minunno, R., O'Grady, T., Morrison, G. M., Gruner, R. L., and Colling, M. (2018). Strategies for applying the circular economy to prefabricated buildings. *Buildings* 8, 125. doi:10.3390/buildings8090125

Moher, D., Tetzlaff, J., Tricco, A. C., Sampson, M., and Altman, D. G. (2007). Epidemiology and reporting characteristics of systematic reviews. *PLoS Med.* 4, e78–e455. doi:10.1371/journal.pmed.0040078

Montiel-Santiago, F. J., Hermoso-Orzáez, M. J., and Terrados-Cepeda, J. (2020). Sustainability and energy efficiency: bim 6d. study of the bim methodology applied to hospital buildings. value of interior lighting and daylight in energy simulation. *Sustain. Switz.* 12, 5731–5829. doi:10.3390/su12145731

Morgan, J., and Mitchell, P. (2015). Employment and the circular economy Job creation in a more resource efficient Britain. Available at: https://green-alliance.org.uk/publication/employment-and-the-circular-economy-job-creation-in-a-more-resource-efficient-britain/(Accessed September 7, 2024).

Moscati, A., Johansson, P., Kebede, R., Pula, A., and Törngren, A. (2023). Information exchange between construction and manufacturing industries to achieve circular economy: a literature review and interviews with Swedish experts. *Buildings* 13, 633. doi:10.3390/buildings13030633

Munaro, M. R., and Tavares, S. F. (2023). A review on barriers, drivers, and stakeholders towards the circular economy: the construction sector perspective. *Clean. Responsible Consum.* 8, 100107. doi:10.1016/j.clrc.2023.100107

Munir, M., Kiviniemi, A., Jones, S. W., and Finnegan, S. (2020). BIM business value for asset owners through effective asset information management. *Facilities* 38, 181–200. doi:10.1108/F-03-2019-0036

Nadazdi, A., Naunovic, Z., and Ivanisevic, N. (2022). Circular economy in construction and demolition waste management in the western balkans: a sustainability assessment framework. *Sustain. Switz.* 14, 871. doi:10.3390/su14020871

Nadeem, A., Wong, A. K. D., Akhanova, G., Azhar, S., and Wong, S. N. (2018). "Application of building information modeling (BIM) in site management—material and progress control," in *Proceedings of the 21st international symposium on advancement of construction management and real estate, 2016* (Springer), 289–297. doi:10.1007/978-981-10-6190-5_26

Ness, D. A., and Xing, K. (2017). Toward a resource-efficient built environment: a literature review and conceptual model. *J. Ind. Ecol.* 21, 572–592. doi:10.1111/jiec.12586

Ngan, S. L., How, B. S., Teng, S. Y., Promentilla, M. A. B., Yatim, P., Er, A. C., et al. (2019). Prioritization of sustainability indicators for promoting the circular economy: the case of developing countries. *Renew. Sustain. Energy Rev.* 111, 314–331. doi:10.1016/j.rser.2019.05.001

Norouzi, M., Chàfer, M., Cabeza, L. F., Jiménez, L., and Boer, D. (2021). Circular economy in the building and construction sector: a scientific evolution analysis. *J. Build. Eng.* 44, 102704. doi:10.1016/j.jobe.2021.102704

Novick, B., Mayston, D., Marcus, S., Barry, R., Fox, G., Betts, B., et al. (2019). Artificial intelligence and machine learning in asset management Background. Available at: https://www.blackrock.com/corporate/literature/whitepaper/viewpoint-artificial-intelligence-machine-learning-asset-management-october-2019.pdf (Accessed September 14, 2024).

Nußholz, J. L. K. (2017). Circular business models: defining a concept and framing an emerging research field. *Sustain. Switz.* 9, 1810. doi:10.3390/su9101810

Oluleye, B. I., Chan, D. W. M., Olawumi, T. O., and Saka, A. B. (2023). Assessment of symmetries and asymmetries on barriers to circular economy adoption in the construction industry towards zero waste: a survey of international experts. *Build. Environ.* 228, 109885. doi:10.1016/j.buildenv.2022.109885

Oluwapelumi, J., Femi Aribisala, A., Yusuf, S. O., and Belgore, U. (2021). The awareness and adoption of artificial intelligence for effective facilities management in the energy sector. *J. Digital Food, Energy and Water Syst.* 2, 1–18. doi:10.36615/digitalfoodenergywatersystems.v2i2.718

Osei-Tutu, S., Ayarkwa, J., Osei-Asibey, D., Nani, G., and Afful, A. E. (2023). Barriers impeding circular economy (CE) uptake in the construction industry. *Smart Sustain. Built Environ.* 12, 892–918. doi:10.1108/SASBE-03-2022-0049

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 372, n71. doi:10.1136/bmj.n71

Pan, W., Gibb, A. G. F., and Dainty, A. R. J. (2007). Perspectives of UK homebuilders on the use of offsite modern methods of construction. *Constr. Manag. Econ.* 25, 183–194. doi:10.1080/01446190600827058

Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K., and Hingorani, K. (2021). Towards a circular economy: an emerging economies context. *J. Bus. Res.* 122, 725–735. doi:10.1016/j.jbusres.2020.05.015

Pedral Sampaio, R., Aguiar Costa, A., and Flores-Colen, I. (2022). A systematic review of artificial intelligence applied to facility management in the building information modeling context and future research directions. *Buildings* 12, 1939. doi:10.3390/buildings12111939

Pedroso, M. F., and Tavares, V. (2024). "Circular economy supporting policies and regulations: the Portuguese case," in *Creating a roadmap towards circularity in the built environment* (Cham: Springer), 277–290. doi:10.1007/978-3-031-45980-1_23

Petrović, E. K., and Thomas, C. A. (2024). Global patterns in construction and demolition waste (C&dw) research: a bibliometric analysis using VOSviewer. *Sustain. Switz.* 16, 1561. doi:10.3390/su16041561

Poirier, E. A., Forgues, D., and Staub-French, S. (2017). Understanding the impact of BIM on collaboration: a Canadian case study. *Build. Res. and Inf.* 45, 681–695. doi:10.1080/09613218.2017.1324724

Pomponi, F., and Moncaster, A. (2017). Circular economy for the built environment: a research framework. *J. Clean. Prod.* 143, 710–718. doi:10.1016/j.jclepro.2016.12.055

Rahla, K. M., Mateus, R., and Bragança, L. (2021). Implementing circular economy strategies in buildings—from theory to practice. *Appl. Syst. Innov.* 4, 26. doi:10.3390/asi4020026

Rahman, M. M. (2014). Barriers of implementing modern methods of construction. *J. Manag. Eng.* 30, 69–77. doi:10.1061/(asce)me.1943-5479.0000173

Rane, N., Choudhary, S., and Rane, J. (2023). Integrating Building Information Modelling (BIM) with ChatGPT, Bard, and similar generative artificial intelligence in the architecture, engineering, and construction industry: applications, a novel framework, challenges, and future scope. *SSRN Electron. J.* doi:10.2139/ssrn.4645601

Reinbold, A., Seppänen, O., Peltokorpi, A., Singh, V., and Dror, E. (2019). "Integrating indoor positioning systems and BIM to improve situational awareness," in *27th annual Conference of the international Group for lean construction, IGLC 2019, (the international group for lean construction)*, 1141–1150. doi:10.24928/2019/0153

Robinson, P., and Lowe, J. (2015). Literature reviews vs systematic reviews. *Aust. N. Z. J. Public Health* 39, 103. doi:10.1111/1753-6405.12393

Saarinen, A., and Aarikka-Stenroos, L. (2023). Financing-related drivers and barriers for circular economy business: developing a conceptual model from a field study. *Circular Econ. Sustain.* 3, 1187–1211. doi:10.1007/s43615-022-00222-5

Salvador, R., Barros, M. V., Luz, L. M. da, Piekarski, C. M., and de Francisco, A. C. (2020). Circular business models: current aspects that influence implementation and unaddressed subjects. *J. Clean. Prod.* 250, 119555. doi:10.1016/j.jclepro.2019.119555

Sanchez, B., Rausch, C., Haas, C., and Hartmann, T. (2021). A framework for BIM-based disassembly models to support reuse of building components. *Resour. Conserv. Recycl* 175, 105825. doi:10.1016/j.resconrec.2021.105825

Sandanayake, M. S. (2022). Environmental impacts of construction in building industry—a review of knowledge advances, gaps and future directions. *Knowledge* 2, 139–156. doi:10.3390/knowledge2010008

Schöggl, J. P., Stumpf, L., and Baumgartner, R. J. (2020). The narrative of sustainability and circular economy - a longitudinal review of two decades of research. *Resour. Conserv. Recycl* 163, 105073. doi:10.1016/j.resconrec.2020.105073

Schroeder, P., Anggraeni, K., and Weber, U. (2019). The relevance of circular economy practices to the sustainable development goals. *J. Ind. Ecol.* 23, 77–95. doi:10.1111/jiec.12732

Senaratne, S., Abhishek, K. C., Perera, S., and Almeida, L. (2021). "Promoting stakeholder collaboration in adopting circular economy principles for sustainable construction," in *Proceedings of the 9th world construction symposium 2021 on reshaping construction: strategic, structural and cultural transformations towards the "next normal* (Colombo: Ceylon Institute of Builders), 471–482. doi:10.31705/WCS.2021.41

Shao, Z., Li, M., Han, C., and Meng, L. (2023). Evolutionary game model of construction enterprises and construction material manufacturers in the construction and demolition waste resource utilization. *Waste Manag. Res.* 41, 477–495. doi:10.1177/0734242X221122548

Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H., and Wang, J. (2021). Enabling a circular economy in the built environment sector through blockchain technology. *J. Clean. Prod.* 294, 126352. doi:10.1016/j.jclepro.2021.126352

Smith, P. (2016). Project cost management with 5D BIM. *Procedia Soc. Behav. Sci.* 226, 193–200. doi:10.1016/j.sbspro.2016.06.179

Smol, M., Kulczycka, J., Henclik, A., Gorazda, K., and Wzorek, Z. (2015). The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy. *J. Clean. Prod.* 95, 45–54. doi:10.1016/j.jclepro.2015.02.051

Sohrabi, C., Franchi, T., Mathew, G., Kerwan, A., Nicola, M., Griffin, M., et al. (2021). PRISMA 2020 statement: what's new and the importance of reporting guidelines. *Int. J. Surg.* 88, 105918. doi:10.1016/j.ijsu.2021.105918

Su, B., Heshmati, A., Geng, Y., and Yu, X. (2013). A review of the circular economy in China: moving from rhetoric to implementation. *J. Clean. Prod.* 42, 215–227. doi:10.1016/j.jclepro.2012.11.020

Sumter, D., de Koning, J., Bakker, C., and Balkenende, R. (2020). Circular economy competencies for design. *Sustain. Switz.* 12, 1561. doi:10.3390/su12041561

Superti, V., Houmani, C., and Binder, C. R. (2021). A systemic framework to categorize Circular Economy interventions: an application to the construction and demolition sector. *Resour. Conserv. Recycl* 173, 105711. doi:10.1016/j.resconrec.2021.105711

Swartz, M. K. (2011). The PRISMA statement: a guideline for systematic reviews and meta-analyses. *J. Pediatr. Health Care* 25, 1–2. doi:10.1016/j.pedhc.2010.09.006

Talla, A., and McIlwaine, S. (2022). Industry 4.0 and the circular economy: using design-stage digital technology to reduce construction waste. *Smart Sustain. Built Environ.* 13, 179–198. doi:10.1108/SASBE-03-2022-0050

Tleuken, A., Torgautov, B., Zhanabayev, A., Turkyilmaz, A., Mustafa, M., and Karaca, F. (2022). "Design for deconstruction and disassembly: barriers, opportunities, and practices in developing economies of central asia," in *Procedia CIRP* (Elsevier B.V.), 15–20. doi:10.1016/j.procir.2022.02.148

United Nations (2015). *Transforming our world: the 2030 agenda for sustainable development*. New York, USA. Available at: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (Accessed August 8, 2024).

United Nations Environment Programme (2022). "2022 global status report for buildings and construction: towards a zero-emission, efficient and resilient buildings and construction sector,". Nairobi. Available at: www.globalabc.org.

Ustinovichius, L., Popov, V., Cepurnaite, J., Vilutienė, T., Samofalov, M., and Miedziałowski, C. (2018). BIM-based process management model for building design and refurbishment. *Archives Civ. Mech. Eng.* 18, 1136–1149. doi:10.1016/j.acme.2018.02.004

Van Den Brink, R., Prins, M., Straub, A., and Ploeger, H. D. (2017). "Finding the right incentives; circular business models for the construction industry," in *Proceedings of the international research conference 2017: shaping tomorrow's built environment*. Available at: http://resolver.tudelft.nl/uuid:f8369093-98ce-4f98-93b4-0c21228da47a (Accessed January 5, 2024).

Velenturf, A. P. M., and Purnell, P. (2021). Principles for a sustainable circular economy. *Sustain Prod. Consum.* 27, 1437–1457. doi:10.1016/j.spc.2021.02.018

Villaschi, F. S., Carvalho, J. P., and Bragança, L. (2022). BIM-based method for the verification of building code compliance. *Appl. Syst. Innov.* 5, 64. doi:10.3390/asi5040064

Wang, H., and Meng, X. (2021). BIM-supported knowledge management: potentials and expectations. *J. Manag. Eng.* 37. doi:10.1061/(asce)me.1943-5479.0000934

Williams, J. (2023). Circular cities: planning for circular development in European cities. *Eur. Plan. Stud.* 31, 14–35. doi:10.1080/09654313.2022.2060707

World Economic Forum (2016). Shaping the future of construction: a breakthrough in mindset and technology. Available at: https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report__.pdf (Accessed March 22, 2024).

World Green Building Council (2023). The circular built environment playbook. Available at: https://worldgbc.org/wp-content/uploads/2023/05/Circular-Built-Environment-Playbook-Report_Final.pdf (Accessed September 6, 2024).

Xiao, Y., and Bhola, J. (2022). Design and optimization of prefabricated building system based on BIM technology. *Int. J. Syst. Assur. Eng. Manag.* 13, 111–120. doi:10.1007/s13198-021-01288-4

Yu, Y., Yazan, D. M., Junjan, V., and Iacob, M. E. (2022). Circular economy in the construction industry: a review of decision support tools based on Information and Communication Technologies. *J. Clean. Prod.* 349, 131335. doi:10.1016/j.jclepro.2022.131335

Zabin, A., González, V. A., Zou, Y., and Amor, R. (2022). Applications of machine learning to BIM: a systematic literature review. *Adv. Eng. Inf.* 51, 101474. doi:10.1016/j.aei.2021.101474

Zhang, F., Chan, A. P. C., Darko, A., Chen, Z., and Li, D. (2022). Integrated applications of building information modeling and artificial intelligence techniques in the AEC/FM industry. *Autom. Constr.* 139, 104289. doi:10.1016/j.autcon.2022.104289

Zhuang, G. L., Shih, S. G., and Wagiri, F. (2023). Circular economy and sustainable development goals: exploring the potentials of reusable modular components in circular economy business model. *J. Clean. Prod.* 414, 137503. doi:10.1016/j.jclepro.2023.137503

Zuofa, T., Ochieng, E. G., and Ode-Ichakpa, I. (2023). An evaluation of determinants influencing the adoption of circular economy principles in Nigerian construction SMEs. *Build. Res. Inf.* 51, 69–84. doi:10.1080/09613218.2022.2142496