frontiers | Frontiers in Built Environment

TYPE Review
PUBLISHED 19 July 2023
DOI 10.3389/fbuil.2023.1239757

OPEN ACCESS

EDITED BY
Assed N. Haddad,
Federal University of Rio de Janeiro, Brazil

REVIEWED BY
Alexander Hollberg,
Chalmers University of Technology, Sweden
Mayara Amario,
Federal University of Rio de Janeiro, Brazil

*CORRESPONDENCE
Eugenia Gasparri,
✉ eugenia.gasparri@sydney.edu.au

RECEIVED 13 June 2023
ACCEPTED 10 July 2023
PUBLISHED 19 July 2023

CITATION
Gasparri E, Arasteh S, Kuru A, Stracchi P and Brambilla A (2023), Circular economy in construction: A systematic review of knowledge gaps towards a novel research framework.
Front. Built Environ. 9:1239757.
doi: 10.3389/fbuil.2023.1239757

Circular economy in construction: A systematic review of knowledge gaps towards a novel research framework

Eugenia Gasparri*, Samaneh Arasteh, Aysu Kuru, Paolo Stracchi and Arianna Brambilla

School of Architecture, Design, and Planning, The University of Sydney, Sydney, NSW, Australia

The current growing interest in the circular economy (CE) offers extensive opportunities to promote the adoption of more sustainable consumption and production practices across industries, which is a top priority in achieving the United Nations' Sustainable Development Goals. The construction sector's shift towards circular models is key to reducing carbon emissions and resource depletion but brings along considerable complexities and challenges, given the industry`s fragmented and conservative nature. Research on CE in construction has been growing exponentially over the past few years, producing a substantial amount of new knowledge in a short time. This study conducted a systematic review to map and synthesise the reported knowledge gaps in the literature. The analysis included forty-one (41) articles published between 2017 and 2022. One hundred fifty-five (155) knowledge gaps were identified and categorised according to seven (7) CE research dimensions—economic, environmental, governmental, methodological, societal, sectoral, and technological—and twenty-six (26) thematic sub-clusters. Findings critically analyse knowledge gaps' frequency of occurrence over time and across dimensions. A new framework for CE implementation is proposed to support critical discussion and identification of future research trajectories towards a systemic transition to a circular economy in the construction sector. The framework identifies three innovation domains: circular product, circular process, and circular platform.

KEYWORDS

systematic review, circular economy, circular research dimensions, innovation framework, multi-disciplinary research, sustainable buildings, resource-efficient construction, carbon neutrality

1 Introduction

Over the past decade, the circular economy (CE) has been promoted across sectors to accelerate the shift towards more sustainable practices worldwide and tackle pressing problems such as climate change, resource depletion, waste and pollution. The CE paradigm proposes to shift from the current "take-make-waste" production and consumption linear patterns to circular ones, where materials and energy are kept in use to minimise waste and create new business value, decoupling economic growth from resource consumption (Perey et al., 2018). This concept has its roots in theories dating back to the 1970 s (Shooshtarian et al., 2021), but only more recently has gained wider attention via the Ellen MacArthur Foundation which describes CE as "an industrial economy that is restorative or regenerative by design".

As largely documented in the literature, the construction industry is responsible for more than one-third of global energy consumption, carbon emissions, resource use, and solid waste production (Shooshtarian et al., 2021; United Nations Environment Programme, 2022, Environment, 2014). Given the industry's significant ecological footprint and environmental impacts, the transition to more sustainable practices becomes a top priority in achieving the UN Sustainable Development Goals (SDGs). Predominantly CE may support SDG 12—sustainable production and consumption, but also SDG 6, SDG 7, SDG 8, SDG 11, and SDG 13, on clean water, affordable and clean energy, economic growth, sustainable cities and climate change respectively (Schroeder et al., 2019; Schöggl et al., 2020).

This has resonated well with the scientific community, leading to the exponential growth of research in CE for the construction sector. A substantial amount of new knowledge has been produced in a relatively short time, which has sometimes resulted in ambiguity, different interpretations or narratives, divergent perspectives, and a lack of common understanding or shared research pathways (Homrich et al., 2018; Merli et al., 2018; Schöggl et al., 2020). Over the past few years, many literature review articles were published in an attempt to consolidate and systematise knowledge, but a substantial need for more definite and shared conceptualisation remains (Reike et al., 2018). Most reviews had focussed on specific sub-fields or narrow research questions. For example, a literature review might examine the barriers to circular business models in a particular industry or investigate the environmental impacts of a specific circular practice. These reviews provide valuable insights within their specific domains, but they often overlook the broader landscape of knowledge gaps in the field. To date, there are no studies that attempts at holistically mapping knowledge gaps in circular economy in construction by systematically examining broadly the existing literature from diverse sub-disciplines and identifying areas where research is limited or lacking.

Drawing upon these premises, this study conducted a systematic literature review (SLR) to identify and synthesise the reported knowledge gaps from previous studies, gain a more comprehensive and organise perspective on collective knowledge, discuss future research trajectories and propose a framework for implementation to accelerate the adoption of CE practices in construction.

Two research questions (RQs) guided the research process:

- **RQ.1:** How has the research on circular economy in the construction sector evolved in recent years?
- **RQ.2:** What are the main reported knowledge gaps (KGs) from previous literature studies to date and how do they inform the future research agenda?

Findings address the two RQs by critically analysing reported KGs in time to gain insights on research advancements, trends and priorities in circular construction over recent years. This literature goes beyond summarizing the existing research and instead aims to identify key research questions that remain unanswered or underexplored across different domains. By addressing these knowledge gaps, researchers can facilitate the development of evidence-based strategies that promote the transition towards a more circular and sustainable economy. A framework for development and future research focus is indeed proposed building upon the literature analysis.

This paper is structured into four main sections: 1. Introduction, 2. Methodology, 3. Results and Discussion, 4. Conclusion.

2 Methodology

A systematic literature review (SLR) is a research method aiming at surveying, identifying, selecting and critically appraising all relevant empirical evidence of a specific topic to answer formulated research questions and provide a complete interpretation of research results (MacKenzie et al., 2012).

SRL generally follows a defined protocol where criteria for identification, screening and inclusion are clearly stated before searching for records.

This study did not register any specific protocol for SRL but used the PRISMA guidelines (http://prisma-statement.org/) as the preferred reference for literature search and data reporting. PRISMA is an evidence-based set of items serving as a common framework for reporting systematic reviews and meta-analyses to assure completeness, transparency and scientific validity of the findings (Moher et al., 2009; Tricco et al., 2018). The PRISMA checklist (when relevant) and the PRISMA flow diagram were used to inform and summarise the search process and its steps, grouped under data collection and data analysis as outlined in the following sections.

2.1 Data collection

Scopus and Web of Science (WoS) were used as the primary research databases to retrieve relevant studies. Given the research objective, aiming at rationalising, consolidating and systematising knowledge to date, the study focussed on published reviews only, where knowledge mapping and research gaps are commonly part of the findings (Hossain and Ng, 2018). The search syntax included then a combination of keywords related to circular economy (CE) and the building or construction sectors, as per the following input string: [(“meta-analy*” OR “meta analy*” OR “meta-analysis*” OR “meta-review*” OR (systematic* W/2 review*) OR (systematic* W/2 map*) OR (evidence W/2 review*) OR (evidence* W/2 map*) OR (scoping W/2 review) OR (rapid W/2 review)) AND (“circular economy” OR “circular design” OR “circularity”) AND (“building sector” OR building* OR “built environment” OR “construction” OR “construction sector”)].

The document types were restricted to peer-reviewed journal articles. Book chapters, conference papers and grey literature are generally excluded from SLR for the less rigorous peer-reviewed process they are subject to (Wuni et al., 2019). Only studies with full text available and written in English were considered. The literature search included papers published after 2016, following the Paris Agreement international treaty on Climate Change adopted by 196 parties at COP 21 on 12 December 2015 (United Nations, 2015).

The main research eligibility criteria are summarised as follows:

- Studies in circular economy and the construction sector;
- Review peer-reviewed journal articles;
- Studies with full text available;
- Studies published in English;
- Studies published between 2016[1] and 2022 (included).

---

[1] No eligible articles were found in 2016. Therefore, the included articles span from 2017 to 2022 (included).

This study adopted a double-step screening process. The first step consisted of reviewing and analysing the titles, keywords and abstracts for exclusion against the above-listed eligibility criteria. As a second step, full texts of the studies deemed potentially relevant were retrieved and thoroughly reviewed in search of reported knowledge gaps. Articles with no reported gaps were excluded from the analysis. At this stage, the articles' reference lists were also scrutinised to identify additional papers that did not come up from the search within the databases search (snowballing).

The literature sampling process is summarised via the PRISMA flow diagram in Figure 1.

2.2 Data analysis

Relevant metadata was extracted from each article, including bibliographic data for descriptive analysis and reported knowledge gaps for content analysis (Vaismoradi et al., 2013). Table 1 presents the list of the included articles with their ID (identification) number, bibliographic reference and publication source.

For the content analysis, the knowledge gaps were mapped, synthesised and categorised according to seven (7) CE dimensions identified in the literature: Economic (Ec), Environmental (En), Governmental (Gv), Methodological (Mt), Societal (Sc), Sectoral (St), and Technological (Tc). These dimensions were determined based on previously developed frameworks and taxonomies found in the literature (Pomponi and Moncaster, 2017; Wuni, 2022b), and implemented by the authors to respond to specific research aims and objectives. Within the CE dimension, authors identified twenty-six (26) thematic sub-clusters that were ranked according to their frequency of occurrence in the literature. This approach allowed us to determine major research trends and the most urgent priorities to accelerate the transition to a circular economy in the construction sector.

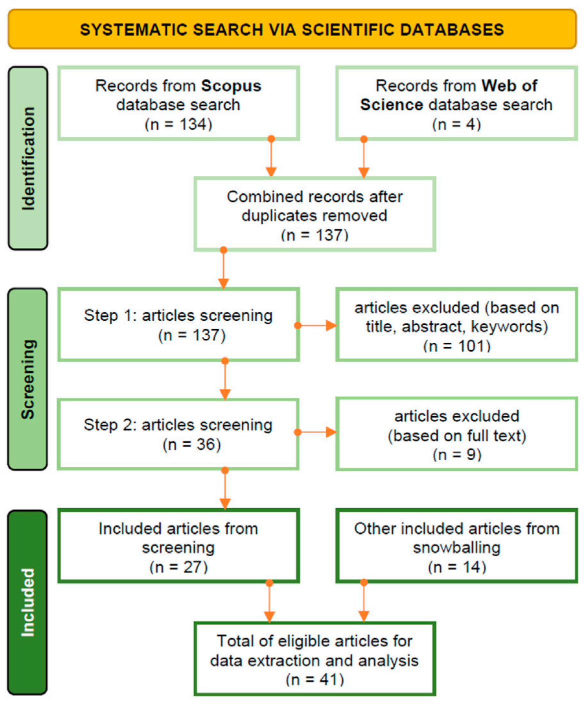


FIGURE 1
PRISMA flow diagram for the literature sampling process.

3 Results and discussion

3.1 Descriptive analysis: characteristics of the eligible studies

The forty-one (41) eligible review articles comprise papers published between 2017 and 2022 (included), while no record was found in 2016. Figure 2 illustrates the annual distribution of review papers, with a steep increase in the past 2 years (2021-2022) when more than 65% of the studies (27/41) were published. This is likely due to the progressive increase in CE research interest following the Paris Agreement in 2015 (United Nations, 2015). The trend seems to suggest a surge in research efforts in the coming year which will bring along the need for further knowledge consolidation and systematisation.

Figure 3 presents the list of journals where the forty-one (41) selected articles were published. Most of the journals are highly diverse and cover domains other than the built environment, suggesting the need for interdisciplinary approaches to CE implementation. The top four (4) journals account for more than 60% of the eligible studies, with the *Journal of Cleaner Production* being the most productive journal and first choice for literature publications on CE in the construction sector, totalling fourteen to forty-one (14/41) articles. The other three major publication venues are the *Journal of Building Engineering* (the only sector-specific one) and *Sustainability* with four (4) articles each, and *Sustainable Production* and *Consumption* with three (3) articles.

3.2 Content analysis: knowledge gaps and future research trajectories

This study identified one hundred fifty-five (155) knowledge gaps reported by forty-one (41) selected articles. As mentioned in the previous section, the knowledge gaps (KGs) extracted were then categorised according to the seven (7) CE research dimensions and twenty-six (26) thematic sub-clusters. The extracted KGs are reported in Supplementary Appendix SA, at the end of this manuscript.

3.2.1 CE dimensions

Table 2 presents a short description of the seven (7) identified CE research dimensions, along with the main keywords used to support the classification of the knowledge gaps across the dimensions, namely, Economic (Ec), Environmental (En), Governmental (Gv), Methodological (Mt), Societal (Sc), Sectoral (St), and Technological (Tc).

It is important to note that some of the extracted knowledge gaps (KGs) were entirely fitting within a single disciplinary domain—ninety-three (93) in total—and therefore attributed to one dimension only. On the contrary, the remaining KGs—sixty-two (62)—referred to themes across disciplines and knowledge domains, being relevant for two or more CE dimensions. For this reason, despite the extracted KGs are one hundred fifty-five (155) in

TABLE 1 IDs and bibliographic data of the included articles.

Paper ID	Reference	Journal
1	Pomponi and Moncaster (2017)	Journal of Cleaner Production
2	Ness and Xing (2017)	Journal of Industrial Ecology
3	Hossain and Ng (2018)	Journal of Cleaner Production
4	Ghisellini et al. (2018)	Journal of Cleaner Production
5	Zvirgzdins et al. (2019)	Procedia CIRP
6	Munaro et al. (2020)	Journal of Cleaner Production
7	Benachio et al. (2020)	Journal of Cleaner Production
8	Cantzler et al. (2020)	Environmental Research Letters
9	Weigend Rodríguez et al. (2020)	Built Environment Project and Asset Management
10	Osobajo et al. (2022)	Smart and Sustainable Built Environment
11	Eberhardt et al. (2022)	Architectural Engineering and Design Management
12	Ogunmakinde et al. (2021)	Clean Technologies and Environmental Policy
13	Hossain et al. (2020)	Renewable and Sustainable Energy Reviews
14	Ruiz et al. (2020)	Journal of Cleaner Production
15	Singh et al. (2021)	Clean technologies and environmental policy
16	Haselsteiner et al. (2021)	Sustainability
17	Wijewickrama et al. (2021)	Journal of Cleaner Production
18	Çimen (2021)	Journal of Cleaner Production
19	Akhimien et al. (2021)	Journal of Building Engineering
20	Mhatre et al. (2021)	Sustainable Production and Consumption
21	Rios et al. (2022)	Sustainable Cities and Society
22	Machado and Morioka (2021)	Journal of Building Engineering
23	Munaro et al. (2021)	Journal of Construction Engineering and Management
24	Munaro and Tavares (2021)	Built Environment Project and Asset Management
25	Díaz-López et al. (2021)	Sustainability
26	Hartwell et al. (2021)	Resources, Conservation and Recycling
27	Norouzi et al. (2021)	Journal of Building Engineering
28	Ahn et al. (2022)	Journal of Building Engineering
29	Yu et al. (2022a)	Resources, Conservation and Recycling
30	Khadim et al. (2022)	Journal of Cleaner Production
31	Yu et al. (2022b)	Journal of Cleaner Production
32	Caldas et al. (2022)	Sustainability
33	Shooshtarian et al. (2022)	Sustainable Production and Consumption
34	Chen et al. (2021)	Journal of Cleaner Production
35	Andersen et al. (2022)	Sustainability
36	Oluleye et al. (2022)	Habitat International
37	Sharma et al. (2022)	Building and Environment
38	Tokazhanov et al. (2022)	Journal of Cleaner Production
39	Wuni (2022a)	Sustainable Production and Consumption
40	Ancapi et al. (2022)	Journal of Cleaner Production
41	Dewagoda et al. (2022)	Journal of Cleaner Production

total, the frequency of occurrence of the KGs across the CE dimensions is two hundred forty-four (244), as multi-dimensional (MD) KGs are counted more than once.

Figure 4 shows the frequency of occurrence of the extracted KGs across each of the CE dimensions in Table 2. The number of KGs extracted per year provides insights into the research progression and trends. For instance, the methodological gaps (Mt) dimension has shown a relatively steady progression across the years. The governamental (Gv) and technological gaps (Tc) seem to have risen considerably over the past couple of years (2021-2022), suggesting a surge in research fervour and interest in these two knowledge domains.

The graph in Figure 4 also presents a breakdown for single-dimensional (SD) and multi-dimensional (MD) KGs, indicating the percentage of KGs classified within a single dimension *versus* the percentage of KGs that sit across multiple dimensions. Percentages are calculated based on the MD/SD KGs numbers indicated in the table below the graph. In general, six out of seven dimensions present more MD KGs than SD ones, suggesting how interdisciplinary research is fundamental in advancing knowledge in CE in the construction sector. This is particularly evident for the environmental (En) and sectoral (St) dimensions where the percentage of MD KGs is respectively 84% and 83%.

The environmental gaps (En), for instance, include the need to rethink sustainability holistically by accounting for social aspects (Sc) or to re-consider the value of construction waste through reusing or upcycling (Ec), or reduce waste altogether by rethinking design practices (Tc), or even understand the effects of the environmental impact across scales and dimensions (Mt).

The sectoral gaps (St) suggest exploring the use of digital technologies to increase transparency and boost efficiency (Tc) or to rethink collaboration models for value co-creation (Ec) and logistics for end-of-life scenarios (Mt), in a way acknowledging fragmentation as the main barrier hindering CE uptake in practice.

Furthermore, a successful CE transition to better practices would require the support of public entities through strategic policy or regulation alignment and incentives; hence the

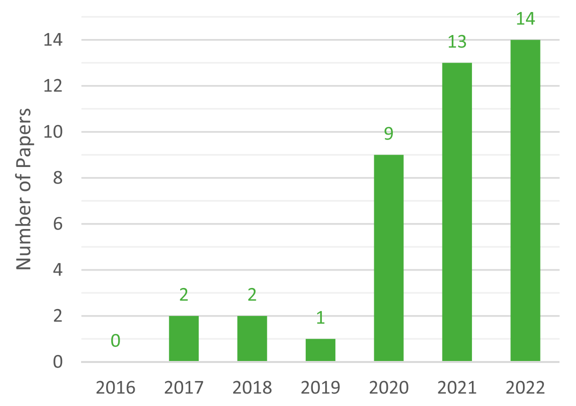


FIGURE 2
Annual distribution of the included studies.

governmental (Gv) gaps dimension follows with 71% of KGs classified as MD.

Figure 5 presents the number of extracted KGs per year (in orange), showing their breakdown across dimensions (in green). The number of papers (NP) increase must also be accounted for in normalising results.

3.2.2 CE dimensions sub-clusters

A second step of analysis consisted of identifying research sub-clusters based on the recurring research themes and topics of the extracted KGs across the seven (7) CE dimensions. Twenty-six (26) thematic sub-clusters were identified and reported in Table 3.

It is important to note that each extracted KG could refer to one or more of the thematic sub-clusters. As an example, a study highlighted the need to explore the adoption of smart materials and blockchain technology to improve process management (Çimen, 2021). This KG refers to both Tc1 "digitalisation" and Tc3 "material/product" sub-clusters in the Technological (Tc) gaps dimension.

Figure 6 illustrates the results provided in Table 3, presenting the frequency of occurrence for each CE dimensions sub-cluster.

The four (4) most recurring themes (in order Tc4 "design," Gv2 "policies/standards," Mt1 "assessment method," Tc1 "digitalisation") across the selected articles account for about 30% of the total and are distributed across three main dimensions (Gv, Mt and Tc). The most recurring KG highlights the need to rethink design practices to maximise CE benefits and uptake across different stages of the lifecycle (Tc4), with 8.9% of frequency. The Tc dimension also includes the fourth-ranked KG, with 6.1% occurrence, which calls for the need for boosting digital tools and technologies used in construction to accelerate the CE uptake (Tc1). The second most cited gap refers to the lack of policies and standards to support the implementation of CE practices (Gv2), with a frequency of 7.5%. Finally, the third-ranked cluster, totalling 6.4%, stresses the importance of implementing holistic assessment methods across CE dimensions and a building's lifecycle stages (Mt1). The two most populated dimensions are in order the technological (Tc) and the methodological (Mt), collecting together almost 50% of the extracted KGs.

The following sections address each of the seven (7) identified dimensions individually and discuss opportunities and future research trajectories to advance the knowledge and accelerate the transition to circular economy practices in construction.

3.2.2.1 Economic gaps

In this section (Ec), three (3) main research priorities were identified and classified according to the following keywords, in

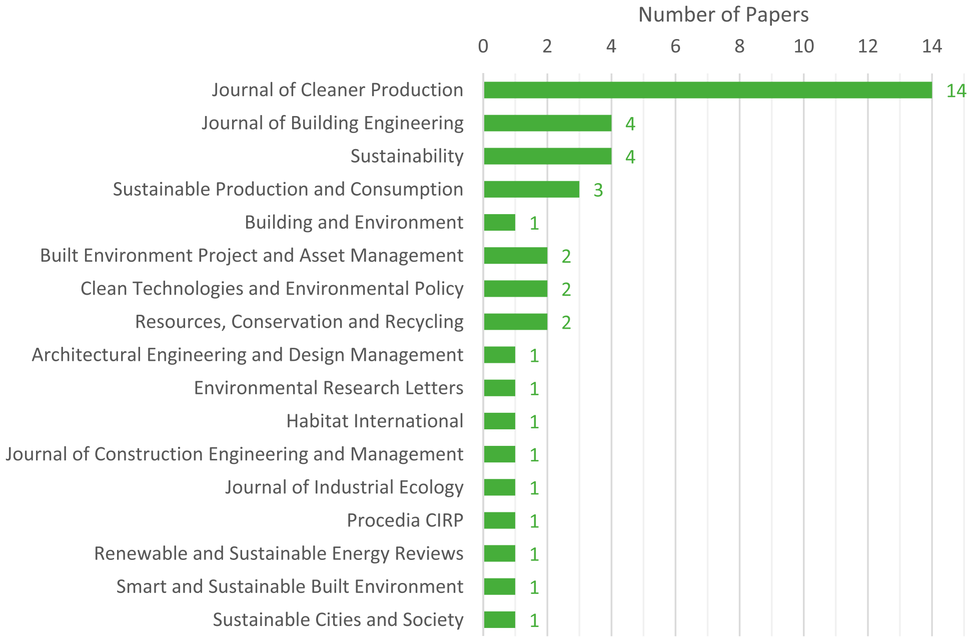


FIGURE 3
Journal distribution of the included studies.

TABLE 2 Research dimensions for knowledge gaps classification.

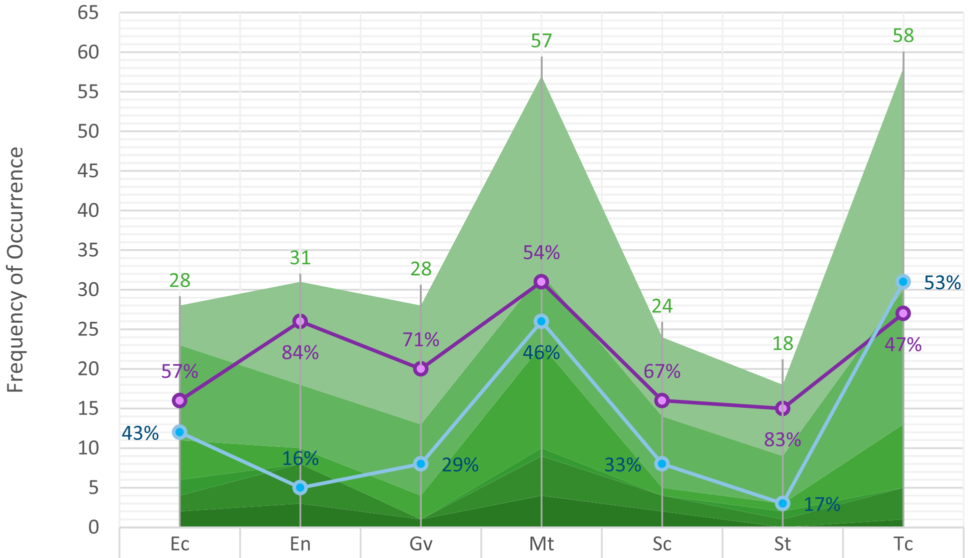
ID	Dimension	Description	Keywords
Ec	ECONOMIC GAPS	refer to the need for rethinking market dynamics, business models and stakeholders' relationships, including the redefinition of ownership and value creation/retention across the entire life cycle of a building and its parts	market*; business*; profit*; cost*; trade*; investment*; business model; econom*; ownership
En	ENVIRONMENTAL GAPS	refer to the need for more sustainable and circular models that can reduce the environmental impact of the building construction sector, including carbon emissions, energy and resource consumption, waste and pollution	resource*; carbon; emissions; pollution; climate; ecolog*; waste; material flow analysis; life cycle analysis; life cycle assessment; greenhouse; energy; water; sustainability
Gv	GOVERNMENTAL GAPS	refer to the need for government support in encouraging and promoting CE practices adoption through economic incentives, new policies and standards and a more agile regulatory and legal framework	polic*; regulat*; guideline*; incentive*; mandate*; tax*; subsid*; law*; government*
Mt	METHODOLOGICAL GAPS	refer to the need for rethinking processes and methods to tackle the sectoral transformation towards CE, including new ways to assess the efficacy of CE adoption and the use of more holistic, integrated, interdisciplinary approaches to design, and new ways to assess the efficacy of CE adoption	framework*; assessment method*; KPI, benchmark*; planning; innovation; approach; integration; case-stud*; application*
St	SECTORAL GAPS	refer to the need for overcoming endemic sector fragmentation by encouraging collaborative models and positive competition among stakeholders, increased transparency, and integrated life cycle approaches	management; supply-chain; logistics; stakeholder*; coordination; collaboration; fragmentation; transparency; value-chain
Sc	SOCIETAL GAPS	refer to the need for people's engagement and participation (both as individuals and as a society) in transitioning to a circular built environment, stressing the importance of education, awareness, perception and behaviour in actioning change	society; justice; fair*; wellbeing; equit*; people; communit*; cultur*; health; educat*; aware*; learn*; decision*; behavi*; attitud*; bias*; trust; perception*; engagement
Tc	TECHNOLOGICAL GAPS	refer to the need for technological advancements in the digital and physical domains to enable circular loops of materials and products, including sector digitisation and new digital platforms, databases and inventories, as well as rethinking design paradigms towards demountable, upgradeable, adaptable buildings	technolog*; digital tool*; internet of things; blockchain; 3D print*; smart; design; DfMA; DfD; component*; assembl*; product*; material*; database

order of frequency: business model (Ec1, 52%), cost or investment (Ec2, 24%), market (Ec3, 24%). The percentage value in brackets is relative to the dimension.

The need for novel circular business models (CBMs) was reported several times across the literature (Benachio et al., 2020; Munaro et al., 2020; Norouzi et al., 2021; Çimen, 2021). Several studies highlighted the importance to learn from the experience of industries other than construction but, at the same time, implementing sector-specific approaches to circularity that could account for all the complexities of the construction sector and business (Mhatre et al., 2021; Munaro et al., 2021; Yu et al., 2022b). There is a need to rethink ownership, for instance, through the adoption of new concepts such as product leasing or product-as-a-service (Hartwell et al., 2021; Çimen, 2021), and promote supply-chain models that foster collaboration among stakeholders and value co-creation (Hossain et al., 2020; Machado and Morioka, 2021). Reshaping collaboration dynamics would necessarily need to be supported by strong demonstrative business cases, able to encourage the uptake of CE practice (Hart et al., 2019). Singh et al. (2021) highlighted the importance of a change in mindset, transitioning from economies of scale to economies of scope, to limit waste associated with mass production favouring product and services diversification which could favour, for instance, secondary materials markets. Some studies focussed particularly on the complexities related to the circulation of materials. Munaro et al. (2021) referred to the need for new CBMs that promote material extended life through maintenance. Ahn et al. (2022) discussed the importance to understand and evaluate the impact of reverse logistics, with a focus on mass timber technologies which could have a central role in meeting sustainability targets.

Another recurring research gap was the need for whole-life cost modelling and assessment that account for resource loops (Osobajo et al., 2022) and enable to verify the economic viability of circular patterns (Pomponi and Moncaster, 2017). Several studies reported the importance of approaching sustainability holistically and; therefore, measuring the economic benefits alongside the environmental and social ones (Ness and Xing, 2017). Future studies should then focus on the systemic adoption of lifecycle sustainability assessment (LCSA) methods, which combine lifecycle assessment (LCA), lifecycle costing (LCC), and social lifecycle assessment (SLCA) (Ghisellini et al., 2018; Hossain and Ng, 2018; Singh et al., 2021) to analyse the environmental impacts, economic performance and social aspects of different processes or products (Heijungs et al., 2010; Ren, 2020).

The third knowledge gap area in this section refers to the need for further investigation of the building stock market dynamics (Chen et al., 2021) and economic barriers to a wider CE market uptake (Díaz-López et al., 2021). Mhatre et al. (2021), for instance, reported on the need to better understand the stakeholders' collaboration opportunities and the associated impacts across different industries. Other studies stressed the importance of



	Ec	En	Gv	Mt	Sc	St	Tc
🟩 2022	5	13	15	25	10	9	28
🟩 2021	12	8	9	9	9	6	17
🟩 2020	5	2	3	13	1	1	8
🟩 2019	2	0	0	1	0	1	0
🟩 2018	2	5	0	5	2	1	4
🟩 2017	2	3	1	4	2	0	1
MD	16	26	20	31	16	15	27
SD	12	5	8	26	8	3	31

FIGURE 4
Knowledge gaps (KGs) breakdown per CE dimension (over time). MD, multi-dimensional KGs; SD, single-dimensional KGs.

regulating the supply-demand market of secondary materials accounting for circular cost-benefit mechanisms across construction lifecycles (Yu et al., 2022a; Yu et al., 2022b), and how this could be supported, for example, via the use of material passports (Munaro and Tavares, 2021).

Wuni (2022a) highlighted the lack of CE-specific economic and market-based instruments (i.e., circular rating systems or circular certificate schemes) to stimulate a shift towards a circular economy.

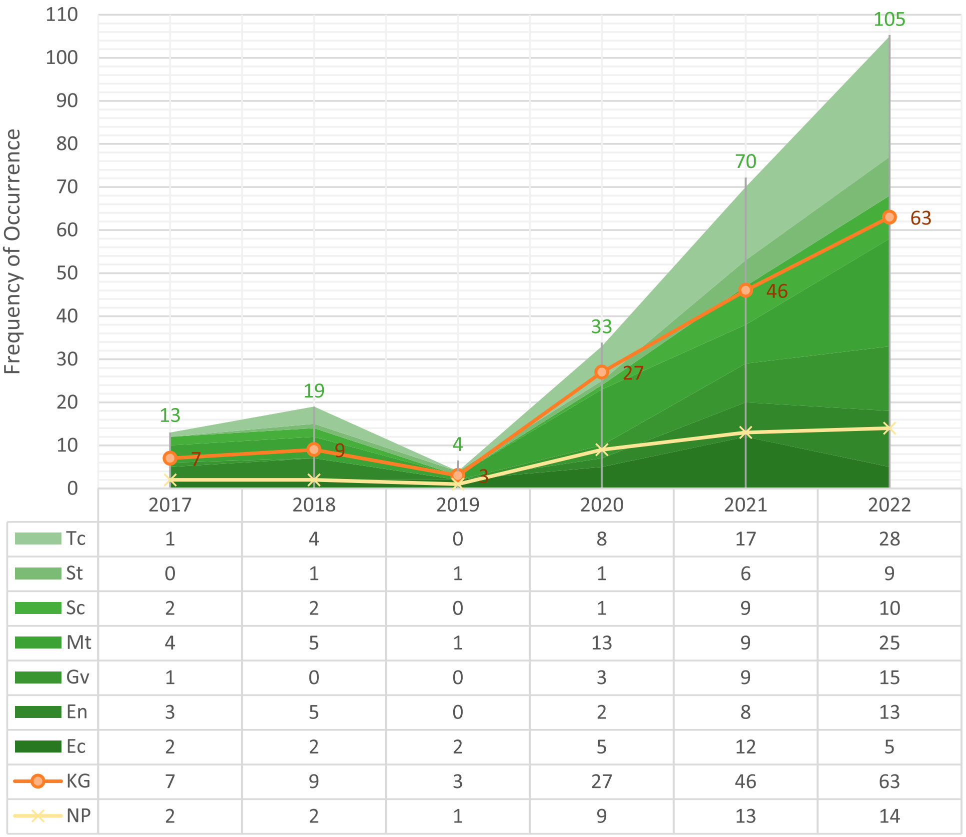
3.2.2.2 Environmental gaps

In this section (En), three (3) main research priorities were identified and classified according to the following keywords, in order of frequency: environmental impact (En2, 41%), waste management (En1, 35%), sustainability (En3, 24%). The percentage in brackets is relative to the dimension.

Several studies highlighted the need for further investigations on the environmental impacts associated with the adoption of CE strategies, including indirect effects and burden-shifting across industries, dimensions (i.e., economical and societal) and construction scales (Cantzler et al., 2020; Andersen et al., 2022; Eberhardt et al., 2022). Future research will need to explore ways to quantify the whole-life impacts holistically and establish a comprehensive framework able to cater for the environmental, economic and social aspects systematically (Ness and Xing, 2017; Ghisellini et al., 2018; Hossain and Ng, 2018; Singh et al., 2021; Ancapi et al., 2022). Hartwell et al. (2021) referred to the importance to regulate and/or implement CE-specific certification schemes. Ness and Xing (2017) suggested a higher emphasis on embodied carbon related to consumption patterns and resource use, while Hossain and Ng (2018) called for more studies on the impacts of non-structural components, which can be considerable.

Hossain and Ng (2018) also focussed on construction and demolition waste (CDW) management—the second most recurring research theme in this section—and the need to include multiple impact categories in building performance assessment, other than just carbon emission or energy consumption (i.e., particulate emissions and potential leaching).

Several studies emphasised the need to explore waste minimisation opportunities across building life stages (i.e., construction, refurbishment, end-of-life), for instance through the adoption of proactive maintenance strategies (Hossain and Ng, 2018; Sharma et al., 2022). It would also be important to better understand the direct impact of both sustainability rating tools and digital technologies in CDW minimisation (Shooshtarian et al., 2022). Finally, there is an urgent need to understand and mitigate barriers (i.e., economic and legal) to sustainable CDW management (Díaz-López et al., 2021; Oluleye et al., 2022), such as the lack of information on building materials end-of-life (Munaro and Tavares, 2021) or the



	2017	2018	2019	2020	2021	2022
Tc	1	4	0	8	17	28
St	0	1	1	1	6	9
Sc	2	2	0	1	9	10
Mt	4	5	1	13	9	25
Gv	1	0	0	3	9	15
En	3	5	0	2	8	13
Ec	2	2	2	5	12	5
KG	7	9	3	27	46	63
NP	2	2	1	9	13	14

FIGURE 5
Knowledge gaps (KGs) breakdown per year (across CE dimensions). NP indicates the Number of Papers.

lack of policy packages to support the shift from waste-centric paradigms towards design-out-waste ones, linking for instance demolition with newly initiated projects in a closed-loop value chain (Yu et al., 2022a; Sharma et al., 2022).

Another knowledge gap area refers to the need for holistic sustainability approaches, leveraging transdisciplinary knowledge (Ancapi et al., 2022), to accelerate the transition to a circular economy. Chen et al. (2021) emphasised the need to incorporate landscape ecology at the urban level, using nature-based solutions for social inclusivity. Haselsteiner et al. (2021) discussed the need for regenerative solutions uptake enabled by novel ad-hoc standards and legislation, simplified bureaucratic procedures, and increased awareness and education.

3.2.2.3 Governmental gaps

In this section (Gv), three (3) main research priorities were identified and classified according to the following keywords in order of frequency: policies/standards (Gv2, 53%), law/regulation (Gv3, 30%), financial incentives (Gv1, 18%). The percentage in brackets is relative to the dimension.

The need for integrated policy packages and standards to promote the CE uptake was widely reported in the literature (Pomponi and Moncaster, 2017; Munaro et al., 2021; Yu et al., 2022a), often alongside the need for higher government support in accelerating transition through regulatory instruments (i.e., building codes, mandatory labelling, etc.), and financial incentives (Hossain et al., 2020; Munaro et al., 2020; Chen et al., 2021; Çimen, 2021; Wuni, 2022a).

Munaro and Tavares (2021), for instance, explained how new policies could help improve recycling targets and life cycle product accountability, while incentives will be particularly useful in encouraging positive customer behaviour. Benachio et al. (2020) emphasised the lack of standard practices for materials reuse, and Ahn et al. (2022) highlight, in particular, the need for standards on mass timber panels reuse and fabrication utilizing salvaged lumber which is currently a barrier to the use of timber in circular projects. Some studies stressed the need for interdisciplinary research investigating CE governance and proposing ICT-based innovative support for policy-making, which would help create streamlined, transparent, collaborative environments for actors at multiple levels (Yu et al., 2022a; Yu et al., 2022b). Ancapi et al. (2022) also called for enhanced theoretical contributions of academia in policy-making processes towards sustainability transitions and radical societal changes.

Lastly, Wuni (2022a) highlighted the need for performance-based regulations (rather than prescriptive) to support innovation in CE for the construction industry.

3.2.2.4 Methodological gaps

In this section (Mt), six (6) main research priorities were identified and classified according to the following keywords, in

TABLE 3 The thematic sub-clusters of CE dimensions for KGs classification.

ID	SUB-CLUSTER	Description	Frequency	Rank
Economic gaps				
Ec1	Business model	define innovative business models for CE transition	15	5
Ec2	Cost/investment	demonstrate successful business cases through the whole life cycle costing	7	17
Ec3	Market	rethink markets to support CE practices across industries and through cycles	7	17
Environmental gaps				
En1	Waste management	define new waste management strategies across the whole value chain	12	9
En2	Environmental impact	cater for CE environmental impacts holistically including indirect effect	14	6
En3	Sustainability	adopt holistic approaches to sustainability including regenerative and social aspects	8	15
Governmental gaps				
Gv1	Financial incentives	boost financial benefits to incentivise the adoption of CE practices	7	17
Gv2	Policies/standards	develop policies and standards to support the implementation of CE practices	21	2
Gv3	Law/regulation	define laws and regulations to promote and facilitate the adoption of CE practices	12	9
Methodological gaps				
Mt1	Assessment method	implement holistic assessment methods across CE dimensions and the building's life cycle stages	18	3
Mt2	KPIs	define wide-ranging KPIs for CE performance evaluation	8	15
Mt3	Integration	promote systemic integration of CE aspects across dimensions and scales	14	6
Mt4	Approach	explore new approaches and strategies to accelerate the CE transition	10	13
Mt5	Framework	develop sector-specific frameworks for CE implementation	7	17
Mt6	Interdisciplinarity	boost interdisciplinary research and collaboration	6	22
Societal gaps				
Sc1	Behaviour	understand the role of people in activating CE transition	5	23
Sc2	Engagement	favour wider stakeholders' engagement	5	23
Sc3	Social benefits	understand direct and indirect social benefits including health and safety	9	14
Sc4	Education	create educational programs and initiatives to increase CE knowledge and awareness	5	23
Sectoral gaps				
St1	Supply-chain	define innovative models for closed-loop supply-chain dynamics	7	17
St2	Logistics	rethink logistics network for industrial symbiosis	4	26
St3	Collaboration	promote new stakeholders' collaboration models for value co-creation	12	9
Technological gaps				
Tc1	Digitalisation	boost the use of digital tools and technologies to accelerate CE uptake	17	4
Tc2	Data/inventories	collect quality data across the building's life cycle stages and build harmonised inventories	12	9
Tc3	Material/product	rethink material production, integration and use to maximise reuse/recycle and limit impacts	13	8
Tc4	Design	rethink design practices to maximise CE benefits and uptake across different life stages	25	1

order of frequency: assessment method (Mt1, 29%), integration (Mt3, 22%), approach (Mt4, 16%), KPIs (Mt2, 13%), framework (Mt5, 11%), interdisciplinarity (Mt6, 10%). The percentage in brackets is relative to the dimension.

The lack of holistic and comprehensive assessment methods, catering for all three sustainability pillars (i.e., environmental, economic and societal) beyond the building lifecycle (i.e., from cradle-to-grave to cradle-to-cradle) was among the most discussed gaps in literature (Ness and Xing, 2017; Ghisellini et al., 2018; Hossain and Ng, 2018; Singh et al., 2021; Andersen et al., 2022). Singh et al. (2021) also highlighted the need for dynamic methods that account for socioeconomic change over time.

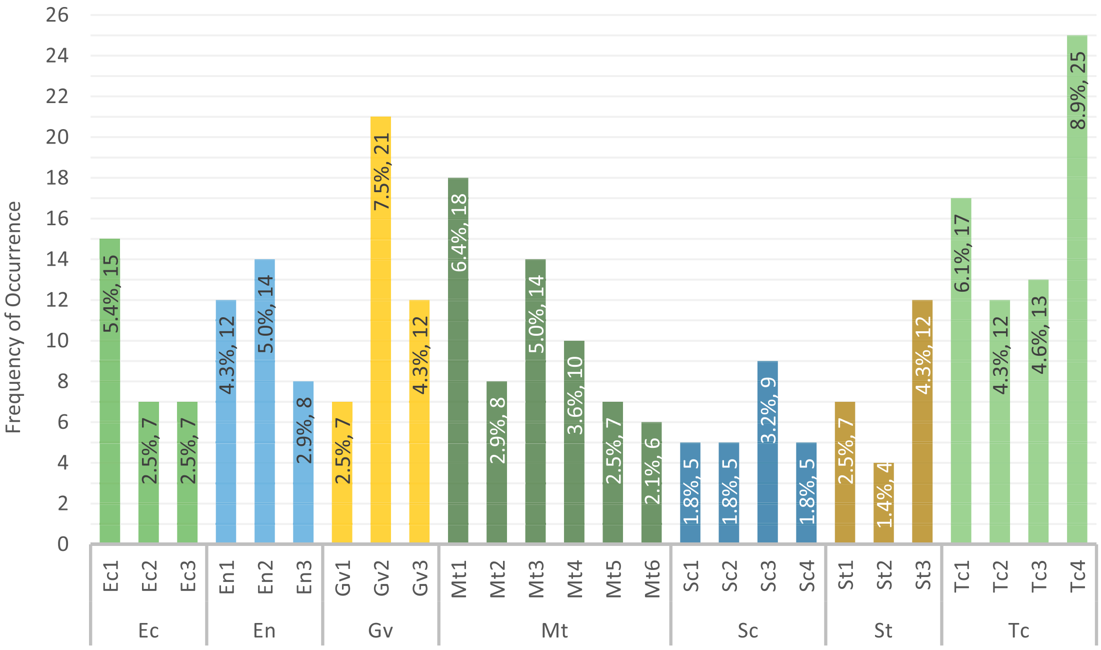


FIGURE 6
Thematic sub-cluster's frequency of occurrence.

Tokazhanov et al. (2022) expressed the importance of cross-industry and cross-disciplinary research to help develop integrated circularity assessment tools for construction projects. Munaro et al. (2020) referred to the need for developing decision-making tools supporting early-design stages. The need for case-by-case context-specific verification methods and validation through case studies was also reported in the literature (Hossain et al., 2020; Ancapi et al., 2022; Wuni, 2022a).

Another identified research gap referred to the need for establishing wide-ranging CE KPIs to quantify the impact and benefits of CE strategies (Hossain and Ng, 2018; Hossain et al., 2020; Ahn et al., 2022; Khadim et al., 2022; Tokazhanov et al., 2022), as well as to understand their relevance and importance case-by-case (Dewagoda et al., 2022).

The lack of integration is the second most cited knowledge gap in this section, as the need for deeper convergence across dimensions (Ec, En, Gv, Sc, St, and Tc), scales (i.e., material, building, city and beyond) or disciplinary fields was mentioned several times (Hossain et al., 2020; Ruiz et al., 2020; Eberhardt et al., 2022; Rios et al., 2022). For instance, Pomponi and Moncaster (2017) suggested further integration between technological and societal challenges to come up with solutions that are well received and/or correctly utilised by the intended users. Other studies discussed the need for new design strategies accounting for complex interrelationships among stakeholders, business processes and construction technologies in circular buildings (Munaro et al., 2021; Yu et al., 2022b).

Several studies emphasised the need for a sector-specific methodological framework that would help implement CE concepts in construction (Ogunmakinde et al., 2021; Khadim et al., 2022; Osobajo et al., 2022), as well as quantifying its performance, benefits and value (Ancapi et al., 2022; Wuni, 2022a).

Finally, a significant increase in interdisciplinary research in CE for the construction sector was noted (Pomponi and Moncaster, 2017; Ancapi et al., 2022; Yu et al., 2022b), and learning for other industries' successful experiences encouraged (Tokazhanov et al., 2022). Oluleye et al. (2022) also highlighted the importance of encouraging joint efforts between public and private organisations, as well as research institutions.

3.2.2.5 Societal gaps

In this section (Sc), four (4) main research priorities were identified and classified according to the following keywords in order of frequency: social benefits (Sc3, 38%), behaviour (Sc1, 21%), engagement (Sc2, 21%), education (Sc4, 21%). The percentage in brackets is relative to the dimension.

The need to focus more on "soft benefits" and social return on investment in circular construction is frequently cited in this section (Chen et al., 2021; Wuni, 2022a). Again, some studies highlighted the need to rethink lifecycle assessment approaches to account for social impacts and quantify social benefits (Ness and Xing, 2017; Ghisellini et al., 2018; Hossain and Ng, 2018; Andersen et al., 2022). Rios et al. (2022) also emphasised the importance of leveraging the societal dimension to encourage the ethical design of CE interventions. Other studies addressed the importance of further investigating CE-related health and safety (H&S) aspects, being them relative to human health benefits to incentivise decision-makers (Çimen, 2021) or, on the contrary, referring to possible H&S hazards connected, for instance, to material reuse and recycling (Osobajo et al., 2022).

The role of people in transitioning to circular built environments is topical (Pomponi and Moncaster, 2017). Some studies discussed the need for a deeper analysis of behavioural factors, and studies on stakeholders' awareness and willingness to implement sustainable CE practices (i.e., use of mass timber) (Ahn et al., 2022; Yu et al., 2022b). Munaro and Tavares

(2021) highlighted the urgency to develop appropriate policies accounting for user behaviour through economic incentives.

Another important area to address would be the need for greater stakeholder engagement, including governments, universities, professional communities and end-users (Wijewickrama et al., 2021; Ancapi et al., 2022; Shooshtarian et al., 2022).

Engagement could be fostered through education (Singh et al., 2021). Various studies emphasised the need to develop training material to educate future professionals (Haselsteiner et al., 2021; Ahn et al., 2022), for instance, regarding the new skills and abilities needed to execute the technical and strategic changes in the design for deconstruction (Munaro and Tavares, 2021).

3.2.2.6 Sectoral gaps

In this section (St), three (3) main research priorities were identified and classified according to the following keywords, in order of frequency: collaboration (St3, 52%), supply-chain (St1, 30%), logistics (St2, 17%). The percentage in brackets is relative to the dimension.

The large majority of research gaps in this section referred to the need for better stakeholders' collaboration models and value chain dynamics, crucial to enable circular innovation and transition in a highly fragmented environment such as the construction sector (Hart et al., 2019; Hossain et al., 2020; Hartwell et al., 2021). There is a need to rethink industry partnerships for value co-creation, for instance through the development of leadership consortia that encourage transparency and knowledge sharing (Hossain and Ng, 2018; Machado and Morioka, 2021; Singh et al., 2021). Wijewickrama et al. (2021) discussed the pivotal role of digital platforms in CE implementation, which will likely see a surge in research interest within the next decade.

Future research will certainly need to explore new supply-chain models that allow for closed-loop value chains, fulfilling the CE paradigm where revenue is generated from otherwise undervalued waste streams (Dev et al., 2020). This can be achieved by linking buildings' end-of-life (i.e., demolition) with newly initiated projects (i.e., design and construction) (Yu et al., 2022a; Yu et al., 2022b), or rethinking ownership together towards building product servitisation (Hartwell et al., 2021).

Chen et al. (2021) also identified great opportunities for future research in logistics network optimisation to allow industrial symbiosis, where waste and by-products from some other industry or industrial process could become raw materials for the construction industry. This would require supply chains' high levels of transparency and data quality, facilitated by the adoption of smart materials, integration of IoT-based tracking systems and blockchain technologies (Chen et al., 2021; Çimen, 2021).

Logistics was another important research gap identified in this section, and the concept of reverse logistics is key to circularity. Ahn et al. (2022), focussing on mass timber, highlighted the importance to account for reverse logistics impact on CE-specific business models. Chen et al. (2021) explained how there are still many uncertainties regarding deconstruction activities logistics, including the storage and transportation of reused and recycled building materials and components.

3.2.2.7 Technological gaps

In this section (Tc), four (4) main research priorities were identified and classified according to the following keywords, in order of frequency: design (Tc4, 37%), digitalisation (Tc1, 25%), material/product (Tc3, 19%), data/inventories (Tc2, 18%). The percentage in brackets is relative to the dimension.

The most recurring technological gap refers to the need for innovative and integrated design strategies to enable circular loops for materials and products. While a lot of effort has so far been placed towards materials' recycling and/or recycled content, there is a need for greater focus on the concepts of rethinking, reducing and reusing[2] as preferred CE-enabling strategies (Cantzler et al., 2020; Hartwell et al., 2021), for instance, through adaptation and resilience (Çimen, 2021). Hartwell et al. (2021) highlighted the need for further research and innovation on design for disassembly (DfD), including a new design that facilitates deconstruction and encourages reuse (i.e., higher standardisation, design redundancies for adaptation, fewer components, reversible connections for deconstruction) but also the development of viable disassembly techniques for existing designs (i.e., adhesive connections and laminated glass). DfD is indeed the key to enabling circular processes; therefore, the deconstruction strategies should be thoughtfully integrated from the early-design stages alongside manufacturing and assembly ones (Munaro and Tavares, 2021; Ahn et al., 2022; Eberhardt et al., 2022). Machado and Morioka (2021) reported on the need to investigate further the contribution of modularity to CE and explore the synergies between product durability and modularity, both theoretically and through practice. Osobajo et al. (2022) discussed the implications and application of circularity in offsite manufacturing processes. Eberhardt et al. (2022) highlighted the need to better understand barriers and drivers to the development of new circular design typologies. Andersen et al. (2022) emphasised the importance to explore circular retrofitting of the existing building stock, still largely untapped.

Lastly, several studies referred to the need for systemic design approaches, shifting from object-centric to system-based practices to cater for the complex interrelationships among technologies, business processes, stakeholders, and applications (Munaro et al., 2021; Yu et al., 2022b; Dewagoda et al., 2022).

Another highly relevant research field refers to the need for increased digitisation and the use of digital tools, technologies and platforms, to enable sectoral transformation and replace resource-intense products and services towards circular built environments (Singh et al., 2021; Wijewickrama et al., 2021). For example, Norouzi et al. (2021) stressed the need for research on Industry 4.0 and smart cities to better understand their contribution to the CE transition. Some referred to the use of ICT-based innovative tools to inform and support policy-making (Yu et al., 2022a; Yu et al., 2022b). The importance of digital integration of circularity is highlighted by many, especially referring to the use of BIM (Building Information Modelling) as a platform for collecting, elaborating and exchanging data (Chen et al., 2021; Munaro et al., 2021; Ahn et al., 2022; Yu et al., 2022b; Caldas et al., 2022; Dewagoda et al., 2022; Khadim et al., 2022). Future studies should also focus on the integration of state-of-the-art technologies (i.e., AR, VR, RFID, IoT, and blockchain), for instance, to enable transparent closed-loop

---

[2] The 9Rs framework by Potting et al. (2017)—https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf

supply chains or advance data management and visualization for end-of-life (EoL) scenarios (i.e., deconstruction) (Chen et al., 2021; Çimen, 2021; Ahn et al., 2022; Caldas et al., 2022).

A third important area to explore refers to construction materials and products. There is a need to better understand the reuse and recycling practices for and impacts on current materials (Hossain and Ng, 2018; Benachio et al., 2020; Ahn et al., 2022), for instance, investigating further possible health and safety-related risks (Osobajo et al., 2022). Ahn et al. (2022) emphasised the need to rethink production for reusability, referring specifically to the use of finishing layers, treatments, and adhesives in mass timber technologies, which considerably reduces the material potential for circular reuse or recycling. Other than existing materials and products, several studies highlighted the importance of exploring the use of alternative sustainable materials (i.e., new bio-based) and smart materials (Norouzi et al., 2021; Çimen, 2021).

Lastly, literature reported a lack of required data (incomplete or commercially sensitive) and standardised, open-source, globally harmonised databases necessary for the implementation of CE in the sector (Singh et al., 2021; Wuni, 2022a; Khadim et al., 2022). Several studies mentioned the need to focus on life cycle inventory data quality (Hossain and Ng, 2018) and create CE-specific material passports including information on materials' EoL stages (Benachio et al., 2020; Munaro and Tavares, 2021). Other studies emphasised the need for integration of CE digital inventories into BIM to support predictive data-driven analytics that looks at EoL scenarios and closed-loop dynamics (Ahn et al., 2022; Yu et al., 2022b).

3.2.3 A novel research framework

Building upon the analysis of the literature, this study proposes a new framework for future research and implementation of Circular Economy (CE) in the construction sector. The framework, in Figure 7, is organised based on three main domains for construction innovation, namely, circular product, circular process, and circular platform. This draws on the understanding that today the binomial product-process construction paradigm does not suffice anymore in capturing the sector complexities and driving change toward concepts of holistic, democratic, and long-term sustainability, balancing between economic, environmental, and social aspects. Sector digitisation and the exploration of new integrated support tools, namely, digital platforms, become strategic in managing product and process complexities toward the transition to more sustainable business operating models.

The gaps identified in the literature informed the development of the proposed novel framework, and the seven (7) CE dimensions (Ec, En, Gv, Mt, Sc, St, and Tc) are mapped accordingly in Figure 7.

Sectoral (St) and Technological (Tc) gaps and sub-clusters were pivotal in the identification of the three construction innovation domains. Indeed, as discussed at length within the previous sections, there is a need to rethink production and consumption patterns and redesign *products* and *processes* to enable circular looping of finite materials and resources (Tc3, Tc4, and St2). Given the complex nature of the construction sector, the use of integrated digital *platforms* (Tc1) is key in managing resources and organisational infrastructures (Tc2, St1) towards circular models of collaboration and value co-creation (St3).

The integration of product, process and platform domains is necessary to enable CE strategies implementation across construction scales and dimensions (Mt3, Mt5) and requires the exploration of multi-disciplinary approaches (Mt4, Mt6) and new holistic assessment (Mt1, Mt2).

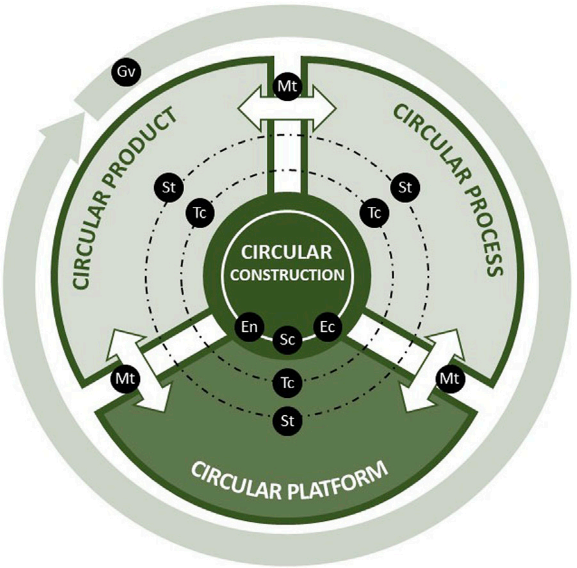


FIGURE 7
Circular economy in the construction sector: a framework for implementation.

Circularity in construction is solidly connected to the three fundamental pillars of sustainability: economic, environmental and social. Shifting from a linear to a circular economy would naturally require: rethinking markets and exploring new business models and practices (Ec1, Ec2, and Ec3); reconsidering environmental impacts holistically and redefining the concept of waste (En1, En2, and En3); understanding implications, influences, impacts and benefits connected to people (Sc1, Sc2, Sc3, and Sc4).

Finally, the role of governments is instrumental in encouraging wider uptake of CE practices through regulation, policies and financial incentives (Gv1, Gv2, and Gv3), and boosting the construction sector's systemic shift towards holistic sustainability.

4 Conclusion

This paper attempted to answer the compelling research question that emerges from the current literature about circular economy in construction. The built environment is among the major contributors to climate change and, whilst the circular economy is proposed and considered a powerful accelerator towards more sustainable practices, its adoption in the construction sector remains slow. This paper undertook a systematic literature review to 1) map and synthesize existing knowledge and 2) identify future research pathways and propose a novel framework that could support the transition towards circular construction practices.

This paper scaffolded upon the previous knowledge to define seven (7) circular economy dimensions, used for the gap mapping. These dimensions have been expanded and specified according to further twenty-six (26) sub-clusters. In total, hundred fifty-five (155) research gaps have been identified, analysed, and mapped.

The analysis highlighted several areas of focus for the development and support of CE in construction, including the adoption of novel circular business models and the need for holistic approaches to sustainability and impact assessment, including social aspects. Among the main barriers, results indicated the lack of CE-specific policy packages and certification schemes to support design-out-waste paradigms and the lack of standard practices for materials reuse. To overcome the barriers, interdisciplinary research, education and training could play an important role. Lastly, it is imperative to rethink design strategies in support of CE implementation at the product and process levels, taking advantage of new digital tools and platforms in managing risks and complexities.

Based on the literature review findings, a novel framework for CE implementation in construction is proposed, aiming at systematising knowledge and guiding the future research agenda in the field. Strong emphasis is placed on the importance of holistic sustainability (economic, environmental, and social) and the central role that governments have in its adoption. The framework identifies three fundamental domains for future systemic research development in CE (circular product, circular process, circular platform) and highlights how digital platforms could provide enormous opportunities in circular transition, serving as a nexus infrastructure between stakeholders, materials and resources, as well as value and performance in time.

4.1 Research limitations

This literature search was limited to Scope and Web of Science. As such, it was not fully comprehensive and relevant publications may have been missed. Grey literature was not directly included, as such, databases available in grey literature could provide additional information, and impact the findings. Only studies published in English were included.

Another important aspect to be kept in mind for this study is that the identified knowledge gaps, classified according to research dimensions and sub-clusters, are not necessarily indicative of the research areas where the least research is conducted. Instead, they could lie within research areas that are more vibrant and mapped than others, and therefore the most knowledge gaps were extracted (i.e., design for circularity).

Author contributions

EG wrote the original manuscript draft, performed data extraction and analysis, and curated datasets, figures and tables. SA, AK, PS and AB contributed to data extraction and analysis, article review and editing. All authors approved the article submitted version.

Funding

This research is funded by the School of Architecture, Design and Planning at the University of Sydney, in alignment with the School Climate Emergency Declaration and the University of Sydney Sustainability Strategy.

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fbuil.2023.1239757/full#supplementary-material

References

Ahn, N., Dodoo, A., Riggio, M., Muszynski, L., Schimleck, L., and Puettmann, M. (2022). Circular economy in mass timber construction: State-of-the-art, gaps and pressing research needs. *J. Build. Eng.* 53, 104562. doi:10.1016/j.jobe.2022.104562

Akhimien, N. G., Latif, E., and Hou, S. S. (2021). Application of circular economy principles in buildings: A systematic review. *J. Build. Eng.* 38, 102041. doi:10.1016/j.jobe.2020.102041

Ancapi, F. B., Van Den Berghe, K., and Van Bueren, E. (2022). The circular built environment toolbox: A systematic literature review of policy instruments. *J. Clean. Prod.* 373, 133918. doi:10.1016/j.jclepro.2022.133918

Andersen, S. C., Birgisdottir, H., and Birkved, M. (2022). Life cycle assessments of circular economy in the built environment—a scoping review. *Sustainability* 14, 6887. doi:10.3390/su14116887

Benachio, G. L. F., Freitas, M. D. 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

Caldas, L. R., Silva, M. V., Silva, V. P., Carvalho, M. T. M., and Toledo Filho, R. D. (2022). How different tools contribute to climate change mitigation in a circular building environment? a systematic literature review. *Sustainability* 14, 3759. doi:10.3390/su14073759

Cantzler, J., Creutzig, F., Ayargarnchanakul, E., Javaid, A., Wong, L., and Haas, W. (2020). Saving resources and the climate? A systematic review of the circular economy and its mitigation potential. *Environ. Res. Lett.* 15, 123001. doi:10.1088/1748-9326/abbeb7

Chen, Q., Feng, H., and De Soto, B. G. (2021). Revamping construction supply chain processes with circular economy strategies: A systematic literature review. *J. Clean. Prod.* 335, 130240. doi:10.1016/j.jclepro.2021.130240

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

Dev, N. K., Shankar, R., and Qaiser, F. H. (2020). Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance. *Resour. Conservation Recycl.* 153, 104583. doi:10.1016/j.resconrec.2019.104583

Dewagoda, K. G., Ng, S. T., and Chen, J. (2022). Driving systematic circular economy implementation in the construction industry: A construction value chain perspective. *J. Clean. Prod.* 381, 135197. doi:10.1016/j.jclepro.2022.135197

Díaz-López, C., Bonoli, A., Martín-Morales, M., and Zamorano, M. (2021). Analysis of the scientific evolution of the circular economy applied to construction and demolition waste. *Sustainability* 13, 9416. doi:10.3390/su13169416

Eberhardt, L. C. M., Birkved, M., and Birgisdottir, H. (2022). Building design and construction strategies for a circular economy. *Archit. Eng. Des. Manag.* 18, 93–113. doi:10.1080/17452007.2020.1781588

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

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. *Procedia Cirp* 80, 619–624. doi:10.1016/j.procir.2018.12.015

Hartwell, R., Macmillan, S., and Overend, M. (2021). Circular economy of façades: Real-world challenges and opportunities. *Resour. Conservation Recycl.* 175, 105827. doi:10.1016/j.resconrec.2021.105827

Haselsteiner, E., Rizvanolli, B. V., Villoria Sáez, P., and Kontovourkis, O. (2021). Drivers and Barriers leading to a successful paradigm shift toward Regenerative neighborhoods. *Sustainability* 13, 5179. doi:10.3390/su13095179

Heijungs, R., Huppes, G., and Guinée, J. B. (2010). Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis. *Polym. Degrad. Stab.* 95, 422–428. doi:10.1016/j.polymdegradstab.2009.11.010

Homrich, A. S., Galvão, G., Abadia, L. G., and Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *J. Clean. Prod.* 175, 525–543. doi:10.1016/j.jclepro.2017.11.064

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

Hossain, M. U., Ng, S. T., Antwi-Afari, P., and Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renew. Sustain. Energy Rev.* 130, 109948. doi:10.1016/j.rser.2020.109948

Khadim, N., Agliata, R., Marino, A., Thaheem, M. J., and Mollo, L. (2022). Critical review of nano and micro-level building circularity indicators and frameworks. *J. Clean. Prod.* 357, 131859. doi:10.1016/j.jclepro.2022.131859

Machado, N., and Morioka, S. N. (2021). Contributions of modularity to the circular economy: A systematic review of literature. *J. Build. Eng.* 44, 103322. doi:10.1016/j.jobe.2021.103322

Mackenzie, H., Dewey, A., Drahota, A., Kilburn, S., Kalra, P., Fogg, C., et al. (2012). Systematic reviews: What they are, why they are important, and how to get involved. *J. Clin. Prev. Cardiol.* 1, 193–202.

Merli, R., Preziosi, M., and Acampora, A. (2018). How do scholars approach the circular economy? A systematic literature review. *J. Clean. Prod.* 178, 703–722. doi:10.1016/j.jclepro.2017.12.112

Mhatre, P., Panchal, R., Singh, A., and Bibyan, S. (2021). A systematic literature review on the circular economy initiatives in the European Union. *Sustain. Prod. Consum.* 26, 187–202. doi:10.1016/j.spc.2020.09.008

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., and PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Ann. Intern. Med.* 151 (4), 264–9. doi:10.7326/0003-4819-151-4-200908180-00135

Munaro, M. R., and Tavares, S. F. (2021). Materials passport's review: Challenges and opportunities toward a circular economy building sector. *Built Environ. Proj. Asset Manag.* 11, 767–782. doi:10.1108/bepam-02-2020-0027

Munaro, M. R., Tavares, S. F., and Bragança, L. (2020). Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *J. Clean. Prod.* 260, 121134. doi:10.1016/j.jclepro.2020.121134

Munaro, M. R., Freitas, M. D. C. D., Tavares, S. F., and Bragança, L. (2021). Circular business models: Current state and framework to achieve sustainable buildings. *J. Constr. Eng. Manag.* 147, 04021164. doi:10.1061/(asce)co.1943-7862.0002184

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

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

Ogunmakinde, O. E., Sher, W., and Egbelakin, T. (2021). Circular economy pillars: A semi-systematic review. *Clean Technol. Environ. Policy* 23, 899–914. doi:10.1007/s10098-020-02012-9

Oluleye, B. I., Chan, D. W., and Olawumi, T. O. (2022). Barriers to circular economy adoption and concomitant implementation strategies in building construction and demolition waste management: A PRISMA and interpretive structural modeling approach. *Habitat Int.* 126, 102615. doi:10.1016/j.habitatint.2022.102615

Osobajo, O. A., Oke, A., Omotayo, T., and Obi, L. I. (2022). A systematic review of circular economy research in the construction industry. *Smart Sustain. Built Environ.* 11, 39–64. doi:10.1108/sasbe-04-2020-0034

Perey, R., Benn, S., Agarwal, R., and Edwards, M. (2018). The place of waste: Changing business value for the circular economy. *Bus. Strategy Environ.* 27, 631–642. doi:10.1002/bse.2068

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

Reike, D., Vermeulen, W. J., and Witjes, S. (2018). The circular economy: New or refurbished as CE 3.0? exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. *Resour. conservation Recycl.* 135, 246–264. doi:10.1016/j.resconrec.2017.08.027

Ren, J. (2020). "Integrated data envelopment analysis, weighting method and life cycle thinking: A quantitative framework for life cycle sustainability improvement," in *Life cycle sustainability assessment for decision-making* (Elsevier).

Rios, F. C., Panic, S., Grau, D., Khanna, V., Zapitelli, J., and Bilec, M. (2022). Exploring circular economies in the built environment from a complex systems perspective: A systematic review and conceptual model at the city scale. *Sustain. Cities Soc.* 80, 103411. doi:10.1016/j.scs.2021.103411

Ruiz, L. A. L., Ramón, X. R., and Domingo, S. G. (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

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. Conservation 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. Industrial Ecol.* 23, 77–95. doi:10.1111/jiec.12732

Sharma, N., Kalbar, P. P., and Muhammad, S. (2022). Global review of circular economy and life cycle thinking in building demolition waste management: A way ahead for India. *Build. Environ.* 222, 109413. doi:10.1016/j.buildenv.2022.109413

Shooshtarian, S., Hosseini, M. R., Kocaturk, T., Ashraf, M., and Arnel, T. (2021). *The Circular Economy in the Australian Built Environment: The State of Play and A Research Agenda*. Geelong, Australia: Faculty of Science, Engineering and Built Environment, Deakin University.

Shooshtarian, S., Maqsood, T., Caldera, S., and Ryley, T. (2022). Transformation towards a circular economy in the Australian construction and demolition waste management system. *Sustain. Prod. Consum.* 30, 89–106. doi:10.1016/j.spc.2021.11.032

Singh, S., Babbitt, C., Gaustad, G., Eckelman, M. J., Gregory, J., Ryen, E., et al. (2021). Thematic exploration of sectoral and cross-cutting challenges to circular economy implementation. *Clean Technol. Environ. policy* 23, 915–936. doi:10.1007/s10098-020-02016-5

Tokazhanov, G., Galiyev, O., Lukyanenko, A., Nauyryzbay, A., Ismagulov, R., Durdyev, S., et al. (2022). Circularity assessment tool development for construction projects in emerging economies. *J. Clean. Prod.* 362, 132293. doi:10.1016/j.jclepro.2022.132293

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., et al. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Ann. Intern. Med.* 169, 467–473. doi:10.7326/m18-0850

United Nations Environment Programme (2022). *Global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector*. Nairobi: UNITED NATIONS ENVIRONMENT PROGRAMME.

UNITED NATIONS (2015). Paris agreement. Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed May 14, 2023).

Vaismoradi, M., Turunen, H., and Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nurs. health Sci.* 15, 398–405. doi:10.1111/nhs.12048

Weigend Rodríguez, R., Pomponi, F., Webster, K., and D'Amico, B. (2020). The future of the circular economy and the circular economy of the future. *Built Environ. Proj. Asset Manag.* 10, 529–546. doi:10.1108/bepam-07-2019-0063

Wijewickrama, M., Rameezdeen, R., and Chileshe, N. (2021). Information brokerage for circular economy in the construction industry: A systematic literature review. *J. Clean. Prod.* 313, 127938. doi:10.1016/j.jclepro.2021.127938

Wuni, I. Y., Shen, G. Q., and Osei-Kyei, R. (2019). Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. *Energy Build.* 190, 69–85. doi:10.1016/j.enbuild.2019.02.010

Wuni, I. Y. (2022a). Burden of proof beyond the triple bottom line: Mapping the benefits of circular construction. *Sustain. Prod. Consum.* 34, 528–540. doi:10.1016/j.spc.2022.10.006

Wuni, I. Y. (2022b). Mapping the barriers to circular economy adoption in the construction industry: A systematic review, pareto analysis, and mitigation strategy map. *Build. Environ.* 223, 109453. doi:10.1016/j.buildenv.2022.109453

Yu, Y., Junjan, V., Yazan, D. M., and Iacob, M.-E. (2022a). A systematic literature review on circular economy implementation in the construction industry: A policy-making perspective. *Resour. Conservation Recycl.* 183, 106359. doi:10.1016/j.resconrec.2022.106359

Yu, Y., Yazan, D. M., Junjan, V., and Iacob, M.-E. (2022b). Circular economy in the construction industry: A review of decision support tools based on information & communication technologies. *J. Clean. Prod.* 349, 131335. doi:10.1016/j.jclepro.2022.131335

Zvirgzdins, J., Plotka, K., and Geipele, S. (2019). "Circular economy in built environment and real estate industry," in Proceedings of the 13th International Conference Modern Building Materials, Structures and Techniques, Vilnius, Lithuania, May 2019, 16–17.