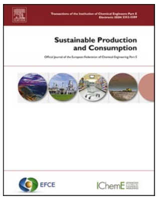
Sustainable Production and Consumption 42 (2023) 196–210

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc



Review Article

Exploring the environmental assessment of circular economy in the construction industry: A scoping review

Santiago Muñoz[a,*], M. Reza Hosseini[a], Robert H. Crawford[b]

[a] Faculty of Science, Engineering and Built Environment, Deakin University, 1 Gheringhap St, VIC, 3220 Geelong, Australia
[b] Melbourne School of Design, The University of Melbourne, Victoria, 3010 Parkville, Australia

ARTICLE INFO

Editor: Prof. K Tsagarakis

Keywords:
Materials flow analysis
Life cycle assessment
Indicators
10R framework
Environmental assessment
Greenhouse gas emissions

ABSTRACT

The literature on the evaluation of environmental performance within the circular economy (CE) domain is notably extensive, encompassing a considerable body of work spanning guidelines, case studies and software tools. Nonetheless, a comprehensive overview that encompasses the entirety of the knowledge landscape in this area remains notably absent. To address this scholarly gap, the present study undertakes a scoping review. Departing from previous inquiries which have predominantly focused on scholarly literature, the study amalgamates diverse knowledge sources. Through a meticulously orchestrated search and analysis process that integrates insights from academic databases and other knowledge reservoirs in the Australian context, a compendium of 249 indicators is delineated. As one of the pioneering endeavours of this nature, this study functions as a contemporary reference, catering to researchers, policy makers and practitioners, while providing multifaceted perspectives on assessing environmental ramifications within CE research. In theoretical terms, this investigation makes an in-depth contribution to the CE field by introducing a methodical and all-encompassing framework, interlinking life cycle phases and system boundaries for environmental evaluation within the CE paradigm. The findings furnish a reliable catalogue of 12 pivotal themes that merit prioritisation in the evaluation of environmental impacts tied to CE strategies. On a practical level, the study yields valuable instruments for researchers, practitioners and policy makers, equipping them with the means to gauge the efficacy of their CE endeavours, thereby facilitating data-driven decision-making processes.

1. Introduction

Globally, the annual extraction of materials amounts to a staggering 100 billion tonnes (Platform for Accelerating the Circular Economy, 2020), while 100 billion tonnes of construction, renovation and demolition waste are also generated (United Nations environment Programme, 2022). Notably, the construction industry is heading towards reaching a one-to-one ratio, wherein the materials extracted for all human activities are matched by the waste produced solely within this sector. These statistics demonstrate the imbalance of materials use and waste within this industry and the importance of the construction industry transitioning from a linear model (based on a 'take-use-dispose approach) to a model informed by circular economy (CE) principles (Kirchherr et al., 2023).

Reduction in environmental impacts is defined as one of the foundational CE aims (Kirchherr et al., 2023). Making connections between the CE concept and environmental assessment, however, has been identified as a conspicuous gap in the existing literature (Balanay and Halog, 2019; Butković et al., 2021). In other words, implementing a CE model does not necessarily result in a more sustainable product or process (Buyle et al., 2019a). In fact, a causal relationship between reducing materials use and improving environmental impacts, such as energy consumption and greenhouse gas (GHG) emissions, cannot always be assumed (Stephan et al., 2020). This distinction is of great significance as existing frameworks do not provide a comprehensive approach to evaluate the CE environmental implications (Australian Circular Economy HUB and EDGE, 2022; Butković et al., 2021). As more established methodologies for adopting CE become available and the adoption of CE moves towards the mainstream, a noticeable gap emerges with suitable methods absent for the assessment of

---

Abbreviations: CE, circular economy; BSI, British Standards Institution; GWP, global warming potential; ISO, International Organization for Standardization; JBI, Joanna Briggs Institute; LCA, life cycle assessment; MFA, materials flow analysis; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

[*] Corresponding author.

E-mail addresses: smunozvela@deakin.edu.au (S. Muñoz), reza.hosseini@deakin.edu.au (M.R. Hosseini), rhcr@unimelb.edu.au (R.H. Crawford).

https://doi.org/10.1016/j.spc.2023.09.022
Received 13 June 2023; Received in revised form 28 September 2023; Accepted 29 September 2023

environmental impacts associated with CE strategies (Balanay and Halog, 2019).

Some reviews have been devoted to CE environmental assessment (Butković et al., 2021; Ghisellini et al., 2018; Munaro et al., 2020). Despite their contribution, these studies have almost entirely excluded the existing grey literature (a term used hereafter when referring to non-academic publications). Non-academic publications have significantly contributed to shaping the current CE concept, as argued by Kirchherr et al. (2023); disregarding these publications may lead to overlooking a substantial portion of the available knowledge on the topic. Furthermore, these studies' findings may not necessarily align with practitioners' priorities and perspectives, further widening the gap between research and practice which will, in turn, impede the consolidation of the concept (Kirchherr et al., 2023). To address this major gap in the CE research field, the present study aims to conduct a replicable literature review that considers both the academic and the grey literature on the environmental impacts of CE adoption.

Within this study's scope, the existing theoretical research is considered to be academic articles, while publications of the empirical world are considered to be grey literature, namely, reports and software tools. The main question of this study is formulated as:

- Which methodologies are currently used to assess the environmental impacts of circular economy adoption?

The main question leads to the following sub-questions:

- What are the related CE overarching guidelines found in the domain — in both the academic and grey literature?
- Which case studies focusing on the environmental assessment of the circular economy are available within the construction industry?
- What software tools are available for evaluating the environmental impact of circular economy strategies and principles — at the material and product levels?
- What are the prioritised environmental assessment indicators in the reviewed literature and software tools?

2. Key concepts

The authors consider that one of the most comprehensive definitions for a CE is the one proposed by Zhai (2020), where the CE is defined as an intentional and purposeful industrial system that prioritises restoration and regeneration in design. Unlike traditional systems with end-of-life concepts, the CE aims to restore resources, employ renewable energy and minimise waste through superior design of materials, products, systems and business models. The CE operates at multiple levels, encompassing products, companies, consumers, eco-industrial parks, cities, regions, nations, etc., with the objective of achieving sustainable development. By enhancing environmental quality, economic prosperity and social equity, the CE seeks to provide benefits to present and future generations.

Indeed, the CE aims to replace the end-of-life concept by using the 10R framework. This framework defines 10 hierarchical strategies that aim to reduce materials use and waste generation (Fig. 1). Ranging from the most effective to the least effective, the 10 strategies are: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover (Potting et al., 2017). Moreover, key strategies are identified in the above CE definition, such as the use of renewable energy and the elimination of toxic materials (Adabre et al., 2023).

In addition, the above definition posits multiple distinct levels of implementation for the CE concept, including the micro level, meso level and macro level. These levels play a crucial role in establishing and fostering the interdependent relationships necessary for successful CE implementation. Indeed, it is imperative for these levels to effectively interact with one another, as relationships across all levels are essential in realising the full potential of the CE paradigm (Zhai, 2020). Lastly, this definition also underscores the fundamental linkage between CE and sustainability, thereby aligning the concept with the three pillars of sustainable development, namely, environmental quality, economic prosperity and social equity. This connection between CE and sustainability has been noted as crucial (Kirchherr et al., 2023), with the risk that CE research that disregards the broader environmental, economic and social implications, will miss the key components of a comprehensive, effective approach to sustainable development (Elghaish et al., 2023; Ghafoor et al., 2023).

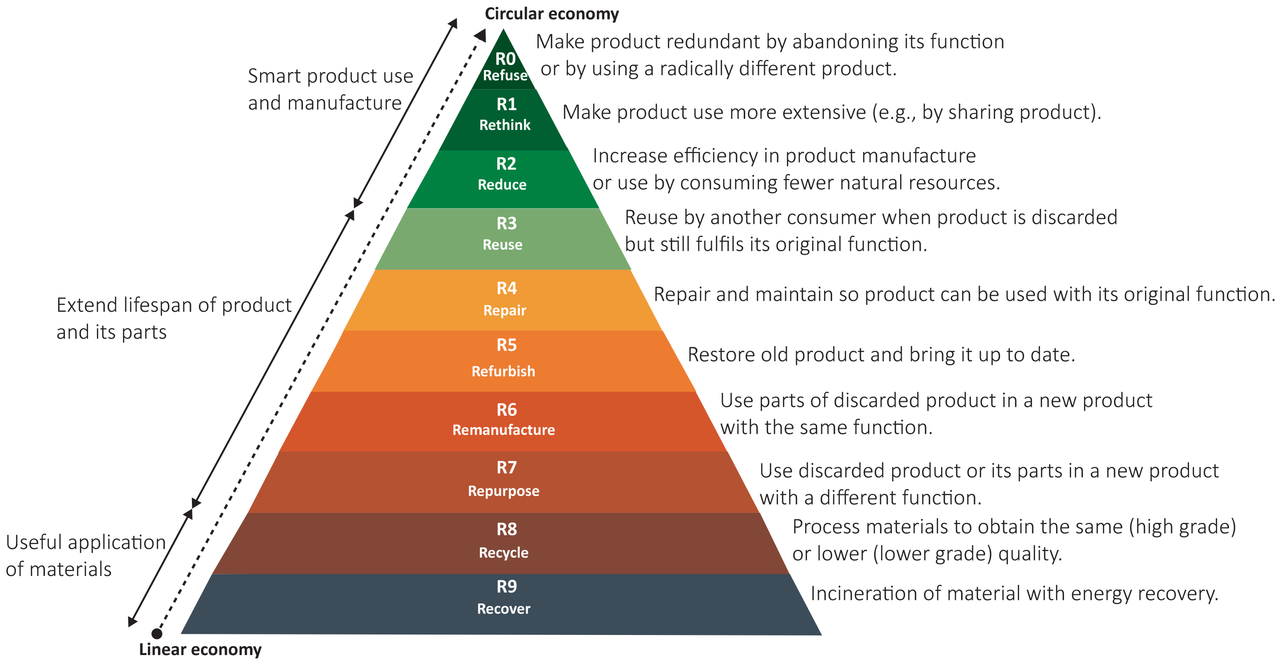


Fig. 1. The 10R framework. Adapted from (Kirchherr et al., 2017).

3. Research design

A scoping review was chosen as the approach for this study. Scoping reviews explore the current state of the literature and inform future research, by mapping and summarising key concepts that underpin any field of research (Arksey and O'Malley, 2005; Tricco et al., 2016). Moreover, scoping reviews follow a systematic method, making them repeatable and verifiable. To provide greater transparency of its results, this study follows the Joanna Briggs Institute (JBI)'s *Manual for Evidence Synthesis*, with the final text verified with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist for scoping reviews (Aromataris and Munn, 2020; Tricco et al., 2018). The filled PRISMA checklist for this review is presented in Table S3.

The scope of this study is depicted in Fig. 2 which outlines three distinct reviews. The first review focuses on overarching guidelines for CE environmental assessment, drawing on both academic and empirical world documents. The second review examines CE environmental assessment case studies within the construction industry, with a focus on academic articles. Finally, the third review explores software tools for CE environmental assessment, with a specific emphasis on materials and products, and relies on grey literature sources. In this context, the term 'overarching guidelines' encompasses a range of standards, frameworks and methodological documents. Additionally, software/tools refer to an "abstract artifact" built by the human mind for a precise purpose (Irmak, 2012). This includes any electronic application or program that performs specific functions, has a user interface and operates on electronic devices.

Likewise, the present study employs a systematic combining approach to effectively integrate current theoretical perspectives with empirical practices (Paré et al., 2015) in the CE field. This approach allows for simultaneous analysis and evolution of the empirical world, theory and case studies, with the ultimate goal of proposing novel theories and frameworks (Dubois and Gadde, 2002). The study involves a comparison of findings from the three reviewed areas to identify key differences and similarities between existing theories and real-world practices. This iterative process, illustrated as 'matching direction and redirection' in Fig. 2, entails data collection, analysis and comparisons between theory, the empirical world and case studies. By integrating these aspects, the aim is to establish a comprehensive understanding that serves as a foundation for developing new theories, as recommended by Dubois and Gadde (2002).

Considering the time and resource constraints, two scope delimitations were established. Firstly, the review of the grey literature was restricted to documents relevant to the Australian context. Hence, overarching guidelines designed for a global scope were reviewed, along with overarching guidelines that were open enough to apply to any country, including Australia. Contrary to this, overarching guidelines specific to other countries were excluded. However, this delimitation does did not apply to software tools, as they are not limited to any country of origin in terms of their applicability. Secondly, all case studies and software tools examined were restricted to the material/product level, which constitutes a part of the micro level within the discussed CE definition. This second delimitation was deemed necessary to address the relative lack of research on this aspect of the CE, as previous studies have typically examined all levels simultaneously (dos Santos Gonçalves and Campos, 2022; Harris et al., 2021) or have prioritised upper levels and business levels (Howard et al., 2019; Mhatre et al., 2021; van Beuren et al., 2021). The delimitation of the material/product level was not applied to overarching guidelines, as only a limited number of guidelines specific to this level were available.

3.1. Search strategy

This study conducts three sets of reviews, as previously discussed and summarised in the PRISMA flow diagram shown in Fig. 3. It's worth noting that the review of CE software tools deviated from the procedural approach followed in the first two reviews. Hence, the steps taken for each of the three reviews are outlined as follows: the initial segment outlines the search strategy employed for overarching guidelines and CE environmental assessment case studies, while the subsequent segment details the search strategy adopted for the review of CE software tools. This structure is maintained throughout the article, where the steps and results for the overarching guidelines are presented first, followed by case studies and, finally, software tools.

3.1.1. Overarching guidelines and CE environmental assessment case studies search strategy

Two widely recognised databases in the field, namely, Scopus and Web of Science, were selected without any limitation on publication dates to ensure comprehensive coverage of the available publications. This resulted in duplications, as many publications are indexed in both databases. Only publications in English were included. These databases were chosen due to their comprehensive coverage of scholarly literature. On 17 October 2022, the search strategy using the following string was implemented, considering the following titles, abstracts and keywords: "Circ*Economy" AND "Construction" OR building*AND "life cycle" AND environment*. The search string was designed to include any type of academic research related to the CE, including overarching guidelines and case studies in the construction industry. The search string also targeted articles that discussed CE from a life cycle perspective and was

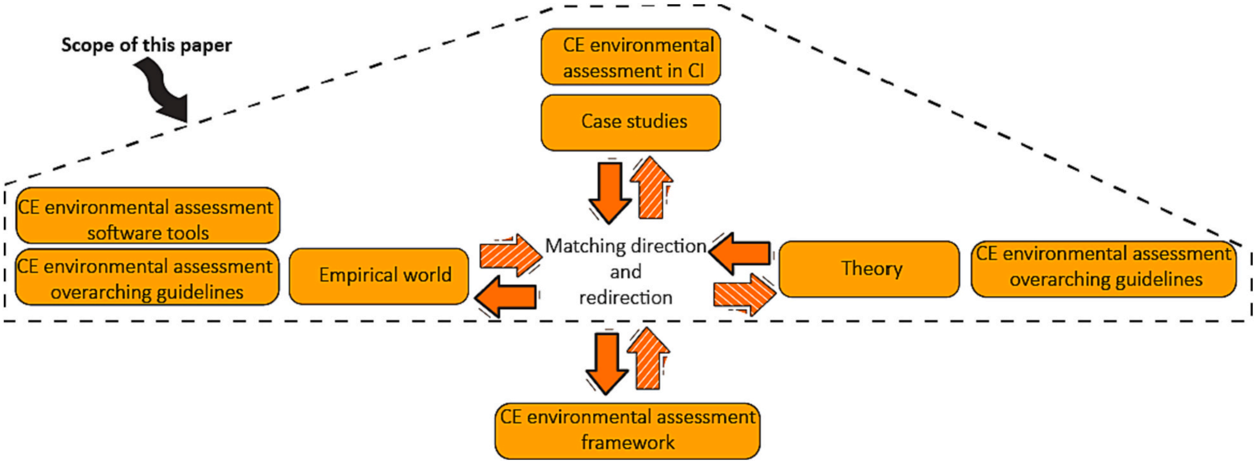


Fig. 2. Systematic combining procedure and study scope. Adapted from (Dubois and Gadde, 2002)
Note: CE = circular economy, CI = construction industry.

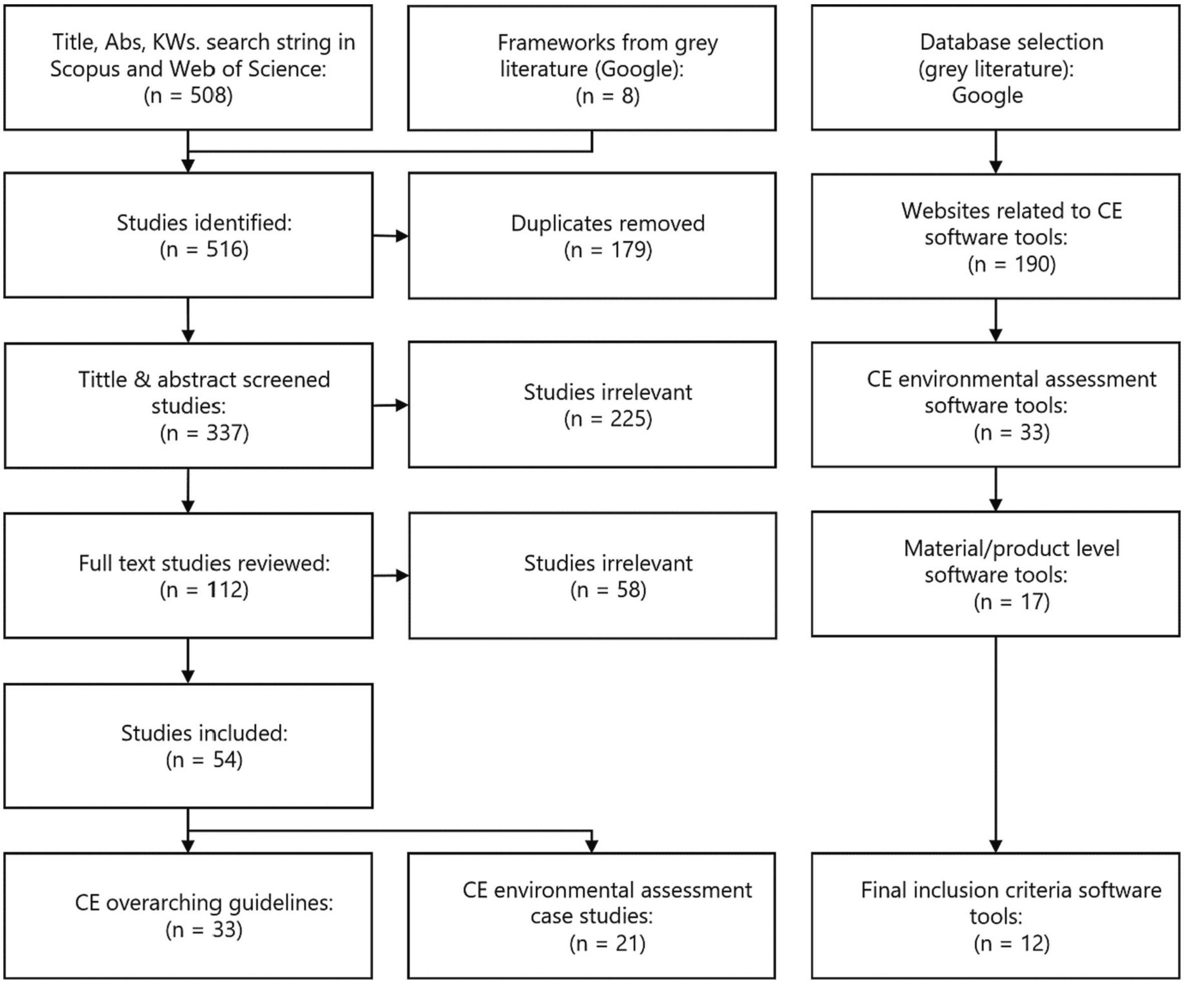


Fig. 3. PRISMA flow diagram.

limited to environmental issues, as social and economic aspects were beyond the scope of this study. The search results were then imported into a reference manager software tool for further screening and analysis.

The second review was based on the grey literature using Google Search. In this review, a series of strings were used to identify overarching guidelines related to CE environmental assessment in the construction industry. Initially, only three overarching guidelines relevant to the construction industry were identified (Dutch Green Building Council, 2021; European Commission, 2021; International Organization for Standardization, 2017). Hence, the scope was broadened in a second series of searches to cover any CE environmental assessment framework relevant to the Australian context, even if it was not oriented to the construction industry. The broadening of scope was necessary to include some of the most common and high-level guidelines that inform practices across various industries, such as the ones proposed by the Ellen MacArthur Foundation and Cradle-to-Cradle Certification (Cradle to Cradle Products Innovation Institute, 2021; Ellen MacArthur Foundation, 2015b). The most recent review update was on 20 December 2022.

3.1.2. *Circular economy environmental assessment software tools search strategy*

Lastly, a review of CE software tools presented in the grey literature was generated. Google Search was selected as the grey literature database which helped include software tools developed by companies and not-for-profit organisations. On 20 June 2022, the following search string was applied: “Circular economy” AND “software” OR “online tool” AND “material” OR “product”, with 190 websites subsequently found. After excluding PDF links, all websites were reviewed. In cases where the website redirected to news, articles or any other text link, the text was thoroughly examined to identify any relevant software tools. The study only considered software tools in the English language that aimed primarily to assess the environmental impact of CE strategies and principles, at the material/product level. Any software tool for which the scope was in doubt proceeded to the next stage. Overall, 33 software tools met the inclusion criteria and advanced to the next stage (the list is presented in Muñoz et al. (2022)).

3.2. *Screening process*

3.2.1. *Overarching guidelines and circular economy environmental assessment case studies screening process*

After conducting a comprehensive search of both academic studies and the grey literature, but excluding software tools, 516 studies were initially identified. After removing duplicates, 337 studies were left for title and abstract screening. Studies were screened based on two criteria: (1) proposing any type of overarching guideline at any level (framework, standard, methodology); (2) generating a CE environmental assessment case study at the material/product level. Studies that did not clearly meet these criteria were further evaluated in the full-text review stage. These studies comprised those that discussed circularity assessment without presenting any particular overarching guideline and those that were devoted to assessments beyond the material/product level, such as case studies at the business level. Of the 112 studies included in the full-text review, 54 complied with the inclusion criteria, while 58 were excluded. Of the 54 relevant studies, 33 focused on CE overarching guidelines while 21 comprised CE environmental assessment case studies.

3.2.2. Circular economy environmental assessment software tools screening process

The search strategy yielded 33 software tools. To categorise these tools based on their CE system level, their websites were reviewed. Of the 33 tools, 13 software tools were designed for use at the business level, with six being administrative tools with plugins or sections with a CE orientation. Three software tools were intended for use in entire buildings, rather than at the product/material level — One Click LCA was a prime example. Software tools aimed at meso or macro levels, as well as those designed for use in entire companies or industries, were excluded. In total, 17 software tools, identified as being at the material/product level, were considered for the next stage of the analysis (see the list in Muñoz et al. (2022)).

4. Results

The results of this review are presented in four sections. The first three sections correspond to the three areas under review, namely: (1) CE overarching guidelines; (2) CE environmental assessment case studies in the construction industry (focusing on academic articles); and (3) CE environmental assessment software tools. In the fourth section, methodologies and indicators used in each of the reviews are discussed to identify the most common approaches in both theoretical and empirical research.

4.1. Circular economy overarching guidelines

Of the 54 relevant studies, 33 pertained to overarching guidelines that proposed a framework, methodology or standard. For each of these guidelines, the authors reviewed the intended level of application, structure, aim and methodologies. The summary of findings is presented in Table S1. In addition, a comprehensive list of indicators proposed in each guideline is provided in Table S2, with this further discussed in Section 5.

The most common structure identified within the academic overarching guidelines was the use of a literature review focused on identifying a gap, with a framework or methodology then proposed. Although, 28 % of articles, apart from their introduction, did not generate a literature review (Andersen and Birkved, 2022; Medina and Fu, 2021; Sandanayake et al., 2022). Moreover, 40 % of the studies generated a narrative literature review, while only 32 % implemented a systematic literature review (e.g., (Abadi et al., 2021; Superti et al., 2021; Taddei et al., 2022).

The grey literature's document structure often defines a table of contents in which the authors describe what will be presented. Usually the introduction, scope of the document, recommendations, and measurement requirements are defined. However, none of these documents stated that their overarching guideline was based on an academic systematic literature review. Instead, grey literature documents are often designed by a group of experts (British Standard Institution, 2017; Cradle to Cradle Products Innovation Institute, 2021; European Commission, 2021).

Fig. 4 presents findings of the environmental assessment methodologies found in overarching guidelines. In total, 30 % did not define a quantitative methodology (British Standard Institution, 2017; Superti et al., 2021; Taddei et al., 2022). Of the overarching guidelines that considered quantitative approaches, materials flow analysis (MFA) and life cycle analysis (LCA) were the two main methodologies identified. Moreover, some overarching guidelines indicated the use of multiple environmental assessment methodologies. Indeed, 18 % of the overarching guidelines proposed the integration of MFA and LCA, or of indicators related to them (Andersen and Birkved, 2022; Hasheminasab et al., 2022; Schützenhofer et al., 2022). Among overarching guidelines that suggested a quantitative methodology, 87 % proposed the use of LCA or indicators related to LCA, while 39 % indicated the use of MFA or MFA-related indicators. Table S1 presents the full list of overarching guidelines found in both the academic and grey literature.

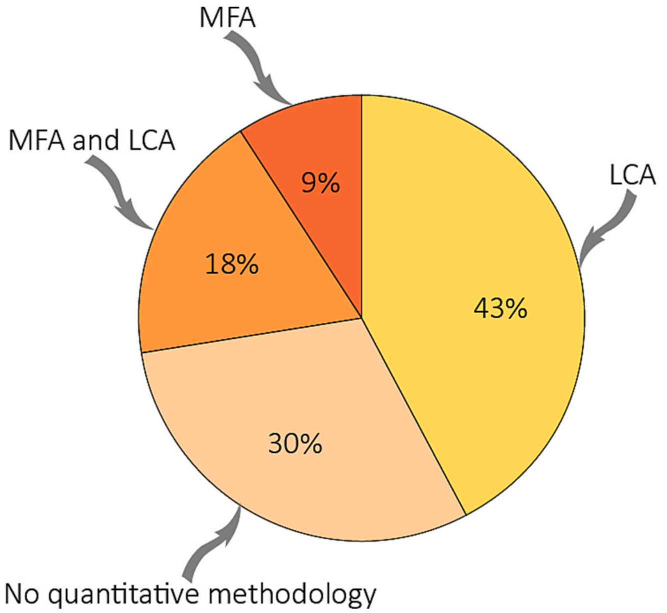


Fig. 4. Environmental assessment methodologies of CE overarching guidelines.

4.2. Circular economy environmental assessment case studies in the construction industry

Through a review of the academic literature, the present study identified 21 case studies that assess the environmental impact of CE practices at the material/product level in the construction industry (CI). The results revealed a scarcity of research on the integration of circular life cycles in construction materials/products (Adams et al., 2017). One of the reasons for the limited research on circular life cycles in construction materials/products is that the CE concept has only recently emerged in the construction industry. Despite the term having been used for several decades, most research in this area has only been conducted in the last decade, indicating a growing interest in the topic (Norouzi et al., 2021). Table 1 presents the relevant case studies described in this section, along with several criteria for each study, including the system boundary, life cycle stages, material/product analysed, indicators used and equations employed to quantify the indicators. Additionally, the methodologies utilised in these studies were reviewed.

Of the case studies identified, the most commonly used environmental assessment methodology was LCA, with all studies incorporating at least one LCA-based indicator. Furthermore, most of the studies examined scenarios that proposed second-life use of materials/products through reusing and recycling strategies. In addition, the environmental benefits of circular scenarios were compared to those of linear scenarios that accounted for the use of virgin resources. Within this comparative framework, 10 case studies (48 %) adopted an open-loop approach, while 10 case studies (48 %) implemented a closed-loop scenario (in which the material was reused for the same purpose in its second life).

The system boundaries in the case studies had two limitations. The first was that studies did not identify their system boundary (Buyle et al., 2019b; Finch and Marriage, 2018; Vitale et al., 2021) in a way that followed the International Organization for Standardization (ISO) standard practices (International Organization for Standardization, 2017). Moreover, as current practices only describe the analysis over

Table 1
Circular economy in construction case studies at material/product level with environmental assessment.

Ref.	Year	System type	Boundary	Material/product	Standard, indicators from
(Bonoli et al., 2020)	2020	Open loop	By-product 2nd production (repurpose)	Steel slag into concrete	Follows ISO 14040 and 14,044 standards. Uses coefficients from databases.
(Ansanelli et al., 2021)	2021	Open loop	End of life (EoL) (recycle) to 2nd production	Photovoltaic (PV) panels glass into concrete	Follows ISO 14040 and 14,044 standards and ReCiPe 2016 midpoint. Use coefficients taken from databases.
(Backes et al., 2022)	2022	Open loop	EoL (recycle) excl (C4)	Concrete	Follows ISO 14040 and 14,044 standards and CML [Center of Environmental Science of Leiden University]2001. Uses coefficients from databases.
(Caldas et al., 2021)	2021	Open loop	EoL (repurpose) to 2nd production excl (C1)	Wood waste into concrete	Follows EN 15978:2011 standard. Uses coefficients from databases.
(Vitale et al., 2021)	2021	Open loop	By-product 2nd production (repurpose)	Carbon fibre into mortar	Follows ISO 14040 and 14,044 standards. Uses coefficients from databases.
(Al-Hamrani et al., 2021)	2021	Open loop	By-product 2nd production (repurpose) to 2nd construction	Excavated boulders into concrete	Follows ISO 14040 and 14,044 standards. Uses coefficients from databases.
(Mostert et al., 2021)	2021	Closed loop	EoL (recycle) to 2nd production	Concrete	Follows EN 15804:2014 standard. Uses coefficients from databases.
(Morsy and Thakeb, 2022)	2022	N/A	EoL (disposal–recycle) to 2nd installation	Geosynthetic mechanically stabilised earth walls	Follows ISO 14040 and 14,044 standards. Uses coefficients from databases.
(Colangelo et al., 2020)	2020	Closed loop	EoL (recycle) to 2nd production	Construction and demolition waste (C&DW) into concrete	Follows IMPACT 2002+ midpoint. Uses coefficients from databases.
(Noparast et al., 2021)	2021	Closed loop	2nd production (recycle)	C&DW into concrete	Uses % of virgin materials and proposes an equation for GHG emissions per unit of product
(Lachat et al., 2021)	2021	Closed loop	EoL (recycle) to 2nd production	C&DW into aggregates	Follows EN 15804:2014 standard. Uses coefficients from databases.
(Rodríguez-Quijano et al., 2015)	2015	Closed loop	EoL (recycle)	Gypsum	Measures materials saved through deconstruction
(Jiménez-Rivero and García-Navarro, 2016)	2016	Closed loop	EoL (recycle) excl (C3)	Gypsum	Uses % of waste sent to landfill and GHG emissions from EoL transport.
(Simon et al., 2019)	2020	Open loop	EoL (recycle) to 2nd production	Glass waste into glass foam	Follows ISO 14040 and 14,044 standards. Uses coefficients from databases.
(Zanni et al., 2018)	2018	Closed loop	2nd production (recycle)	C&DW into concrete	Follows IMPACT 2002+ midpoint methodology. Uses coefficients from databases.
(Niu et al., 2021)	2021	Closed loop	EoL (recycle) to 2nd production excl (C2, A2)	C&D solid wood waste into timber glulam (i.e., glued laminated timber) beams	Follows EN 15804:2012 standard, ReCiPe midpoint V1.13, CML 2001 and International Reference Life Cycle Data System (ILCD) 2.02018. Uses coefficients from databases.
(Da Silva et al., 2021)	2021	Open loop	2nd production (recycle)	Glass waste into foam glass board	Follows ISO 14040 and 14,044 standards. Uses coefficients from databases.
(Finch and Marriage, 2018)	2018	Closed loop	Not clear. Focuses on end-of-life (reuse) to production	Timber frame reuse over multiple cycles	% of material not irreversibly damaged after one complete use cycle
(Peceño et al., 2021)	2021	Open loop	By-product 2nd production (recycle)	Seashell waste used as fireproofing	Follows ISO 14040 and 14,044 standards and ReCiPe 2016 midpoint. Uses coefficients from databases.
(Buyle et al., 2019b)	2019	Closed loop	EoL (reuse and recycle) to 4th production excl (A4,A5, B1,B2,B3, B6, B7)	Internal wall assemblies reuse and recycle scenarios	Follows ISO 14040 and 14,044 standards and ReCiPe v1.13. Uses coefficients from databases.
(Fořt and Černý, 2020)	2020	Open loop	EoL (recycle) to 2nd production	Waste brick into aggregates, cement replacement and alkaline activation	Follows IMPACT 2002+ midpoint and endpoint. Uses coefficients from databases.

Note: For boundary explanation, refer to Section 5.2.1.

one life cycle, the system boundaries defined did not describe the actual analysis undertaken. Indeed, several authors identified their system boundary as cradle-to-gate (A1–A3) (Caldas et al., 2021; Da Silva et al., 2021; Mostert et al., 2021), or cradle-to-grave (A1–C4) (Ansanelli et al., 2021; Morsy and Thakeb, 2022; Peceño et al., 2021). However, when analysing their studies, their system boundaries were more aligned with the use of by-products on a second life cycle, or end-of-life (C1–C4) to beyond system boundaries (D) assessments, where the production, transportation and construction stages of a second life cycle were assessed (A1–A5).

Fig. 5 presents the materials and products analysed in these case studies. Ten case studies (48 %) reviewed concrete products, while glass, gypsum and timber were reviewed in two studies each. Bricks, photovoltaic (PV) panels, earth walls, internal wall assemblies and fireproofing products were only found in one case study. End-of-life materials recycled in new concrete-related materials (replacing virgin aggregates or cement) was the most common end-of-life scenario identified (Backes et al., 2022; Bonoli et al., 2020; Mostert et al., 2021). Indeed, great interest has been found in the replacement of cement with materials such as fly ash and brick powder to reduce the environmental burden of concrete (Le and Bui, 2020; Noparast et al., 2021; Smol et al., 2015). In the study by Al-Hamrani et al. (2021), a different approach was taken in which, instead of sending site-excavated materials to a landfill, they were used on-site to produce cyclopean concrete.

The structure of the case studies reviewed was found to be relatively consistent. Typically, an introduction to the topic was provided, followed by the definition of one or more circular scenarios for comparison with a linear scenario. The intention was to use the circular scenarios to suggest potential savings in materials use and waste in the CE context. To evaluate the environmental implications of each scenario, LCA was commonly implemented. In some instances, studies also considered variations in the materials used, such as the use of recycled mixtures and steel slags in asphalt mixtures, which were evaluated for their physical and mechanical performance (Bonoli et al., 2020).

All studies in this section that conducted an LCA utilised coefficients obtained from databases that were specific to the location of the assessment. Furthermore, the vast majority (72 %) of the reviewed articles stated that they adhered to either the ISO 14040 standard or the European Standard (EN) 15,804 standard for their environmental assessment. A wide variety of indicators were identified across these

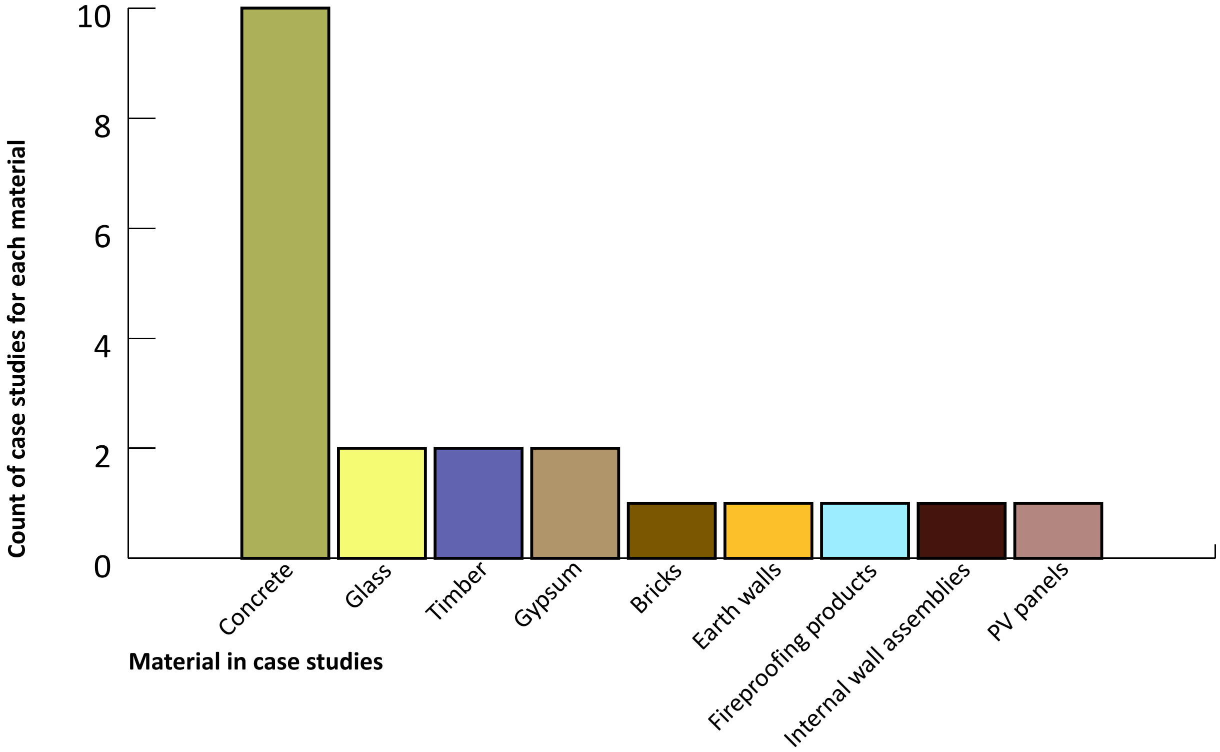


Fig. 5. Materials/products analysed in CE case studies.

case studies, with a total of 55 indicators implemented. The complete list of indicators can be found in Table S2. Fig. 6 displays the top five most frequently used indicators, with global warming potential (GWP) being the most common (found in 95 % of the case studies), followed by ozone depletion (38 %), ionising radiation (28 %), marine aquatic ecotoxicity (28 %) and terrestrial acidification (28 %). Surprisingly, the indicator for materials flows was not among the top five most commonly used indicators, although, as previously mentioned, all studies conducted an analysis of circular scenarios against linear ones, suggesting savings in materials use and waste generation. When the identified indicators were categorised by topic, 95 % of the studies related to greenhouse gas (GHG) emissions, 62 % to materials use or waste generation, while 43 % reported on water-focused indicators and 29 % reported on energy use indicators. Section 4.4 presents further details on the review of indicators against the 12 key topics identified.

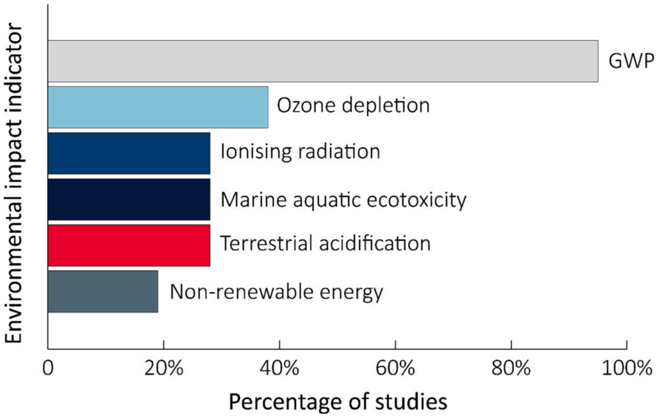


Fig. 6. Most common indicators used in reviewed CE case studies.
Note: GWP = global warming potential.

4.3. *Circular economy environmental assessment software tools at the material/product level*

The grey literature review found 17 software tools related to the environmental performance of CE at the material/product level. The software tools' websites, reports, guidelines and free trial versions (if available) were analysed. The study's inclusion criteria for the software tools were: (1) the software tool's website was publicly available and (2) the primary purpose of the software tool was CE environmental assessment. For instance, software tools for administrative purposes that could be used partially for environmental measurement were not considered. Five software tools did not comply with one or both criteria, reducing the final number to 12 software tools. Table 2 presents the 12 software tools and their access complexity, environmental categories and indicators used, overarching guidelines and standards considered, developer name, required end-user level of expertise and platform support. Key findings related to these previous studies are synthesised below.

All the software tools were developed by companies or not-for-profit organisations, with none created by a single author. Moreover, regarding access complexity, five tools had free-to-use versions, five tools had free trial versions, and only two tools required purchase (circular-IQ.com and KPMG, n.d.; circularise.com, n.d.). In nine of the 12 software tools, the level of expertise was oriented to professionals. However, two were identified as intermediate, while one was applicable to beginners. Furthermore, platform support was focused on dynamic webpages, with seven tools using this platform. Two tools were designed as phone applications, while desktop applications, MS Excel spreadsheets and both desktop and phone applications were found, with one tool for each. Only three software tools clearly stated the overarching guidelines or standards used (circular-IQ.com and KPMG, n.d.; IDEAL&CO Explore BV, n.d.; Sphera, n.d.), with LCA ISO 14040 and ISO 14044 standards often being mentioned. Indeed, within quantitative approaches, the use of LCA and MFA techniques was prevalent. However, no common set of indicators was identified among the tools reviewed.

The uniformity of indicators between software tools was clear. First though, two software tools did not clearly state the indicators

Table 2
Circular economy environmental assessment software tools at the material/product level. Adapted from Muñoz et al. (2022).

Tool name	Developer	Access complexity	Level of expertise	Platform support	Overarching guidelines	Environmental Indicators
CE Analyst	KATCH_e Knowledge Platform	Free to use	I	Dynamic webpage	Not found, but guideline uses EPD as LCA database which is based on ISO14040/14044/14025 standards	Carbon footprint and maximum circular value capture (MCVC)
Circularise	circularise.com	No free trial	P	Desktop and phone app	Not found	Not shared on website
Circularity Calculator	IDEAL&CO Explore BV	Free trial	I	Dynamic webpage	Not found, but one conference article discusses details on how indicators are measured	Four key performance indicators for improving circularity across product generations: circularity, value capture, recycled content, reuse index
CTI Tool	WBCSD, KPMG, circular-IQ.com	Free trial	P	Dynamic webpage	Proposes the circular transition indicators framework	Four categories: close, optimise, value and impact of the loop; 18 indicators across three CE levels
GaBi Circularity Toolkit	Sphera	Free trial	P	Desktop app	ISO 14040/14044, Publicly Available Specification (PAS) 2050 and GHG protocol	MCI score, LCA environmental categories
Idemat	Marinus Meursing Inventions, Patents and Patent Applications	Free to use	B	Phone app	Not found	Resource depletion, ecotoxicity, human health, carbon footprint, eco-cost
IdematLightLCA	Marinus Meursing Inventions, Patents and Patent Applications	Free to use	P	Phone app	Not found, although it uses SimaPro databases which follow ISO 14044-14,044	End-user can change environmental impact categories; predefined carbon footprint and eco-cost
Material Circularity Indicator (MCI)	Ellen MacArthur Foundation	Free to use	P	MS Excel spreadsheet	Not defined in guideline, but states the importance of using British Standards Institution (BSI), ISO and GHG protocol in calculations	Eight MFA indicators grouped into a single indicator
MI: Product Intelligence	ANSYS Granta, Ellen MacArthur Foundation	Free trial only to CE 100 members	P	Dynamic webpage	Not found	Not shared on website, but mentions a "product circularity indicator"
PIQET	PIQET	Free trial	P	Dynamic webpage	Not found, but uses Ecoinvent database, which follows ISO14040/14044 standards	16 indicators, including carbon footprint, water footprint, product environmental footprint from the European Union, marine and terrestrial litter, global packaging protocol indicator, renewable content and material circularity index
Circular IQ platform	circular-Q.com, KPMG	No free trial	P	Dynamic webpage	Global Reporting Initiative (GRI), C2C certified, ISO 14040/14044	Same indicators as CTI Tool
Circularity Check	ecopreneur.com, We Sustain	Free to use	P	Dynamic webpage	Not found	Five indicators with no shared equations: circularity design procurement & production, delivery, use, and recovery and sustainability

Note: Level of expertise: P = professional, I=Intermediate, B=Beginner.

implemented (ANSYS Granta and Ellen MacArthur Foundation, n.d.; circularise.com, n.d.) (with these software tools unable to be completely reviewed as they did not have free trial versions). Implementing a qualitative approach, the Circularity Check measured five indicators based on answers obtained through the website's questionnaire (Ecopreneur, 2022). Conversely, when using quantitative approaches, different indicators were proposed. The Circularity Calculator defined four key performance indicators (de Pauw et al., 2021; IDEAL&CO Explore BV, n.d.), while the circular transition indicators (CTI) tool and the circular-IQ platform proposed the website's own framework which considered four categories and 11 indicators (circular-IQ.com and KPMG, n.d.; WBCSD et al., n.d.) PIQET (Packaging Impact Quick Evaluation Tool) used the Ecoinvent database, providing up to 22 indicators. Idemat and IdematLightLCA had predefined assessments for carbon footprints and eco-costs, with IdematLightLCA providing the option for the end-user to include other environmental impact categories for each life cycle stage (Marinus Meursing Inventions, P. a. P. A, 2021a, 2021b). Furthermore, CE Analyst implemented two indicators (KATCH_e Knowledge Platform, n.d.), while the material circularity indicator (MCI) considered eight indicators which were aggregated to produce a single score and general indicator (Ellen MacArthur Foundation, 2015a). The MCI was also used in the GaBi circularity toolkit, which generated the MCI score and LCA impact categories assessment (Sphera, n.d.).

Among the most used indicators, six software tools, representing 50 % of the total, considered the carbon footprint, acknowledging their interest in the mitigation of greenhouse gas (GHG) emissions and reducing climate change (circular-IQ.com and KPMG, n.d.; PIQET, 2017; WBCSD et al., n.d.). Moreover, five of the software tools implemented indicators related to MFA, aiming to close loops, reduce waste and incentivise the use of the 10R strategies (Ellen MacArthur Foundation, 2015a; IDEAL&CO Explore BV, n.d.; Sphera, n.d.). The approaches used with the MFA indicators varied considerably between tools. Hence, the values they presented should not be compared, as each tool measured different MFA aspects. The full list of indicators and equations in the reviewed software tools is presented in Table S2.

4.4. *Circular economy environmental indicators found across the entire scoping review*

The comprehensive list of indicators identified in the three reviews, namely, the CE overarching guidelines; CE environmental assessment case studies in the construction industry (CI); and CE environmental assessment software tools, are presented in Table S2. The indicators were categorised into 12 key topics as illustrated in Table 3. The '10R framework' relates to indicators based on MFA, such as percentages of

Table 3
Most used indicator topics for each review.

Topics	Overarching guidelines		Software tools		Case studies		Overall	
	% indicators covered	Rank	% indicators covered	Rank	% indicators covered	Rank	% indicators covered	Rank
10R framework	21.12 %	1	36.73 %	1	9.26 %	4	22.37 %	**1**
Water	7.45 %	6	12.24 %	3	19.14 %	1	12.94 %	**2**
GWP	12.42 %	2	10.20 %	5	13.58 %	3	12.07 %	**3**
Materials use	5.59 %	8	18.37 %	2	7.41 %	5	10.45 %	**4**
Chemical use/ toxicity	6.21 %	7	0.00 %		17.90 %	2	8.04 %	**5**
Energy	12.42 %	2	6.12 %	6	4.94 %	7	7.83 %	**6**
Waste	8.70 %	5	12.24 %	3	2.47 %	10	7.80 %	**7**
Connections/ disassembly	9.94 %	4	0.00 %		0.00 %		3.31 %	**8**
Ozone layer	1.86 %	12	0.00 %		6.17 %	6	2.68 %	**9**
Land use	2.48 %	10	0.00 %		4.94 %	7	2.47 %	**10**
Lifetime	3.11 %	9	4.08 %	7	0.00 %		2.40 %	**11**
Acidification	2.48 %	10	0.00 %		4.32 %	9	2.27 %	**12**
% Total covered	93.8 %		100.0 %		90.1 %		94.64 %	

materials reuse/recycled/remanufactured/incinerated, renewable content, design for recycling, efficiency in the recycling process, etc. 'Water' relates to indicators that consider impacts on water and water use, such as eutrophication potential, industrial water recycling rate, unrecovered aqueous, water quality, water scarcity, water use, percentage of water circularity, etc. 'Global warming potential (GWP)' relates to indicators that consider the potential for global warming by measuring the GHG emissions generated throughout various life cycle stage boundaries. 'Materials use' is comprised of indicators that consider the inflows in materials flow analysis (MFA), such as circular inflows, critical inflow, linear flow index, resource/abiotic/fossil fuel depletion, virgin materials use, mineral extraction and mineral resource scarcity. 'Chemical use/ toxicity' relates to indicators measuring hazardous waste, human radiation or ecotoxicity. 'Energy' comprises indicators that consider overall energy use, use stage energy use, potential renewable energy use, renewable energy use and non-renewable energy use. 'Waste' relates to indicators that consider the outflows in materials flow analysis 'MFA', including the percentage of materials sent to landfill, percentage of circular outflow, harmless disposal rate, hazardous waste, landfill, materials source output, radioactive waste, waste prevention, mass of unrecoverable waste, etc. 'Connection/disassembly' relates to indicators that consider aspects such as design for adaptability/assembly/disassembly, time for disassembly, connection types, painted surfaces and reversible joints. 'Ozone layer' relates to indicators that measure impacts on the ozone layer (e.g., ozone depletion, ozone formation and ozone depletion potential). 'Land use' comprises indicators that consider land occupation/use intensity, land impact and risk, natural land transformation and urban land occupation. 'Lifetime' relates to indicators that consider the life expectancy of products and their functionality against the industry average. Lastly, 'acidification' relates to indicators that measure the reduction of the PH (i.e., acidity) in both soils and water.

It is worth noting that each indicator could potentially have a relationship with more than one topic. For instance, the freshwater aquatic ecotoxicity indicator relates to both chemical/toxicity and water topics. Thus, to ensure consistency, the percentages reported in this section were based on the final number of data points analysed, rather than the initial number of indicators. The frequency of each indicator across the identified topics was determined for each review, with an overall average computed. Given that case studies represented both theoretical and empirical perspectives, the overall values were calculated based on an average across the three reviews, with equal weight assigned to each. Notably, more than 90 % of the indicators were covered in each of the reviews within the 12 topics presented, resulting in an average coverage of 94.64 %.

In each of the three reviews (i.e., CE overarching guidelines; CE environmental assessment case studies in CI; and CE environmental assessment software tools), a similar allocation of importance for some topics was noticeable in a few instances. For example, the 10R framework was ranked first in the CE overarching guidelines and CE environmental assessment software tools reviews; fourth in the CE environmental assessment case studies in CI review; and first overall, confirming its significance in both the empirical world and theory. In addition, water prevailed in the CE environmental assessment case studies in CI and CE environmental assessment software tools reviews, positioning it at the second overall rank (excluding the indicators that considered water acidification, which would have increased its general rank even further). Global warming potential (GWP) appeared in the top five topics in all three reviews, with a third overall ranking.

On the other hand, some topics were only mentioned in one of the reviews, which placed them in the middle to low rank. Material use was frequently referenced in software tools, placing it in the fourth overall rank, while chemical use/toxicity was highly cited in the case studies, ranking fifth overall. Energy was identified as a key topic in the overarching guidelines, placing it in the sixth overall rank. Waste was frequently mentioned in software tools but was rarely cited in case studies, leaving it in the seventh rank. Connection types/disassembly was a significant topic in the overarching guidelines but was not applied in software tools or case studies, resulting in an eighth overall rank. The final key topics, namely, ozone layer, land use, lifetime and acidification, each covered between 2 % and 3 % of the overall coverage, leaving them to have a similar overall importance despite their ranking differences.

5. Discussion

A timeline based on all the reviews that generated this study's findings is presented in Fig. 7. This timeline presents the key events based on the authors' criteria. However, the search strings had limitations (refer to Sections 3 and 6) which may have omitted relevant events. This section analyses and consolidates the implications of the findings from the three literature reviews: (1) guidelines for environmental assessment in the CE; (2) case studies of environmental assessment in the construction industry (CI); and (3) software tools for environmental assessment in the CE. This discussion highlights research gaps and potential areas for further investigation. A separate section presents the findings from the quantitative environmental indicators.

5.1. Circular economy overarching guidelines

In this literature review, a total of 33 studies with overarching guidelines were identified. Despite limiting the grey literature search to documents that applied to the Australian context, 24 % of the analysed documents were found in the grey literature. This finding highlights the importance of considering the grey literature in future CE reviews. Table S1 presents the aim, structure and quantitative methodology

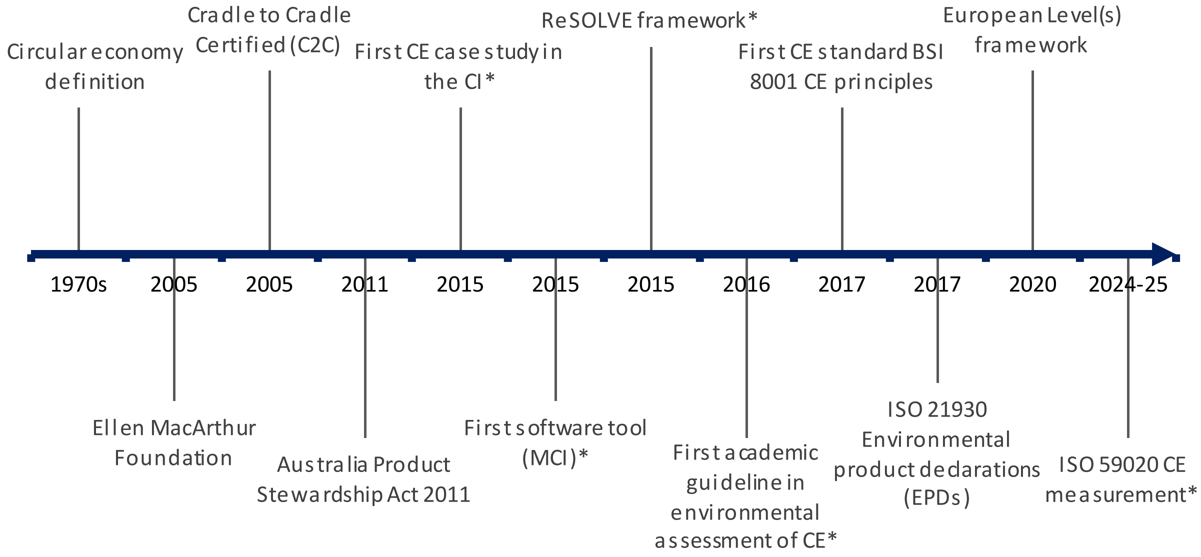


Fig. 7. Key CE events timeline based on scoping review findings.
Note: *estimated dates based on this study's findings; MCI = material circularity indicator tool, ISO 59020 is currently in preview version.

proposed in each overarching guideline, while Table S2 presents the quantitative indicators proposed. These resources are intended to facilitate new research in the field and to encourage a broader implementation of frameworks as needed by each reader. The British Standards Institution (BSI) ISO 59020 is worth mentioning as it is a standard currently under development so it was not included in this study, but it should be considered when its final version is released.

Among the academic studies with overarching guidelines, a literature review followed by proposing a new framework or methodology based on the identified gap was the most common structure. Only 28 % of studies adopted a systematic review approach, leaving the rest of the literature reviews unverifiable. This raises concerns about the reliability and validity of the overarching guidelines, as the preferences of the author (or authors) may introduce bias. Moreover, as the bias of the author (or authors) is often not clearly defined, it can be assumed that few studies have implemented strategies to minimise them. Grey

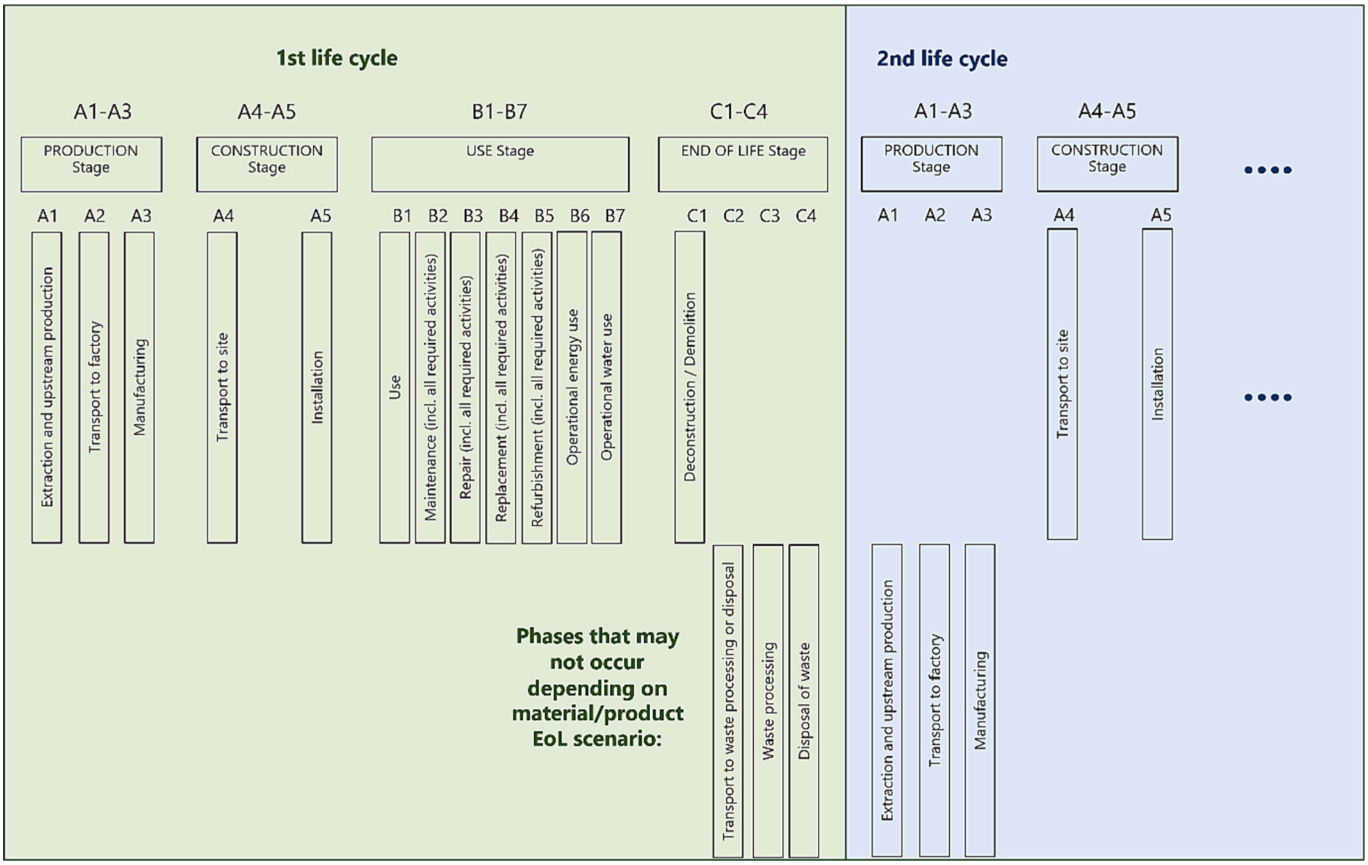


Fig. 8. Construction works life cycle. Source: Adapted from International Organization for Standardization (2017).

literature documents also lack transparency in terms of their development process, as they do not use systematic reviews, nor clearly state how the documents were developed. Therefore, to facilitate future research, all documents need to prioritise more transparency.

5.2. Circular economy case studies

5.2.1. Case studies' system boundaries

In order to conduct an analysis of case studies' system boundaries, the authors of this article adapted Fig. 8 from the ISO standard for environmental product declarations (EPDs) of construction products and services. The modification proposed in this study increases the system boundary to multiple life cycles, allowing for a more comprehensive representation of CE models. Furthermore, depending on the end-of-life (EoL) scenario, six phases may not be necessary. For example, in a model where a product is deconstructed and transported to a new site to begin a second life, the product would skip phases C2, C3, C4, A1, A2 and A3. This scenario represents the ideal situation where product life is extended without any loss of value. More common scenarios may involve the exclusion of phases C4 and A1. In this case, a product would be disassembled, transported to a waste processing facility, processed to retrieve specific materials, which will then be transported to a factory and used in a second manufacturing process (replacing virgin materials used in the second life cycle).

In Section 4, several case studies were observed to lack specificity regarding their system boundaries. Furthermore, the case studies that did specify their boundaries often failed to provide sufficient detail about the scope of their research. In particular, most of the reviewed case studies examined the production stage, considering a second life of by-products; or focused on products at their end-of-life phases (C1–C4), extending their assessments beyond system boundaries (D) to include them as replacements of virgin materials in a second life cycle (A1–A5). To enhance communication regarding system boundaries in the context of multi-life cycle analyses, the use of the nomenclature presented in Eq. (1) is recommended. This equation is based on the work life cycle stages for construction as shown in Fig. 8:

$$BP\ 1_{cl}\ F_{st}(10R\ strategy)\ to\ L_{cl}L_{st}\ excl\ (P_{cl1}, P_{cl2}\ldots P_{cln}) \tag{1}$$

where:

BP = State if the material studied is a by-product of a secondary process. If it is not, leave empty.

1_{cl} = First cycle considered in the scope of the analysis (as this will always be 1, it can be omitted in the nomenclature).

F_{st} = First stage considered in the scope of the analysis.

$10R\ strategy$ = 10R strategy or strategies considered within the first cycle.

L_{cl} = Last cycle considered in the scope of the analysis.

L_{st} = Last stage considered in the scope of the analysis.

$excl$ = Exclusion(s) in the scope of the analysis.

$P_{cl1}, P_{cl2}\ldots P_{cln}$ = Phases excluded in each life cycle of the scope of the analysis.

In circular scenarios when optional phases are not actually occurring (C2, C3, C4, A1, A2 and A3), they should not be listed in the equation as excluded.

For example, Eq. (2) defines the system boundary from the end-of-life stage of the first life cycle to the production stage of the second life cycle, while excluding the transport to waste or disposal (C2) and transport to factory (A2) phases (for further information on construction life cycle stages and phases, see International Organization for Standardization (2017) for guidance on construction life cycle stages and phases). Similarly, Eq. (3) considers a by-product as a replacement of virgin materials in the production stage of a secondary product, excluding the transport to factory (A2) phase. As the equation only considers one stage, it is simplified. To encourage its adoption and provide a clearer distinction of system boundaries in the case studies analysed, Table 1 applies the proposed system boundary nomenclature.

$$EoL(Recycle)\ to\ 2_{cl}\ production\ excl\ (C2_{cl1}, A2_{cl2}) \tag{2}$$

$$By-product\ 2_{cl}\ production\ (Recycle)\ excl\ (A2_{cl2}) \tag{3}$$

Furthermore, it is essential to include the materials/products being analysed alongside the proposed equations, as outlined in Table 1. This is critical for providing a clear and concise understanding of the analysis scope which, in turn, simplifies communication and enables future research that compares case study results through approaches like a meta-analysis. In situations where case studies generate multiple scenarios, it is imperative to clearly state the materials/products analysed, along with their respective life cycle system boundary for each generated scenario.

5.2.2. Further limitations of case studies

A clearer distinction between case studies that analyse manufacturing by-products and those that analyse end-of-life waste should be highlighted, as proposed in Eq. (2) and Eq. (3). Manufacturing waste, also known as by-products, comprises materials that currently do not have added value and usually end up in landfill. Exploring how to integrate this manufacturing waste into the economy is to truly apply the waste elimination concept of the CE definition. Conversely, case studies that recycle end-of-life waste in a new cycle are losing the opportunity to increase their environmental savings with more efficient CE strategies such as reusing and remanufacturing (refer to Fig. 1). For instance, concrete case studies that are replacing cement with fly ash waste produced from manufacturing processes are generating substantial environmental savings in materials use. In contrast, case studies that address the demolition of old concrete products to use the waste generated as new aggregates do not generate the same benefit. The most recent studies neglect the exploration of higher hierarchical CE strategies, such as reusing and remanufacturing concrete elements. Likewise, these case studies neglect the use of detachable joint connections which would enable concrete elements to be disassembled at the end of a new building's use stage. Indeed, exploring better strategies should be prioritised in future case studies where the scope is end-of-life to second-life analysis.

In addition, the case studies reviewed in the present study have predominantly focused on remediation strategies. The environmental assessments of the identified case studies have primarily aimed to investigate waste management strategies, with a focus on identifying opportunities for second-life products, such as recycling opportunities for construction demolition waste (CDW), as well as the use of aggregates and fly ash in new concrete (Bonoli et al., 2020; Da Silva et al., 2021; Smol et al., 2015). While these scenarios generate substantial benefits, they do not aim to understand the implications of multiple life cycles of the same product, as they only extend the material's life to one more cycle inside the current industrial system. However, this limitation is not entirely aligned with the CE principles, as CE best practices aim to maximise the value of materials through higher-level CE strategies (refer to Fig. 1) and to produce closed-loop scenarios that are repeatable multiple times.

Indeed, closed-loop systems are the most aligned with CE principles (Linder et al., 2017). The reviewed literature reveals that closed-loop systems offer long-term benefits by minimising product impacts across multiple life cycles. Among the case studies examined, closed-loop scenarios were identified for gypsum, timber and concrete-related products. Conversely, open-loop scenarios were observed for bricks, PV panels, glass, fireproofing materials and concrete-related products. In the identified case studies, partial recycling was the primary strategy employed in the second life cycle of these materials. However, limitations to the environmental benefits were reported based on transportation distance. Moreover, additional time and labour were a common theme in the literature (Da Silva et al., 2021; Fořt and Černý, 2020). As crucial as these studies have been to initiate a discussion about

CE strategies for construction materials, they have not adhered to the 10R framework, having primarily focused on recycling, one of the least valuable strategies within the CE framework. Despite reuse being regarded as a more advantageous strategy than recycling within the overarching CE guidelines, only two studies have undertaken research with a focus on reuse (Buyle et al., 2019b; Niu et al., 2021).

The CE concept necessitates a decision-making system that assists in determining the environmental effects of adopted strategies to guarantee that these effects are minimised. This literature review confirms the insufficient amount of research targeting the measurement of the CE environmental impacts at the material/product level in buildings (Elia et al., 2017). Butković et al. (2021) argued that current assessment methods for evaluating CE in construction projects and materials are limited by their descriptive nature, leading to a decision-making process that lacks reliable analysis and relies heavily on the evaluator's expertise and opinion. This limitation is evident in the few case studies available in the literature, where a specific methodology has not been adopted to address the implications of CE strategies. The absence of a methodology has resulted in studies that are not easily comparable and do not consider all aspects of the CE definition. Indeed, studies have not prioritised their comparability; instead, they have aimed to address research gaps based on researchers' specific needs and scopes.

5.3. *Circular economy software tools*

Twelve (12) software tools available for assessing the environmental performance of CE at the material/product levels were reviewed. The software tools presented a wide range of environmental assessment approaches, with each defining its own framework. In these software tools, MFA and LCA were the most commonly used approaches for assessing environmental impacts. Closed-loops systems and waste reduction strategies were commonly generated, while incentivisation targeted the use of the 10R strategies, MFA indicators and visualisations of results. Conversely, the software tools used a wide variety of MFA indicators, often without explanation for their selection and, in some cases, without publicly available information on how they were measured. This highlights the confusion in the empirical world and underscores the importance of a framework to regulate how to deal with CE environmental assessment at the material and product levels.

A frequent indicator found within this literature review was the material circularity indicator (MCI). The MCI has its own software tool generated in an MS Excel spreadsheet. Moreover, it was verified to be used in the Sphera (n.d.), while ANSYS Granta and Ellen MacArthur Foundation (n.d.) and PIQET (2017) mentioned they used the “product circularity indicator” and “material circularity index” respectively. These two indicators could not be verified, as their calculation methods were not publicly available, but they may refer to the MCI by these terms. However, the MCI score does not consider the full scale of the 10R framework, nor the butterfly diagram of the Ellen MacArthur Foundation and Arup Group Limited, thus omitting key CE strategies from the assessment. Indeed, an indicator that considers the hierarchy of the 10R framework was not found.

The ISO 14040 and ISO 14044 standards were constantly mentioned as standards that regulate how LCA was conducted in software tools. Moreover, the carbon footprint or GHG emissions were prevalent in several tools, confirming the interest of the empirical world in assessing climate change impacts. The LCA databases varied across the software tools, with GaBi and PIQET having the most comprehensive LCA databases, although PIQET limited end-user access to the Ecoinvent database (PIQET, 2017). Additionally, the list of parameters to be defined by the end-user in the PIQET tool is limited, which can be considered as a limitation for advanced users but results in a more user-friendly tool. Moreover, none of the identified software tools provided incentives to use the hybrid LCA databases, which is based on the most comprehensive method (Crawford, 2011). This highlights one key limitation of current software tools. LCA assumptions and methods (process, input-output, or hybrid) can substantially change the assessment outputs. Therefore, they are critical when presenting environmental assessment results, and should be clearly stated within software tools.

5.4. *Circular economy environmental indicators*

In this article, indicators from all three reviews were considered, with these comprising the review of CE overarching guidelines; the review of construction materials and products case studies in academic articles; and the review of software tools applicable to the material/product level. Without excluding duplicates, 348 indicators were found in this literature review, as presented in Table S2. After excluding duplicates, 249 indicators were identified in this review. This comprehensive list can be used for future studies and further analysis of current trends in CE environmental assessment at the material and product level, both in theory and empirical world practices.

The indicators were grouped into 12 key topics, covering 94.64 % of the total indicators. This approach revealed a clear relationship between the strategies defined in the 10R framework and how the empirical world and theory are approaching CE environmental assessment at the material/product level. Moreover, the key topics most frequently studied in the reviewed documents were water use, global warming, materials use, chemical use and energy use, respectively. Future research could prioritise which indicators should be used for each of these areas and explore how to integrate these key topics.

5.5. *Scoping review limitations*

The study has certain acknowledged limitations, mainly related to the scope of the search strategy — due to space and time constraints. Most academic articles generated in the past decade were included in the findings, but previous studies exploring end-of-life scenarios, like waste reuse, might have used different keywords such as ‘reverse logistics‘ in construction. Future studies should consider broader search terms to encompass such scenarios. Additionally, the search string focused on environmental studies using the term ‘life cycle’, potentially skewing the findings towards methods like life cycle assessment (LCA). To address this, future studies should use a more diverse range of search terms to cover various approaches to environmental assessment.

Furthermore, the grey literature review done in this study identified only three overarching guidelines for CE environmental assessment specifically oriented to the construction industry. Hence, an additional review comprising overarching guidelines for any CE environmental assessment framework was also done. However, for manageability, this second review was limited to documents relevant to the Australian context. This review could be broadened to review all documents available in more countries, providing a more comprehensive overview. Moreover, only documents and software tools available in English were analysed, but future studies could consider a broader range of languages. Lastly, exploring the relationship between qualitative and quantitative indicators was not considered in this review, which could provide a fertile ground for future research.

6. Conclusion

As one of the first comprehensive scoping review studies on CE environmental assessment in the construction industry, this article takes into account both empirical and theoretical research. It synthesises the findings of three major reviews: (1) CE overarching guidelines; (2) construction materials/products case studies in academic articles; and (3) software tools for measuring the environmental impacts of CE at the material/product level.

As a novel contribution, the scoping review presented in this article elucidates the evolutionary trajectory of the CE concept and examines the varied approaches articulated within overarching CE environmental assessment guidelines. Notably, these guidelines have witnessed significant development over the past decade. Findings provide enlightening insights into the existing deficiencies within these guidelines. These deficiencies manifest in the absence of replicable systematic literature reviews serving as foundational support for these guidelines. Additionally, there is frequently a lack of clarity regarding the methodology employed in formulating these approaches. This has resulted in a range of guidelines proposing different approaches, with a great lack of consistency. While the constant use of MFA and LCA as environmental assessment methodologies in CE overarching guidelines was observed, the approaches proposed varied considerably. It is advisable that future endeavours in this field prioritise the identification of commonalities and strategies for the harmonious integration of the prevailing overarching guidelines.

The findings related to case studies reveal that LCA stands as the predominant methodology, with each study incorporating at least one LCA-based indicator. It is noteworthy that the reviewed case studies adopt varying definitions of their system boundaries. To mitigate this limitation, this article introduces a novel nomenclature, aimed at enhancing the clarity and effectiveness of communication concerning system boundaries in environmental assessments pertaining to CE scenarios. Additionally, regarding the 12 software tools reviewed, most of them employed quantitative approaches, with the use of LCA and MFA being prevalent. However, this study also revealed a lack of transparency in terms of the overarching guidelines, with only three clearly stating them. This presents an opportunity for future software tools to ensure greater transparency in their approaches.

Furthermore, this article serves as a dependable point of reference for both researchers and practitioners by compiling a comprehensive list of indicators utilised or suggested for application in the measurement of CE environmental assessments. The findings collate these indicators from a range of sources, including academic articles, grey literature, and software tools, thereby establishing a comprehensive resource. Without excluding duplicates, findings gathered 348 indicators, with no common set prevalent. The identified indicators were grouped and ranked by their number of repetitions into 12 key topics, which covered 94.64 % of the total indicators found. It is prudent to prioritise these key topics in future research, given that they have garnered support from both the grey literature and academic research. Additionally, the findings underscore a discernible correlation between the strategies outlined in the 10R framework and the concurrent approaches embraced by empirical practice and theoretical discourse concerning CE environmental assessment in the context of materials and products.

This article's contribution lies in its systematic approach to reviewing the literature and identifying gaps in current research on a topic overlooked in the existing literature. By considering both the academic and the grey literature, the review provides a comprehensive overview of the current state of research on the CE environmental assessment in the construction industry. The inclusion of software tools also provides valuable insights in terms of practical applications of CE environmental assessment in the industry. Furthermore, the review highlights the need for a standardised framework to assess CE environmental performance at the material and product level. The identified indicators and key topics can serve as a basis for future studies to prioritise which indicators to use and how to integrate them. Finally, the review emphasises the importance of considering the 10R framework strategies in CE case studies and the need for further research in this area.

CRediT authorship contribution statement

SM, MRH and RHC designed the original research. SM collected and analysed the data. SM wrote the draft of the manuscript, with both MRH and RHC revising, editing and improving the text. SM and MRH designed the figures, with SM as the corresponding author.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors express their gratitude to the editor and the five anonymous reviewers for their constructive feedback and valuable suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2023.09.022.

References

Abadi, M., Moore, D.R., Sammuneh, M.A., 2021. A framework of indicators to measure project circularity in construction circular economy. Proc. Inst. Civ. Eng.: Manag. Procure. Law 40 (XXXX), 1–13. https://doi.org/10.1680/jmapl.21.00020.

Adabre, M.A., Chan, A.P.C., Darko, A., Hosseini, M.R., 2023. Facilitating a transition to a circular economy in construction projects: intermediate theoretical models based on the theory of planned behaviour. Build. Res. Inf. 51 (1), 85–104. https://doi.org/10.1080/09613218.2022.2067111.

Adams, K.T., Osmani, M., Thorpe, T., Thornback, J., 2017. Circular economy in construction: current awareness, challenges and enablers. Proc. Inst. Civ. Eng. - Waste Resour. Manag. 170 (1), 15–24. https://doi.org/10.1680/jwarm.16.00011.

Al-Hamrani, A., Kim, D., Kucukvar, M., Onat, N.C., 2021. Circular economy application for a Green Stadium construction towards sustainable FIFA world cup Qatar 2022TM. Environ. Impact Assess. Rev. 87, 106543. https://doi.org/10.1016/j.eiar.2020.106543.

Andersen, S.C., Birkved, M., 2022. Reconsidering the assessment method of environmental implications of Circular Economy in the Built Environment. IOP Conf. Ser.: Earth Environ. Sci. 1078 (1), 012007 https://doi.org/10.1088/1755-1315/1078/1/012007.

Ansanelli, G., Fiorentino, G., Tammaro, M., Zucaro, A., 2021. A life cycle assessment of a recovery process from end-of-life photovoltaic panels. Appl. Energy 290. https://doi.org/10.1016/j.apenergy.2021.116727.

ANSYS Granta, & Ellen MacArthur Foundation. (n.d.). MI:Product Intelligence. In https://www.grantadesign.com/industry/collaborations/collaborative-rd-projects/ce100/.

Arksey, H., O'Malley, L., 2005. Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. 8 (1), 19–32. https://doi.org/10.1080/1364557032000119616.

Aromataris, E., Munn, Z., 2020. JBI Manual for Evidence Synthesis. In: JBI.

Australian Circular Economy HUB, EDGE, 2022. Measuring the Circular Economy: An Australian Perspective. https://acehub.org.au/knowledge-hub/research/measuring-the-circular-economy-an-australian-perspective.

Backes, J.G., Del Rosario, P., Petrosa, D., Traverso, M., Hatzfeld, T., Günther, E., 2022. Building sector issues in about 100 years: end-of-life scenarios of carbon-reinforced concrete presented in the context of a life cycle assessment, focusing the carbon footprint. Process 10 (9). https://doi.org/10.3390/pr10091791.

Balanay, R., Halog, A., 2019. Tools for Circular Economy. Elsevier, pp. 49–75. https://doi.org/10.1016/b978-0-08-102630-4.00003-0.

van Beuren, B.J.A., Iyer-Raniga, U., Leenders, M.A.A.M., Argus, K., 2021. Comprehensiveness of circular economy assessments of regions: a systematic review at the macro-level. Environ. Res. Lett. 16 (10), 103001. https://doi.org/10.1088/1748-9326/ac209c.

Bonoli, A., Degli Esposti, A., Magrini, C., 2020. A case study of industrial symbiosis to reduce GHG emissions: performance analysis and LCA of asphalt concretes made with RAP aggregates and steel slags. Front. Mater. 7, 572955. https://doi.org/10.3389/fmats.

British Standard Institution, 2017. BS 8001:2017. In: Framework for Implementing the Principles of the Circular Economy in Organizations - Guide.

Butković, L.L., Mihić, M., Sigmund, Z., 2021. Assessment methods for evaluating circular economy projects in construction: a review of available tools. Int. J. Constr. Manag. 1–10. https://doi.org/10.1080/15623599.2021.1942770.

Buyle, M., Galle, W., Debacker, W., Audenaert, A., 2019a. Consequential LCA of demountable and reusable internal wall assemblies: a case study in a Belgian context. IOP Conf. Ser.: Earth Environ. Sci. 323, 012057 https://doi.org/10.1088/1755-1315/323/1/012057.

Buyle, M., Galle, W., Debacker, W., Audenaert, A., 2019b. Sustainability assessment of circular building alternatives: consequential LCA and LCC for internal wall assemblies as a case study in a Belgian context. J. Clean. Prod. 218, 141–156. https://doi.org/10.1016/j.jclepro.2019.01.306.

Caldas, L.R., Saraiva, A.B., Lucena, A.F.P., Da Gloria, M.H.Y., Santos, A.S., Filho, R.D.T., 2021. Building materials in a circular economy: the case of wood waste as CO2-sink in bio concrete. Resour. Conserv. Recycl. 166, 105346. https://doi.org/10.1016/j.resconrec.2020.105346.

circular-IQ.com, & KPMG. (n.d.). The Circular IQ platform. In https://circular-iq.com/.

circularise.com. (n.d.). Circularise. In https://www.circularise.com/manufacturers.

Colangelo, F., Navarro, T.G., Farina, I., Petrillo, A., 2020. Comparative LCA of concrete with recycled aggregates: a circular economy mindset in Europe. Int. J. Life Cycle Assess. 25 (9), 1790–1804. https://doi.org/10.1007/s11367-020-01798-6.

Cradle to Cradle Products Innovation Institute, 2021. Cradle to Cradle certified®Product Standard. In: Version 4.0, p. 98.

Crawford, R.H., 2011. Life Cycle Assessment in the Built Environment, , 1st edVol. 30. Routledge. https://doi.org/10.4324/9780203868171.

Da Silva, R.C., Puglieri, F.N., De Genaro Chiroli, D.M., Bartmeyer, G.A., Kubaski, E.T., Tebcherani, S.M., 2021. Recycling of glass waste into foam glass boards: a comparison of cradle-to-gate life cycles of boards with different foaming agents. Sci. Total Environ. 771, 145276. https://doi.org/10.1016/j.scitotenv.2021.145276.

Dubois, A., & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of business research*, *55*(7), 553-560. Doi:doi:https://doi.org/10.1016/S0148-2963(00)00195-8.

Dutch Green Building Council, 2021. Circular Buildings – Disassembly Potential Measurement Method. https://www.dgbc.nl/publicaties/circular-buildings-een-meetmethodiek-voor-losmaakbaarheid-v20-41.

Ecopreneur, 2022. The Circularity Check. In. https://ecopreneur.eu/circularity-check-landing-page/.

Elghaish, F., Hosseini, M.R., Kocaturk, T., Arashpour, M., Bararzadeh Ledari, M., 2023. Digitalised circular construction supply chain: an integrated BIM-Blockchain solution. Autom. Constr. 148, 104746. https://doi.org/10.1016/j.autcon.2023.104746.

Elia, V., Gnoni, M.G., Tornese, F., 2017. Measuring circular economy strategies through index methods: a critical analysis. J. Clean. Prod. 142, 2741–2751. https://doi.org/10.1016/j.jclepro.2016.10.196.

Ellen MacArthur Foundation, 2015a. Material Circularity Indicator (MCI). In. https://ellenmacarthurfoundation.org/material-circularity-indicator.

Ellen MacArthur Foundation, 2015b. Towards a Circular Economy: Business Rationale for an Accelerated Transition. https://www.ellenmacarthurfoundation.org/publications/towards-a-circular-economy-business-rationale-for-an-accelerated-transition.

European Commission, 2021. Level(s) – A Common EU Framework of Core Sustainability Indicators for Office and Residential Buildings. In.

Finch, G., Marriage, G., 2018. Reducing Building Waste through Light Timber Frame Design.

Fořt, J., Černý, R., 2020. Transition to circular economy in the construction industry: environmental aspects of waste brick recycling scenarios. Waste Manag. 118, 510–520. https://doi.org/10.1016/j.wasman.2020.09.004.

Ghafoor, S., Hosseini, M.R., Kocaturk, T., Weiss, M., Barnett, M., 2023. The product-service system approach for housing in a circular economy: an integrative literature review. J. Clean. Prod. 403, 136845. https://doi.org/10.1016/j.jclepro.2023.136845.

Ghisellini, P., Ripa, M., 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. https://doi.org/10.1016/j.jclepro.2017.11.207.

Harris, S., Martin, M., Diener, D., 2021. Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy. Sustain. Prod. Consum. *26*, 172–186. https://doi.org/10.1016/j.spc.2020.09.018.

Hasheminasab, H., Hashemkhani Zolfani, S., Kharrazi, M., Streimikiene, D., 2022. Combination of sustainability and circular economy to develop a cleaner building industry. Energ. Buildings 258. https://doi.org/10.1016/j.enbuild.2022.111838.

Howard, M., Hopkinson, P., Miemczyk, J., 2019. The regenerative supply chain: a framework for developing circular economy indicators. Int. J. Prod. Res. 57 (23), 7300–7318. https://doi.org/10.1080/00207543.2018.1524166.

IDEAL&CO Explore BV. (n.d.). Circularity Calculator. In http://www.circularitycalculator.com/.

International Organization for Standardization, 2017. ISO 21930:2017. In: Sustainability in Buildings and Civil Engineering Works — Core Rules for Environmental Product Declarations of Construction Products and Services.

Irmak, N., 2012. Software is an abstract artifact. Grazer Philos. Stud. 86 (1), 55–72.

Jiménez-Rivero, A., García-Navarro, J., 2016. Indicators to measure the management performance of end-of-life gypsum: from deconstruction to production of recycled gypsum. Waste Biomass Valoriz. 7 (4), 913–927. https://doi.org/10.1007/s12649-016-9561-x.

KATCH_e Knowledge Platform. (n.d.). CE Analyst In https://www.katche.eu/knowledge-platform/tools-and-training-materials/katch_e-tools/ce-analyst/.

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

Kirchherr, J., Yang, N.-H.N., Schulze-Spüntrup, F., Heerink, M.J., Hartley, K., 2023. Conceptualizing the circular economy (revisited): an analysis of 221 definitions. Resour. Conserv. Recycl. 194, 107001. https://doi.org/10.1016/j.resconrec.2023.107001.

Lachat, A., Mantalovas, K., Desbois, T., Yazoghli-Marzouk, O., Colas, A.S., Di Mino, G., Feraille, A., 2021. From buildings' end of life to aggregate recycling under a circular economic perspective: a comparative life cycle assessment case study. Sustainability 13 (17). https://doi.org/10.3390/su13179625.

Le, H.-B., Bui, Q.-B., 2020. Recycled aggregate concretes – a state-of-the-art from the microstructure to the structural performance. Constr. Build. Mater. 257, 119522. https://doi.org/10.1016/j.conbuildmat.2020.119522.

Linder, M., Sarasini, S., van Loon, P., 2017. A metric for quantifying product-level circularity. J. Ind. Ecol. 21 (3), 545–558. https://doi.org/10.1111/jiec.12552.

Marinus Meursing Inventions, P. a. P. A, 2021a. Idemat. In: Version 2.4.2. http://idematapp.com/.

Marinus Meursing Inventions, P. a. P. A, 2021b. IdematLightLCA. In: Version 2.4.2. http://idematapp.com/coll-page-section/lightlca/.

Medina, E.M., Fu, F., 2021. A new circular economy framework for construction projects. Proc. Inst. Civ. Eng. Eng. Sustain. 174 (6), 304–315. https://doi.org/10.1680/jensu.20.00067.

Mhatre, P., Panchal, R., Singh, A., Bibyan, S., 2021. A systematic literature review on the circular economy initiatives in the European Union. Sustain. Prod. Consum. 26 https://doi.org/10.1016/j.spc.2020.09.008.

Morsy, K.M., Thakeb, H., 2022. Comparative evaluation of the environmental impacts of geosynthetic mechanically stabilized earth walls. J. Clean. Prod. 374 https://doi.org/10.1016/j.jclepro.2022.133912.

Mostert, C., Sameer, H., Glanz, D., Bringezu, S., 2021. Climate and resource footprint assessment and visualization of recycled concrete for circular economy. Resour. Conserv. Recycl. 174 https://doi.org/10.1016/j.resconrec.2021.105767.

Munaro, M.R., Tavares, S.F., 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. https://doi.org/10.1016/j.jclepro.2020.121134.

Muñoz, S., Hosseini, M.R., Crawford, R.H., 2022. Circular economy software tools at the material and product level: a scoping review. In: 55th International Conference of the Architectural Science Association (ANZAScA), Perth, Australia.

Niu, Y., Rasi, K., Hughes, M., Halme, M., Fink, G., 2021. Prolonging life cycles of construction materials and combating climate change by cascading: the case of reusing timber in Finland. Resour. Conserv. Recycl. 170 https://doi.org/10.1016/j.resconrec.2021.105555.

Noparast, M., Hematian, M., Ashrafian, A., Amiri, M.J.T., Azarijafari, H., 2021. Development of a non-dominated sorting genetic algorithm for implementing circular economy strategies in the concrete industry. Sustain. Prod. Consum. 27, 933–946. https://doi.org/10.1016/j.spc.2021.02.009.

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

Paré, G., Trudel, M.-C., Jaana, M., Kitsiou, S., 2015. Synthesizing information systems knowledge: a typology of literature reviews. Inf. Manag. *52* (2), 183–199. https://doi.org/10.1016/j.im.2014.08.008.

de Pauw, I., van der Grinten, B., Flipsen, B., Alvarez-Mendez, L., 2021. The Circularity Calculator, a Tool for Circular Product Development With Circularity and Potential Value Capture Indicators. https://pure.tudelft.nl/ws/files/102485098/de_Pauw_et_al_2021_The_Circularity_Calculator.pdf.

Peceño, B., Alonso-Fariñas, B., Vilches, L.F., Leiva, C., 2021. Study of seashell waste recycling in fireproofing material: technical, environmental, and economic assessment. Sci. Total Environ. 790 https://doi.org/10.1016/j.scitotenv.2021.148102.

PIQET, 2017. Packaging Impact Quick Evaluation Tool (PIQET). In: Version 4.24. https://piqet.com/.

Platform for Accelerating the Circular Economy, 2020. The Circularity Gap Report. https://www.circle-economy.com/resources/circularity-gap-report-2020.

Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A., 2017. Circular Economy: Measuring Innovation in the Product Chain. PBL Publishers.

Rodríguez-Quijano, M., Jiménez-Rivero, A., de Guzmán-Báez, A., García-Navarro, J., 2015. Gypsum Plasterboard Deconstruction to Recycling Economic Study in Europe.

Sandanayake, M., Law, D., Sargent, P., 2022. A new framework for assessing the environmental impacts of circular economy friendly soil waste-based geopolymer cements. Build. Environ. 210 https://doi.org/10.1016/j.buildenv.2021.108702.

dos Santos Gonçalves, P.V., Campos, L.M.S., 2022. A systemic review for measuring circular economy with multi-criteria methods. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-022-18580-w.

Schützenhofer, S., Kovacic, I., Rechberger, H., 2022. Assessment of sustainable use of material resources in the architecture, engineering and construction industry – a conceptual framework proposal for Austria. J. Sustain. Dev. Energy Water Environ. Syst. *10* (4) https://doi.org/10.13044/j.sdewes.d10.0417.

Simon, A., Voith, K., Mannheim, V., 2019. Investigation of different foam glasses with life cycle assessment method. In: Solutions for Sustainable Development. CRC Press, pp. 254–266.

Smol, M., Kulczycka, J., Henclik, A., Gorazda, K., 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. https://doi.org/10.1016/j.jclepro.2015.02.051.

Sphera. (n.d.). GaBi Circularity Toolkit. In https://gabi.sphera.com/software/gabi-software/gabi-circularity-toolkit/.

Stephan, A., Muñoz, S., Healey, G., Alcorn, J., 2020. Analysing material and embodied environmental flows of an Australian university — towards a more circular economy. Resour. Conserv. Recycl. 155, 104632. https://doi.org/10.1016/j.resconrec.2019.104632.

Superti, V., Houmani, C., 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. https://doi.org/10.1016/j.resconrec.2021.105711.

Taddei, E., Sassanelli, C., Rosa, P., Terzi, S., 2022. Circular supply chains in the era of industry 4.0: a systematic literature review. Comput. Ind. Eng. *170* https://doi.org/10.1016/j.cie.2022.108268.

Tricco, A.C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., Levac, D., Ng, C., Sharpe, J.P., Wilson, K., Kenny, M., Warren, R., Wilson, C., Stelfox, H.T., Straus, S.E., 2016. A scoping review on the conduct and reporting of scoping reviews. BMC Med. Res. Methodol. 16 (1), 15. https://doi.org/10.1186/s12874-016-0116-4.

Tricco, A.C., Lillie, E., Zarin, W., O`Brien, K.K., Colquhoun, H., Levac, D., Moher, D., Peters, M.D., Horsley, T., Weeks, L., 2018. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann. Intern. Med. 169 (7), 467–473.

United Nations environment Programme, 2022. Global Status Report for Buildings and Construction. https://globalabc.org/our-work/tracking-progress-global-status-report.

Vitale, P., Napolitano, R., Colella, F., Menna, C., Asprone, D., 2021. Cement-matrix composites using CFRP waste: a circular economy perspective using industrial symbiosis. Materials 14 (6), 1484. https://doi.org/10.3390/ma14061484.

WBCSD, KPMG, & Circular IQ. (n.d.). CTI Tool. In https://ctitool.com/.

Zanni, S., Simion, I.M., Gavrilescu, M., Bonoli, A., 2018. Life cycle assessment applied to circular designed construction materials. Procedia CIRP 69, 154–159. https://doi.org/10.1016/j.procir.2017.11.040.

Zhai, J., 2020. BIM-based Building Circularity Assessment from the Early Design Stages. Eindhoven University of Technology.