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Sustainability: Science, Practice and Policy

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tsus20

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To cite this article: Miguel Torres Curado, Ricardo Resende & Vasco Moreira Rato (2024) Circular economy: current view from the construction industry based on published definitions, Sustainability: Science, Practice and Policy, 20:1, 2364954, DOI: 10.1080/15487733.2024.2364954

To link to this article: https://doi.org/10.1080/15487733.2024.2364954

SUSTAINABILITY: SCIENCE, PRACTICE AND POLICY
2024, VOL. 20, NO. 1, 2364954
https://doi.org/10.1080/15487733.2024.2364954

BRIEF REPORT

Circular economy: current view from the construction industry based on published definitions

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ABSTRACT

The third decade of this millennium has seen a growing interest in using the circular economy (CE) concept to achieve the broad goals of sustainable development. Still, like the latter, the former notion has different meanings to different audiences in general and in the construction sector in particular. This Brief Report assesses how the construction sector regards the CE concept, or more precisely, how it defines it. We draw on previous research, applying an existing generic framework to the construction sector, dividing the CE into its main components and subcomponents, and quantifying the extent of their acceptance. The main contribution of this work lies in establishing a benchmark for comparison with other industries and across time within the construction industry. We start with an analysis of the available literature and then focus on how the reviewed works perceive the scope of CE, its deployment systems, enablers, and its relationship with sustainable development. Our results confirm that the sector is embracing the linkage of CE to sustainable development while revealing a lesser concern for CE's social and future dimensions. This Brief Report also shows that the understanding of CE actions in terms of a hierarchy is still limited. However, its three main components (Reduce, Reuse, Recycle) are almost universally espoused, while the Recover component is mentioned by just over half of the reviewed works.

ARTICLE HISTORY
Received 30 June 2023
Accepted 3 June 2024

KEYWORDS
Circular economy; definition; sustainability; green buildings; construction; built environment

Introduction

Circular economy (CE) is a broad concept that moves from the linear end-of-life model of production to reducing, reusing, recycling, and recovering materials with the aim of, as the name hints, achieving a hypothetical goal of closed loops for material management. At the current stage of development, only 7.2% of the world's economy is circular and, despite interest in the notion of CE, this amount is declining due to rising volumes of material extraction and use (Circle Economy 2023).

Construction and buildings account for 30% of global energy use and 37% of carbon dioxide (CO_2) emissions (UNEP 2022). A world in continuous growth and accelerated urbanization is aggravating the already substantial impact of buildings and infrastructure on the climate. Nonetheless, the advertised benefits of CE are multifold as CE aims to mitigate greenhouse-gas (GHG) emissions, water pollution, and deforestation associated with the construction industry by reducing the use of virgin materials and minimizing waste. Additionally, the CE aspires to extend the lifespan of building materials by designing them for reuse, repair, and recycling and it seeks to create new economic opportunities for the construction industry by developing new services and products that support circular practices. CE intends to achieve cost savings for businesses by reducing waste-disposal costs and increasing the value of materials. Further, it strives to create jobs and improve the quality of life in communities by promoting local sourcing of materials and reducing the need for landfill disposal. Proponents of CE also want to improve the health and safety of construction workers by, for example, reducing exposure to hazardous materials.

In the not too distant past, the construction sector's main effort toward sustainability often went no further than recycling construction and demolition waste (Adams et al. 2017). The sector's horizon widened in the 2010s and early 2020s and now aims to incorporate facets of CE, whose principles are now pervasive. However, the understanding of the CE concept in construction is diverse rather than

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Supplemental data for this article is available online at https://doi.org/10.1080/15487733.2024.2364954

monolithic, so we find it necessary to assess the sector's perception of CE and its reach at this stage. This Brief Report addresses this question through the study of the extant definitions of CE. The definitions illustrate the differing scopes attributed to CE by various authors and differences in deployment, enablers, and its relationship with sustainable development (SD).

Published articles offer a wide range of definitions of CE within the context of the construction industry, yet a study comparing the scope of such definitions was not available and has not to date been published. Therefore, our research questions are (1) How does the scientific community in the construction sector perceive the CE? and (2) Does this perception differ from the economy as a whole, based on the available data and the definitions of CE included in scientific publications?

We start by analyzing CE's context, origins, scope, relationship with SD, feasibility, and metrics. We then address the research questions presented above, first describing the methodology which entails an oriented literature analysis, detailing the sample selection, coding choices, and analysis criteria. Finally, we present and discuss the results.

Our analysis confirms the sector's acceptance of the connection between CE and SD while showing less interest in the social and future dimensions of SD. It is also clear that the priorities stemming from the actions hierarchy in CE are not fully comprehended, and this may lead to wasted opportunities as lower priority actions are adopted by, for instance, recycling (downcycling) concrete structures as aggregates instead of reusing the structural elements.

The main contribution of this work lies in establishing a benchmark, allowing for comparing the view of CE in construction with that of other industries and future developments within the construction industry and identifying areas for improvement. It can also provide perspective when developing circularity indicators.

The CE context

Origins and scope of CE

It is essential to assert the scope of interest of this research by addressing what the CE covers and contrasting it with SD. The CE concept stems from nature and is therefore as ancient as nature itself, in the sense that the material cycles in a CE contribute to eliminating waste.

Early concerns about growth limits and resource scarcity can be traced back to the nineteenth century and the writings of the political economist Ricardo (1817). Concepts resembling CE, with closed loops without waste, were formulated in classic essays by the authors Simmonds (1862) and Babbage (1885). The different resource strategies underlying the CE are not novel; it is their consolidation into a coherent structure that is a recent development (Blomsma and Brennan 2017). Still, the foundations of the modern CE concept were designed in the context of 1960s-era environmentalism. Arguably, the defining moment was the publication of the article "The Economics of the Coming Spaceship Earth" by the economist Kenneth Boulding (1966), which provided both a seminal text and a metaphor describing the limited resources of planet Earth and the resulting global problems for humanity. However, this metaphor of a closed system is flawed, as the planet receives vast amounts of energy from the sun. A few years later, the ecological economist Georgescu-Roegen (1971) formalized the concept of a CE without assigning it a name. He was concerned with the thermodynamic limits of CE and argued that entropy would increase as more materials and energy were extracted. Thus, recirculation of both materials and energy could reduce the demand for new resources, delaying entropy growth.

Stahel and Reday (1976) further developed Boulding's concepts, eventually influencing German government policies (Triebswetter and Hitchens 2005). Germany was the first country to incorporate CE into national legislation in 1994 with the publication of the "Circular Economy and Waste Act" (Bundestag 1994). Regarding the term, economist Alan Kneese (1988) was one of the earlier users of the term "circular economy," if not the first. By the mid-1990s, the concept started attracting the attention of a broader community of policymakers. For instance, in a seminal textbook, Pearce and Turner (1990) explained the shift from the traditional linear economic system to the CE system, thus defining linear economy as the antipode of CE.

Ghisellini, Cialani, and Ulgiati (2016) took a broad perspective in a comprehensive literature review, defending that the origins of CE are primarily rooted in ecological and environmental economics and industrial ecology. Wautelet (2018) identified five primary schools of thought from which CE developed: industrial ecology, cradle-to-cradle, performance economy, blue economy, and biomimicry.

There is no all-embracing definition of the CE—Korhonen et al. (2018) consider it an essentially "contested concept." Stakeholders approach CE from different angles with specific and often narrow agendas. Diversity is such that Blomsma and Brennan (2017) classify CE as an "umbrella concept" or a "bandwagon" onto which a diverse number of people have jumped, with an explosion in interest coalescing after the publication of a notable report by the Ellen MacArthur Foundation (EMF 2012). Widespread media coverage has since been given to EMF's initiatives and its definition of CE (EMF 2013) as "an industrial system that is restorative or regenerative by intention and design." This definition has been the most referenced source, as determined by a systematic literature review of CE in the construction industry by Benachio, Freitas, and Tavares (2020).

Cramer (2014) probably offers the broadest scope definition and considers that CE covers nine strategies, the so-called 9 Rs (see Table 1): Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, and Refuse (translated from Dutch by RLI 2015). Circularity is about ensuring raw materials are retained at the highest level possible; therefore, there is a clear hierarchy of actions (also known as a "waste hierarchy"), where R9—Recover—is the option of last resort and landfills should be made obsolete. This hierarchy is not novel. It was introduced in 1979 by the scientist-politician Ad Lansink in a bill submitted to the Dutch House of Representatives, containing six steps, that have become known as "Lansink's Ladder" which is a diagram showing the order of preference for waste-management options, with disposal at the bottom and prevention at the top (Lansink 1979) (see Figure 1). Since then, the concept has become mainstream and integrated into the European Waste Framework Directive (2008/98/EC 2018) (European Parliament and Council 2008). However, assessing the hierarchy's implementation is far from trivial, as shown by Pires and Martinho (2019).

Institutional definitions of CE have also influenced the field, particularly those of the European Union (EU) and China. The EU adopts a 4R framework: Reduce, Reuse, Recycle, and Recover (European Parliament and Council 2008) while China drops "Recover" and takes a 3R approach in the Circular Economy Law of the People's Republic of China (National People's Congress 2008). It should be noted that China is the leader in publications concerning the CE for the construction industry in the 2005–2020 period, albeit with a low number of citations per document (Norouzi et al. 2021).

Standards may also play a role in defining the scope of the CE. The International Organization for Standardization (ISO) has under publication a standard entitled "Circular Economy—Vocabulary, Principles and Guidance for Implementation" (ISO 59004) (ISO 2024). The British Standard BS8001 (BSI 2017) acknowledges the definition issue, stating that "there are various interpretations of the idea across organizations" but ultimately uses the definition proposed by EMF.

Kirchherr, Reike, and Hekkert (2017) took an in-depth look into the definitions of CE, compiling 114 relevant definitions. They find that the most common definition comprises only 3 Rs (Reduce, Reuse, and Recycle) and practitioners frequently neglect Reduce. Furthermore, anecdotal evidence—see, for example, Bulkeley and Gregson (2009)—points out that policies have been directed to one R, namely Recycle.

Still, this is a fast-evolving field, and researchers, policymakers, and practitioners are still grasping the full implications of CE. A comprehensive CE integration and methodology framework is yet to be developed (Hossain et al. 2020), and a universal understanding of its scope has not emerged.

CE as an enabler for sustainability

The protean concept of SD initiated great expectations and quickly became omnipresent in a variety of forms outside academia. It has been 17 years since Johnston et al. (2007) estimated the definitions of SD as "some three hundred." This ubiquity has come at a cost. Pesqueux (2009) calls sustainable development a "vague" theory, providing empirical proof of this vagueness. The United Nations (2015) tried to address this ambiguity by setting 17 global goals to meet environmental, social, political, and economic challenges. Nevertheless, three and a half decades have passed since the Brundtland report (1987), and the data demonstrates an increasing use of resources,

Table 1. CE actions hierarchy adapted from Cramer (2014) and translated by RLI (2015).

1.	Refuse: preventing the use of raw materials
2.	Reduce: reducing the use of raw materials
3.	Reuse: product reuse (second-hand, sharing of products)
4.	Repair: maintenance and repair
5.	Refurbish: refurbishing a product
6.	Remanufacture: creating new products from (parts of) old products
7.	Repurpose: product reuse for a different purpose
8.	Recycle: processing and reuse of materials
9.	Recover: energy recovery from materials

Figure 1. Lansink's Ladder (RecyclingNL, CCA 3.0 license). *Note:* A (Prevention), B (Reuse), C (Recycling), D (Energy), E (Incineration), F (Sorting).

with projections of a doubling by 2060 if the pattern is not changed (IRP 2019). The evidence shows that SD has not lived up to its promises on the implementation side.

CE aspires to be a tool to break this trend by promising and promoting some degree of disconnect between economic growth and both the use of resources and environmental impacts. The CE seems to be gaining traction with less fanfare than SD. For instance, China, a significant resource user, has taken the lead in this area, having introduced in 2008 the Circular Economy Law of the People's Republic of China, "formulated for the purpose of promoting the development of the circular economy, improving the resource utilization efficiency, protecting and improving the environment and realizing sustainable development" (Article 1). The Western world lacks this top-down approach, but this does not mean lack of action, as the EU's "Circular Economy Action Plan" demonstrates (European Commission 2015, 2020). Still, a review by Ghisellini, Cialani, and Ulgiati (2016) points out that in the EU, Japan, and the United States, CE "policies and actions are mainly identified within [the] waste area," showing that CE deployment is still at an incipient state. Kirchherr and van Santen's (2019) analysis of 160 articles on CE reflects this state and the authors observe that "advice geared toward scholars" is abundant, while "actionable advice to practitioners" is scarce.

However, while it seems widely accepted that the so-called economic and environmental pillars of SD can be targeted through CE, addressing the social pillar is still an open question. Boström (2012), in a non-industry specific article, calls it a "missing pillar." In an analysis of articles on the issue, the author finds that the main challenges to the integration of social aspects derive from high expectations; vague, subjective, and ideological framing; and the historical roots of SD. In a construction-industry context, Gregson et al. (2015) consider the need for "morally defined materials circuits" and Ghisellini, Cialani, and Ulgiati (2016) criticize the CE for neglecting the social dimension of sustainability. Murray, Skene, and Haynes (2017) consider that CE "is virtually silent on the social dimension, concentrating on the redesign of manufacturing and service systems to benefit the biosphere." This is not unexpected, as CE stems from the need to reconcile economic and environmental problems. D'Amato et al. (2017) explain it as a pedigree issue and remark that "CE is embedded in the context of industrial systems." Still, work is being developed to address this issue with, for example, Nikanorova, Imoniana, and Stankeviciene (2020) proposing a concept of the social dimension of the CE.

In addition to the economic, environmental, and social dimensions, SD also emphasizes intergenerational equity. However, clarity of the possible contributions of CE to fairness to future generations is conspicuously missing, as Murray, Skene, and Haynes (2017) have notably pointed out.

Feasibility of CE

Although CE is the subject of a growing number of publications, that does not mean per se that CE is feasible or to what degree it is achievable. Cullen (2017) reminds us that "CE in practice has often downplayed or conveniently overlooked material losses and energy requirements of closed loops…In a perfect CE, the quantity of materials in 'closed loops' must be conserved…In practice, materials are leaked from recycling loops or delayed from exiting the economy." There is then the issue of quality, where CE must face the second law of thermodynamics: the total entropy of an isolated system can never decrease. Cullen (2017) points out that local entropy increases can only be prevented by adding energy to the system, so material downcycling occurs naturally. Even in nature, recycling depends on energy-expensive processes, such as reduction and oxidation (Skene 2018). Still, if in energy terms the planet is an open system (Kiehl and Trenberth 1997) with constant input from the sun, the same cannot be said (so far) for matter. Apart from meteorites landing, space vehicles leaving, and hydrogen atoms lost at the upper layers of the atmosphere, new matter will not form, and the existing matter will not disappear. Korhonen, Honkasalo, and Seppälä (2018) conclude that "product reuse, remanufacturing, and refurbishment should be the first desirable options in light of thermodynamics." Nonetheless, the incongruity remains that once waste is a resource, demand for it may increase, decreasing the incentive to reduce it.

The desire for continued economic growth cannot be ignored, leading to increased use of resources, so the so-called "closed loop" economy needs new inputs. Allwood et al. (2011) found no evidence to support the idea that secondary production can completely replace primary production and we witness a search for an optimal level of recycling/reuse (Stahel 2017). Even with efficiency gains, the Jevons effect cannot be ignored: Jevons (1865) argued that when technological progress or government policy improves resource efficiency, consumption rises due to increasing demand. No empirical data support that CE can have any impact on curbing the growth in demand, and Rizos, Tuokko, and Behrens (2017) suggest that there is limited information on CE changes in "consumption spending patterns." Millar, McLaughlin, and Börger (2019) state that "the negative environmental impact will ultimately be the same as that of the linear economy, albeit occurring over a much greater time period."

There is abundant research on resource flows but less on stocking. Economic growth leads to stocking: retained resources unavailable for secondary production. Schiller, Müller, and Ortlepp (2017) call it "anthropogenic stock" and they assessed material stock for Germany, finding that it keeps growing. In other words, inflows exceed outflows and

> [t]he total anthropogenic material stock of buildings, infrastructure and building services as well as durable consumer goods is roughly 79 times the annual material inflow to these goods (~350 million tons). Only 0.8% of material stock of these classes of goods leaves as outflow (~210 million tons) whilst the net annual rate of growth is about 0.5%.

Elhacham et al.'s (2020) work illustrates the real scale of stocking, comparing human-made mass and living biomass and Figure 2 shows that around 2025 concrete and aggregates will have reached the total weight of all Earth's biomass.

Transition to CE is not the mere evolution of existing practices and it will require "a fundamental shift instead of incremental twisting of the current system" (Kirchherr, Reike, and Hekkert 2017), achieved through the deployment of new systems. Such systems can exist at three levels—macro, meso, and micro—corresponding to the whole economy, sectors/clusters, or regions and individual organizations or products. Adams et al. (2017) synthesize this perspective as "thinking in systems by studying the flows of material and energy through industrialized systems, understanding the links, how they influence each other and the consequences, enabling closed-loop processes where waste serves as an input."

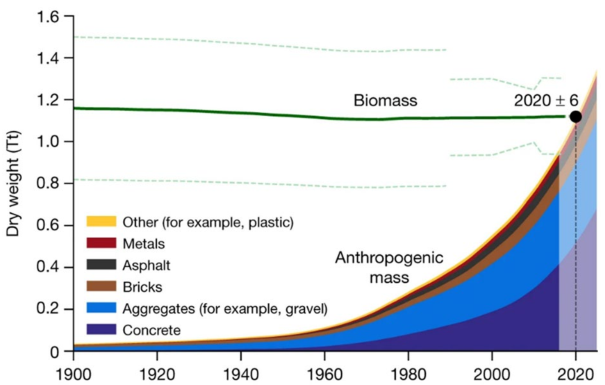

Figure 2. Biomass and anthropogenic mass estimates since the beginning of the twentieth century on a dry-mass basis. *Source:* Elhacham et al. (2020).

Barriers to CE

Barriers to CE appear at several levels and we begin with the economic barriers. Higher upfront costs are to be expected as circular construction practices may have higher upfront costs than traditional construction practices. This is due to factors, such as the higher cost of reused or recycled materials and the need to invest in new technologies and processes (Ritzén and Sandström 2017). Unfortunately, there are still few financial incentives to support CE practices in construction, and government taxation and subsidy policies need to be accelerated for the concept to become more firmly embedded in practices (Ghisellini, Cialani, and Ulgiati 2016).

There are also behavioral barriers. At the most basic level, many construction-industry stakeholders are unaware of the benefits of CE or how to implement it, and the industry's project-based nature can be a further obstacle (Eberhardt, Birgisdottir, and Birkved 2019). The sector is also known for its conservatism and risk-averse culture (Ruparathna and Hewage 2015), which can make stakeholders reluctant to adopt new practices, even if they are potentially beneficial.

Kanters (2020) finds that there is a lack of political priority, which may be reflected along the construction chain. There is a lack of government policies and regulations supporting CE implementation in construction and this includes efforts to promote the use of recycled materials, to encourage the adoption of circular design principles, and to support research and development on the CE. The regulations governing the use of recycled materials in construction are often unclear and unduly complex.

Finally, there is currently no standardized set of methods for assessing the circularity performance of buildings and construction projects at a technical level. This situation makes it difficult to compare the circularity of different projects and to track progress over time (Khadim et al. 2023). Moreover, if we cannot easily assess circularity, it is also hard to promote it.

Available measures of circularity

Measuring circularity is crucial to understanding the impact of individual actions and diagnosing broader trends. Still, measurement becomes a hostage of the concept being measured, and as seen earlier, CE comes in a variety of flavors, and measurement is a consequence of the definition. Haupt and Hellweg (2019) find that most indicators "fail to cover the environmental perspective." Parchomenko et al. (2019) assess 63 CE metrics and 24 features relevant to CE. They "distinguish three main clusters of metrics: (i) resource efficiency cluster, (ii) materials stocks and flows cluster, (iii) product-centric cluster," noting that the scope is still narrow and "most prevailing CE perspectives focus on waste disposal, primary vs. secondary use of resources, resource efficiency/productivity and recycling efficiency," with no attention to the social angle.

A similar scenario can be observed in the construction industry, with much written about recycling measurement. Heisel and Rau-Oberhuber (2020) emphasize that the sector has an "undocumented and unspecified stock of material resources" but some solutions have surfaced. Nuñez-Cacho et al. (2018) propose "seven different weighted dimensions: four related to resource management: 3Rs (Reduce, Reuse, and Recycle), Efficient Management of Energy, Water, and Materials; two dimensions regarding environmental impact: Emissions and Wastes generated; and one providing indicators of transition to the CE."

Recent years have seen the emergence of building-circularity indicators (BCIs), sets of metrics used to assess the circularity performance of buildings. Dozens are available and include, for example, Verberne Building Circularity Indicator (VBCI), Material Circularity Indicator (MCI), Bâtiment Bas Carbone (BBCA), Flex, and so forth. They provide a quantitative approach to evaluating how well a building is designed, constructed, and operated to minimize its environmental impact and maximize resource efficiency. BCIs can provide valuable information to decision-makers, helping them select materials, design strategies, and develop operational practices that minimize environmental impact and maximize resource efficiency. BCIs can also track progress toward circularity goals at the building, project, and organizational levels. Although focusing on buildings, such indicators are less suitable to assess the circularity performance of organizations. However, there is currently no standardized set of BCIs (Khadim et al. 2022), and their "methodologies lack consensus on CE definition and scope" (Khadim et al. 2023). The availability of data for calculating BCIs can be limited, especially for older buildings. Moreover, BCIs typically focus on the environmental impact of buildings, but they may not fully capture other aspects of circularity, such as social and economic impacts. Nonetheless, as BCIs continue to be developed and refined, they are likely to become increasingly important for assessing the circularity performance of buildings and guiding decision-making toward a more sustainable future.

How does the construction industry define CE?

As described above, the CE can have a broad scope of interpretation and application. We have analyzed the relevant publications to discern how the construction industry understands the concept. Our approach is akin to Kirchherr, Reike, and Hekkert (2017) but limited to a particular sector. We use their framework for what can be included in the definition of CE and check for its presence or absence. This approach has certain advantages and disadvantages. On one hand, this framework is not particular to any industry so its application to construction is straightforward. On the other hand, it does not provide sector-specific information on technological or management issues.

Materials and methods

Sample

The sample comprises all of the publications where the authors present a definition of CE, either their own or adopted from elsewhere. We used the Scopus database to obtain an initial list of publications, as it indexes a more exhaustive list of recent sources than the Web of Science, which is stronger in historical content. Search terms were selected to focus the results on CE papers concerning the construction industry. An initial search of the subset "title, abstract and keywords" was conducted for the strings "circular economy" AND ("building" OR "construction" OR "built environment") in research and review articles published in journals (articles and reviews), written in English, by far the most employed and generally considered as the international academic language. We did not use a starting date cutoff and the last search date was December 31, 2022. Non-relevant scientific areas were unselected.

This search yielded 1,326 articles. To narrow the pool, we performed a second search for those articles containing ("definition" OR "defined"), returning a total of 374 documents. A similar search (before narrowing the pool) was conducted using Web of Science to validate the choice of Scopus, resulting in only 112 articles vs. 1326 articles in Scopus. A title analysis for relevance reduced the pool of 374 to 210 articles, with an abstract analysis producing a final count of 195.

We were able to obtain full text for all 195 articles and we carried out a first reading to scan for definitions of CE, with 101 (51.8%) addressing the concept in one form or another. The process is illustrated by a Prism flow diagram (Figure 3). Of these

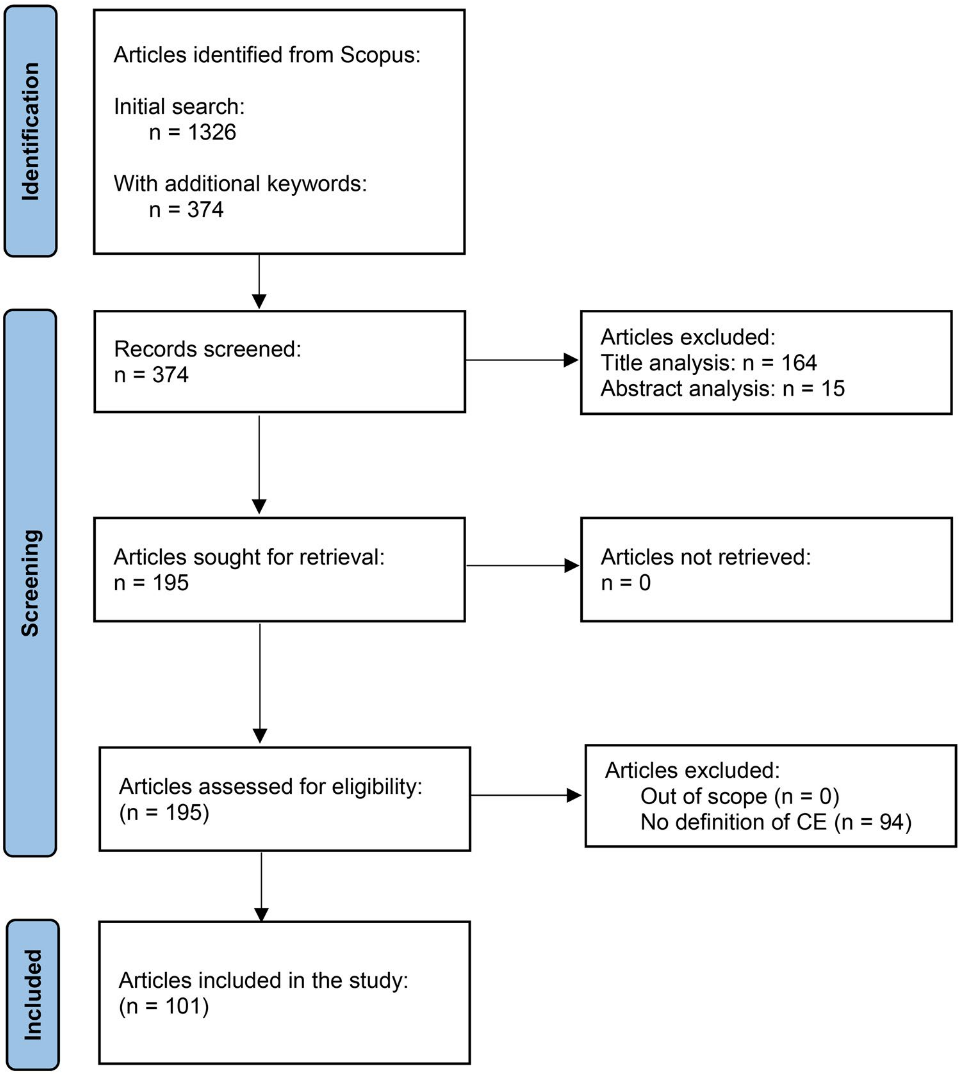

Figure 3. Article-selection process illustrated using a PRISMA flow diagram.

101 articles, 16 were literature reviews containing multiple definitions collected from other publications. Still, it was possible to obtain the authors' perspectives from all articles. Literature in this area is very recent: 87 out of 101 articles were published in 2020–2022 (see Figure 4).

Coding framework

As mentioned above, this study applies the approach of Kirchherr, Reike, and Hekkert (2017) to the construction industry and we consequently used the same coding framework. For further details and justification refer to their article. These are the coding dimensions that we adopted.

1. Core principles
i. The 4 R CE framework (Reduce, Reuse, Recycle, Recover) from the EU's Waste Framework Directive (2008/98/EC) (European Parliament and Council 2008) with the hierarchy of Rs used to maximize value and minimize downcycling.
ii. CE Systems perspective: macro, meso, and micro CE systems (referring to the entire economy, eco-industrial parks/regions, and products/individual enterprises/consumers, respectively).
3. CE aims: SD was included as the coding dimension by itself when mentioned without detail, and through Environmental Quality, Economic Prosperity, Social Equity, and the time factor (Future Generations).
4. CE enablers
i. Business models
ii. Consumers

The final coding framework, which consists of 17 coding dimensions employed to code all 101 definitions, is depicted in Table 2.

Coding procedure

The coding was done manually to prevent loss of meaning from a statistical analysis by automated software, as Kirchherr, Reike, and Hekkert (2017)

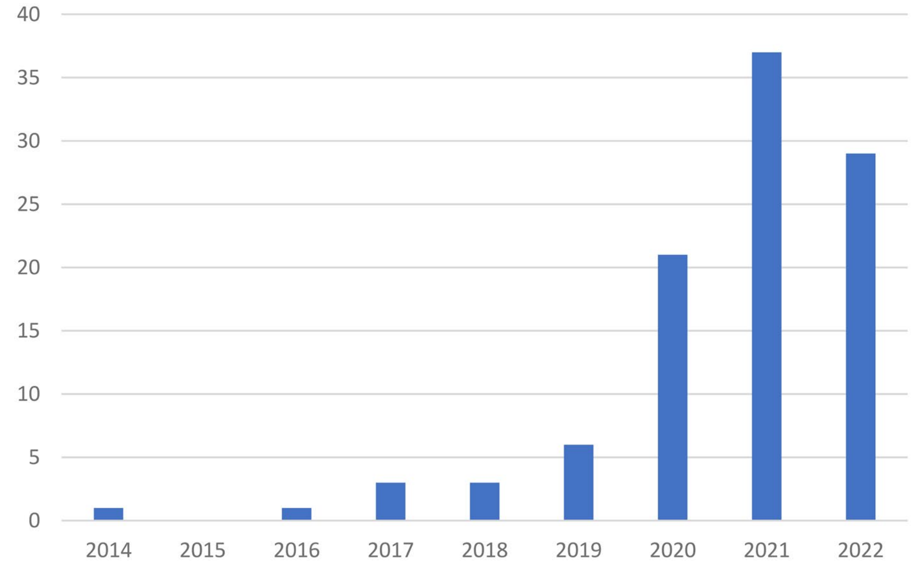

Figure 4. Number of articles with CE definitions per year.

Table 2. Sample coding dimensions.

	Mentioning of (in sample)	
1		Reduce
2		Reuse
3		Recycle
4		Recover
5		Waste hierarchy
6	Systems perspective	
7		Micro-systems perspective
8		Meso-systems perspective
9		Macro-systems perspective
10	Aim: Sustainable development (SD)*	
11	Aim: All dimensions of SD	
12		Environmental quality
13		Economic prosperity
14		Social equity
15		Future generations (time dimension)
16	Enabler: Business models	
17	Enabler: Consumers	

*SD only, without subdimensions.

have justified in detail. We performed the coding by a single coder, who had to make decisions in ambiguous situations. Such cases were discussed among the authors. Some authors are present in multiple articles, often with varying co-authors. These articles were fully considered, as often there were different definitions or an evolution of the perspective on CE. A spreadsheet with the results is provided as Supplementary Material.

Analysis criteria

We looked for concise CE definitions in the analyzed articles, but these were not always available. The authors' views were often dispersed throughout the text, requiring a full-text study to determine if the 17 coding dimensions were present. Although dispersed definitions were gathered, we only considered explicit mentions that did not infer implicit meanings and did not make any interpretations other than the use of synonyms.

Limitations

The core limitation of this study is its focus exclusively on scientific articles, leaving the industry and other documents and practitioners' opinions untapped. Furthermore, it is a long leap from what gets published in a journal to what gets implemented in actual practice. The exclusive use of Scopus may also have left some works out of the analysis. The analysis-framework base (Kirchherr, Reike, and Hekkert 2017) could have been updated, but that would have impaired comparisons with the original study. It was also impossible to correlate the definitions with their author's qualifications, familiarity with the CE, or area of work or experience. Our methodology could have benefited from further

Table 3. Coding results on core principles.

Mentioning of (in sample)		%
CE dimensions		
	Reduce	92
	Reuse	100
	Recycle	100
	Recover	58
	Waste hierarchy	22
Systems perspective		34
	Micro	16
	Meso	9
	Macro	12

Note: Full sample = 101 definitions.

Table 4. Coding results on aims and enablers.

Mentioning of (in sample)		%
Aims		
- Sustainable development (SD)		20
- All dimensions of SD		41
	Environmental quality	73
	Economic prosperity	68
	Social equity	41
	Future generations (time dimension)	8
Enablers		
- Business models		45
- Consumers		16

Note: Full sample = All 101 definitions.

validation using multiple coders, but limited resources did not allow for such a process.

Results

Core principles of the circular economy

Not surprisingly, there is the universal embrace of recycling (Table 3), which has been ingrained in the culture for decades, and reusing, which is immediately associated with CE. The reduction component also scores very high while the recovery component raises less interest. This may be partially explained by articles of Chinese origin, where the 3Rs are set in law. To a certain degree, articles share cultural features connected to the authors' provenance and notably are influenced by European or Chinese legislation. However, this issue is worth further study.

The waste hierarchy that prevents resources from being used below their maximum potential is present in only 26% of articles. Explicit discussion of CE as a system is still not predominant, appearing in 43% of cases, with the micro-systems perspective being the most common.

Aims of the CE

Of the articles in the sample, 73 and 68% show an explicit role of CE as a way of fulfilling the environmental and economic aims of SD, respectively (Table 4). However, only 41% of the articles embraced the three pillars of sustainability, as many ignored social equity (41%). SD's time dimension, the equitable treatment of future generations, is of concern only in 8% of the cases. SD as an undetailed aim appears in 20% of the cases.

Enablers of CE

The construction industry still has a long way to go in internalizing the relevance of CE enablers. Only 16% of the articles saw consumers as drivers of CE. Less than half (45%) of articles understood the relevance of conceptualizing novel circular business models, which are already commercially available, for example, in the form of services in lieu of products. Nevertheless, due to market pressure or sustainability concerns, many large corporate consumers are at the vanguard as certification schemes that include aspects of SD are concerned (e.g., BREEAM, LEED, WELL), some of which also incorporate elements of the social pillar.

Challenges and future direction of CE in the construction industry

The results presented above show there are challenges with respect to understanding the waste hierarchy, adopting a systems perspective, embracing social equity, and considering future generations and the role of consumers.

Future developments should fill these gaps. We anticipate the increased adoption of circular design principles, allowing for a cascade effect on the downstream activities, resulting in broader coverage of the CE principles, and allowing better choices in the actions hierarchy. This is an incipient process, and Dokter, Thuvander, and Rahe (2021) show that implementation thus far has been mostly limited to the reuse of materials for the design of new buildings and structures. Their research reveals some of the challenges, particularly the need for flexibility within the design process, due to uncertainty regarding what components and materials will be available.

Upstream, similar developments from materials and equipment suppliers are in some cases being pushed by CE-oriented procurement rules, being deployed particularly at the municipal level, in a variety of cities, from Lisbon to Phoenix (EMF 2023). In parallel, frameworks are being developed for circular supplier selection (Tushar, Bari, and Khan 2022).

Metrics for social equity in the sector are emerging (Jones and Armanios 2020) and there are signs of growing pressure to address the social equity area. Gurmu et al. (2022) assessed the social equity situation in the construction industry. They identified increasing awareness, market pressure, client requirements, incentives, ability to spend, international certifications, investor pressure, lack of resistance to implementation, regulatory compliance, and pressure from employee unions and social organizations as the main factors enabling social equity.

Policies are also evolving, as governments worldwide recognize the importance of CE and are developing policies to support its implementation. Above, the efforts of the EU and China were mentioned, but several other countries also have moved in the same direction, among them Japan (METI 2020) and South Korea (National Assembly of Korea 2023).

Discussion

This work establishes a benchmark for comparison with other sectors and across time within the construction industry and identifies weak points where progress is required. Results confirm the underdeveloped view of CE within the construction industry's research community, with varying opinions of what it comprises, its aims, and requirements, in some cases there is also a superficial view of the aims of SD, with a lack of attention to each main component.

The sector is clearly embracing the linkage of CE to SD while revealing a lesser concern for the social dimension of SD, which should be addressed. Here we see important roles for both procurement rules and regulations and for the training of construction professionals. A certain hyperopia may also exist, with a concern for abstract, distant social improvements, while the construction industry itself experiences enduring issues, such as poor health and safety and inferior working conditions (Abrey and Smallwood 2014). While the well-being facet of the social dimension should be within reach of the industry, the areas of equity and human rights of both people and communities seem, from our perspective, less actionable.

The future dimension of SD is also neglected, which is paradoxical in an industry based on long-term products, often designed in a short time and with obvious impacts on the living conditions of future generations. The social and intergenerational equity dimensions of SD in the construction industry are open avenues meriting further research.

The inadequately addressed areas mentioned above illustrate a less-than-perfect overlap of the perception of CE vis-a-vis SD. Germane to this observation is also the analysis of Geissdoerfer et al. (2017) who compared the two concepts and point out that SD aims to benefit the environment, the economy, and society at large, while CE has the "Economic actors…at the core." Corvellec, Stowell, and Johansson (2022) describe the issue in blunter terms: "Circular economy is based on an ideological agenda dominated by technical and economic accounts, which brings uncertain contributions to sustainability and depoliticizes sustainable growth."

Our study also reveals a still limited understanding of the waste hierarchy in CE as it pertains to the construction industry. Its three main components (Reduce, Reuse, Recycle) are almost universally espoused but the Recover component is mentioned in just over half of the documents. A lack of understanding of the structure of priorities may explain this situation or even be a consequence of decades when Recycling was on the table or was the most comfortable option for pushing responsibilities to the actors who manage the waste. Still, this may also be due to some stakeholders being less inclined to embrace Reuse (or even Refuse and Reduce), as associated strategies could undermine consumption and economic growth. The industry-specific SD tools should evolve to include the notion of hierarchy in decision-making. In the construction industry, early decisions in the Reduce and Reuse areas can produce significant impacts, as each "product" typically mobilizes vast resources for a long time. For example, such upstream decisions may cut carbon emissions and land use.

Accepting a "systems perspective" is still limited at the micro, meso, or macro levels (Table 3). This is not surprising as it requires a change in mental framework, and although a systems perspective appeared in the early publications on CE, it was often lacking as per Webster (2013). Work by Adams et al. (2017) shows "limited research on the application of circular economy principles in the built environment, within a whole systems context." Still, the results are better at the micro level than at the meso or macro levels, as organizations within the construction industry will grasp the processes that concern them directly as opposed to the sectoral or economy-wide impacts of their actions. Recent standards for CE developed by the ISO and national standardization bodies may positively impact this issue, similar to what happened in the past with quality management.

Further to a systems perspective, switching from the current linear model of the economy to CE requires the support of novel business models and comprehensive structures for an organization's business processes in the context of its supply chain. These enablers can "catalyze on collaboration and technological innovation, and the improvements of performance and efficiency" (Antwi-Afari, Ng, and Hossain 2021). These models will compete with extant linear flow models and older CE business models (Korhonen, Honkasalo, and Seppälä 2018). Our results show that the perception of this need for change is not widespread but already quite relevant, at 45% of articles. Sometimes, these models are externally imposed, as in some instances of public procurement rules for construction contracts. The construction industry's growing adoption of digital technologies (e.g., BIM) and trends, such as transforming products into services lend a positive note in this area.

Consumers are not a major element among the definitions that we examined. The lack of appreciation of consumers as CE enablers may be linked to the above issue of business models that have consequences on consumption models. Hobson (2019) considers this partly a result of CE being founded in work with little concern for the end user. The concept of collaborative consumption models has been cited as one of the best alternatives to shift from the current business-as-usual model to CE by authors like Ghisellini, Cialani, and Ulgiati (2016) or Ness (2008). However, collaborative consumption in the construction industry still faces major implementation hurdles and Naderpajouh, Zolghadr, and Clegg (2024) find that "such forms of resource sharing are impeded by tensions associated with uniqueness, complexity, and spatiality of projects, criticality of project success, resource relevance, industry norms, common practices, regulatory issues, and perceptions of risks and redundancies."

Governments and the public sector are significant clients of the construction industry and have the potential to drive change both as large consumers and as producers of legislation that shape the rules for the private markets. In construction, many organizations do not deal directly with the final user of their product, being more concerned with the requirements of property developers and other project promoters. They are, therefore, only indirectly aware of the consumers' values and dispositions. Additionally, the concern of individual consumers with SD in other areas of their lives still has to be nudged to extend this concern to the buildings where they live, work, or invest.

Not only are the definitions under development but also the methods and tools are in flux. It is worth noting that the so-called digital transformation of the construction sector may become an essential tool for developing and incorporating CE goals. For, as noted above, BIM methodologies are a testbed for techniques and transformation models when integrated with diagnostic tools, materials, and product data. Through the utilization of digital technologies, the construction industry can enhance information flows, improve sustainability, and effectively manage waste (Mêda et al. 2021). Digital solutions facilitate the reuse of materials, efficient demolition processes, and streamlined waste management (Sivers, Fröhlich, and Fivet 2022). Digital technologies can support circularity by enabling the creation of sustainable circular products and enhancing customer engagement (Maury-Ramírez, Illera, and Mesa 2022). A comparison of the construction industry with Kirchherr, Reike, and Hekkert's (2017) more general methodology illustrates where construction differs from the economy as a whole. The comparison only makes sense for the "2012 or later" part of their sample, as the earliest article in our sample dates from 2014. The results are displayed in Table 5. Values for the 4 Rs are all higher in construction, which may be since, on average, our sample is younger. Our results regarding CE systems are lower, except for micro-systems. Construction-sector numbers for "aims" are higher, but they parallel the findings of Kirchherr et al. in that social and intergenerational equity rank very low. Novel CE business models score much higher in our work, again probably because of the more recent nature of the sample. Consumers as enablers rank low in both samples.

Conclusion

We started by asking "How does the scientific community in the construction sector perceive the CE?" The results show that although since 2020 there was an explosion in the number of publications dedicated to CE in the sector, the industry's grasp of the concept is underdeveloped. Since the examined publications emanate from the research community, the situation may not be better among practitioners.

Table 5. Comparison with Kirchherr, Reike, and Hekkert (2017).

Mentioning of (in sample) …		% Kirchherr ≥2012	% Construction sector	Dif.
CE dimensions				
	Reduce	48–49	92	>
	Reuse	75–76	100	>
	Recycle	73–75	100	>
	Recover	6–7	58	>
	Waste hierarchy	23	22	≈
Systems perspective		47	34	<
	Micro	22	22	=
	Meso	24	9	<
	Macro	22	12	<
Aims				
- Sustainable development (SD)		12	20	>
- All dimensions of SD		13–14	41	>
	Environmental quality	35–36	73	>
	Economic prosperity	45	68	>
	Social equity	16–18	41	>
	Future generations (time dimension)	1	8	>
Enablers				
- Business models		14	45	>
- Consumers		20	16	<

An extended period where recycling ruled as the core perceived contribution of the industry to SD still influences current views, and only gradually, a more comprehensive approach, going beyond end-of-pipe solutions, is evolving. The perception of the relation to SD is currently incomplete. The implications of the above findings consist essentially of wasted opportunities and suboptimal solutions due to a lack of understanding of the full scope of CE.

The reasons for this deficit should be a subject of further research, which should also cover a broader range of actors. Further research should also reduce the fuzziness of areas that fall under the social dimension of SD. This leaves a lot of open opportunities for developing industry-specific tools that consider not only technological aspects but also organizational characteristics, particularly the industry's project-oriented identity. It should also be remembered that early decisions will have the most significant impacts: CE deployment in construction-design activities should be a priority.

Still, and concluding on a positive note, these fragmented views of CE are a sign of an ongoing process where the vitality of transformation precludes the quick emergence of a consensus. The conception and deployment of adequate techniques to bring SD to the construction industry have been ongoing for three decades, with the digital tools that support it only emerging in the last twenty years. Previous developments may help place things in perspective, and we should remember that it took centuries to create the current building structural analysis methods, which continue to evolve.

Acknowledgements

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Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by the SECClasS–Sustainability Enhanced Construction Classification System funded by EEA Grants and partially supported by Fundação para a Ciência e a Tecnologia, IP (FCT) [ISTAR Projects: UIDB/04466/2020 and UIDP/04466/2020].

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