An Analysis of the Circularity Indicators at the Building Design Level

Bahar Feizollahbeigi and Ricardo Mateus( )

ISISE, ARISE, Department of Civil Engineering, University of Minho, Guimarães, Portugal
ricardomateus@civil.uminho.pt

Abstract. The built environment is responsible for around 50% of the total extraction of raw materials and 25% of all waste in the European Union, which comprises numerous materials that still have the potential for reuse and recycling. Due to the planet's nite reserves, transitioning towards a circular approach in the built environment to achieve sustainability, particularly at the building design stage, is inevitable. At this level, the role of indicators as the primary measurement tools is essential to assess the circularity in the built environment and guide the implementation of circular economy (CE) principles into the design and construction of buildings and infrastructure. This study aims to analyse international and European policies and standards and extract and present the remarkable and relevant existing circularity indicators at the building design level. Subsequently, a categorised list of the most employed indicators to measure building design-level circularity is discussed. To achieve this goal, a bibliographic-analytical approach is used to analyse the prevalence and alignment of several sustainability and circularity criteria in international policies and standards at the building design level. Finally, the indicators are classi ed into seven categories: Material and Resources, Energy resources, Water resources, Waste Management, Environment, social and economic indicators. In conclusion, suggestions for further research that have the potential to facilitate the design processes of engineers, architects, and stakeholders are presented. The outcomes of this research can signi cantly contribute to creating a more circular and, consequently, sustainable built environment.

Keywords: European policies and standards · circularity indicators · building design · the 9Rs framework

1 Introduction

The construction industry consumes more than three billion tons of raw materials [1], and buildings are responsible for 25–40% of the global total energy consumption, contributing hugely to carbon dioxide emissions [2]. Although recent decades have seen many improvements, the built environment continues to be designed around the linear 'take-make-dispose' model, in which materials are sourced, used, and disposed of as waste. This approach results in signi cant environmental problems. For instance, construction and demolition accounts for 25–30% of all waste generated in the EU3 (France, Germany, and Italy, three large founding members of the European Union) [3]. Additionally,

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buildings in the European Union are responsible for 40% of energy consumption and 36% of greenhouse gas emissions [4]. The solution that the world community agrees on to overcome the negative consequences caused by the built environment is a transition from a linear to a CE. Based on Ellen MacArthur's Foundation (EMF), the CE is a system solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. The CE is also governed by the 9Rs framework, which defines the major strategies that aim to reduce materials use and waste generation and includes ten strategies [5]: R0 (Refuse), R1 (Rethink), R2 (Reduce), R3 (Reuse), R4 (Repair), R5 (Refurbish), R6 (Remanufacture), R7 (Repurpose), R8 (Recycle), and R9 (Recover).

In the CE, design and innovation are critical components of all activities [6]. The design stage is the second phase of the building life cycle, and it is when comprehensive plans for the structure's final design are drawn up, and all the preparation required to begin construction occurs [7]. Regarding the considerations in the design phase, the EMF defines the CE based on three principles, driven by design [8]: 1) Design out waste and pollution; 2) Keep products and materials in use; 3) Regenerate natural systems. A circularity assessment must be done to ensure that the CE principles are implemented. Basically, for any type of assessment, a set of indicators is needed to monitor the implementation of the policies [9].

The standards and frameworks are primarily used to assess the sustainability of the construction, not necessarily the CE. Circularity and sustainability are confused and somewhat interchangeable. According to the U.S. Chamber of Commerce [10], sustainability describes all activities that ensure that human beings can co-exist with the natural world around them. In comparison, circularity is deciding which raw materials go where and how to retain their value for the maximum time. Also, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [11]. However, it defines the CE as a new and inclusive economic paradigm that aims to minimize pollution and waste, extend product lifecycles, and broadly share physical and natural assets [12].

Over the past decade, academics, professionals, and governmental officials have shown significant interest in implementing the CE principles within industries that significantly affect the environment, including the construction sector. In this regard, various research studies have been done. In 2021, Rahla et al. [13] reviewed current trends of criteria for building materials to identify selection criteria for building elements according to CE principles through a review of the latest research. Results have shown that little has been concretely achieved in terms of a paradigm shift to CE because the literature focuses on the recyclability of building materials and components at their end-of-life. In 2018, EMF, in cooperation with Arup (a British multinational professional engineering consultant) [14], designed a comprehensive circular building design toolkit to assess the circularity of the building at the design level. The toolkit [14] has a total of 10 indicators, which are based on current international leading policies and guidelines such as Level(s). In another study done in 2019, Corona et al. [15] conducted a review study and critical assessment of current circularity metrics to map methodological developments regarding circularity metrics to identify the foundations of circularity metrics and their applications. The result of the study revealed that none of the assessment frameworks address the CE concept in full, potentially leading to undesirable burden shifting from reduced material consumption to increased environmental, economic, or social impacts.

This study aims to analyse the indicators provided by the standards and frameworks in the construction industry and extract and classify a set of circularity indicators of building design level.

2 Methodology

This study is qualitative comparison-oriented research and aims to analyse the sustainability indicators provided by the international frameworks in the built environment, extracting the circularity indicators of building design level using the 9Rs framework, which defines the major strategies to do the process in an eco-friendly way [13], and finally providing a list of final indicators based on their impact areas.

2.1 Structure and Steps of Analysis

Reviewing the International Framework: A comprehensive study was conducted on international frameworks in construction. Among all reviewed references, frameworks that provide a set of indicators, including Level(s) [16], EN 15804 [17], EN 15643 [18], and ISO 21929 [19], were considered in the analysis.

Screening the CE Indicators: At this stage, it was necessary to identify CE indicators in the sustainability indicators. So, a comparative methodology was adopted to compare all the extracted indicators with the circularity 9Rs framework. The indicators corresponding directly to at least one of the 9Rs were selected as circularity indicators.

Uniformisation of Indicators: References provide indicators that, despite having different names, are used to measure an identical parameter. Therefore, through detailed analysis and comparison of all the indicators, a unification was done to remove the duplicate items and integrate similar indicators.

Categorising the Final Circularity Indicators: The categorisation of the circularity indicators was based on a framework developed by Kubbinga et al. in 2018 [20], which defined the design and construction indicators that promote circular buildings to be integrated into the BREEAM (Building Research Establishment Environmental Assessment Method) [21].

3 Results and Discussion

Regarding the differences between sustainability and circularity, not all the indicators presented for sustainability assessment can necessarily be employed to measure circularity, so in this study, a methodology was defined to extract the circularity indicators from the sustainability ones by the following frameworks.

3.1 Reviewing the International Standards and Framework

Among all the standards and frameworks presented in the eld of construction sustainability, four references were reviewed to analyse their circularity streaks in detail as follows, and compliance with 9Rs has also been done.

Level s)

Level(s) is a common European framework that emerged in 2018 to help construction sector professionals assess and monitor buildings' circularity and sustainability throughout their life cycle. The Level(s) framework comprises 16 indicators, grouped into six macro-objectives belonging to 3 thematic areas [22]. These core sustainability indicators measure carbon, materials, water, health, comfort, and climate change impacts throughout a building's life cycle. Level(s) promote circularity, especially on its macro-objective 2, "Resource-ef cient and circular material life cycles," which aims to ensure resource-ef cient and circular material life cycles [16]. Figure 1 demonstrates the relationship and frequency of circularity 9Rs with the Level(s) sustainability indicators.

Considering that the most circularity indicators in Level(s) are with emphasis on R2-Reduce, R3-Reuse, R4-Repair, and R5-Refurbish, the circularity indicators of Level(s) are highly compatible with the principle 2 of Ellen Macarthur CE principals which is "Keep products and materials in use."

EN 15804:2012+A2:2019 Sustainability of construction works-environmental product declarations - Core rules for the product category of construction products

EN 15804 is a European Standard under the responsibility of CEN/TC 350, considered the most popular global standard for producing Environmental Product Declarations for construction products [17]. Comparing EN 15804 and the circularity 9Rs framework revealed that these two frameworks share objectives of promoting sustainability, resource ef ciency, and circularity in the construction industry. By reviewing the frequency of 9Rs in the indicators of EN 15804, it was found that among all 9Rs, R2-Reduce, R0-Refuse, and R3-Reuse have the most compatibility with the EN 15804 sustainability indicators, which demonstrate the emphasis of this standard in resources use and material conservation, which are compatible with principal 1 and 2 of Ellen Macarthur CE principals "Design out waste and pollution ", and "Keep products and materials in use".

EN 15643 WI=00350031): Sustainability of construction works-framework for assessment of buildings and civil engineering works

EN 15643 is a series of European Standards under the umbrella of CEN/TC 350 that provide a system for the sustainability assessment of buildings' environmental, social, and economic performances and civil engineering works [18]. The connection between EN15643 and circularity lies in the standard's approach to assessing the environmental performance of buildings, namely through EN15643-2. As shown in Fig. 1, the comparative alignment of the EN15643 indicators with the 9Rs framework revealed that, among all the 9Rs, R2-Reduce, followed by R0-Refuse and R3-Reuse, were the most frequent among the 9Rs.

ISO 21929 Sustainability in Building Construction _ Sustainability indicators. Framework for the development of indicators and a core set of indicators for buildings
The ISO 21929 framework includes a list of critical environmental, social, and economic impact indicators [19]. The connection between ISO 21929 series and circularity lies in the attempt of this standard to introduce a framework for the development of indicators, including a set of environmental indicators, such as using renewable resources, water consumption, and waste production, which are aligned with the principles of the CE. Analysing Fig. 1, R2-Reduce was the most repeated with a frequency of 10, which shows that this standard also emphasises principle 2 of the CE: "Keep products and materials in use".

3.2 Harmonisation of Indicators

By screening all the indicators provided by reviewed references, 56 initial indicators were extracted as circularity indicators (Table 1). In this section, harmonisation was done through a detailed analysis of all indicators to remove duplicates and integrate similar indicators into one.

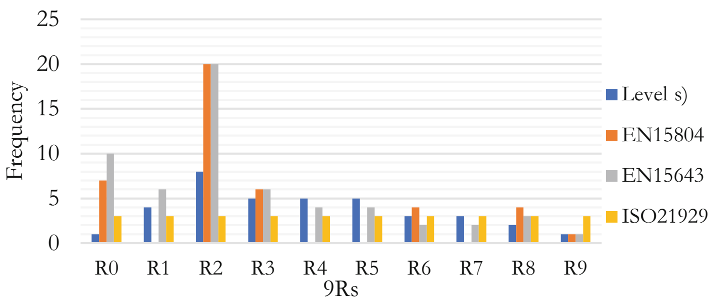

Fig. 1. Frequency of circularity 9Rs in the reviewed frameworks.

As indicator 1 measures the mass of construction products and materials necessary to complete the building, this indicator is classi ed under the material and resources class [18]. Indicators 2 and 3 measure renewable sources as raw materials (other than energy), so they were uni ed as the "Use of renewable resources as raw material" indicator. Indicators 4–7 also measure the non-renewable and recycled resources as raw materials. Accordingly, they were uni ed as "Use of non-renewable resources as raw material". Indicator 8 was considered separate because it refers to reuse, which means using a material with its original function [14]. The indicators 9–11 were merged since they all measure "Non-hazardous waste". The same logic was used to unify indicators 12 and 13, and 14 and 15. Indicator 16 was removed since it was covered under the coverage of other harmonised indicators of this class. Regarding energy resources, indicators 17–19 were merged since they all measure the same parameter. Indicators 20 and 21 refer to renewable primary energy; therefore, they were merged too. The same happened for indicators 22 and 23 since both are to measure renewable secondary fuels. Indicators 24 and 25 also measure the same metric.

Table 1. Harmonisation of the extracted circularity indicators of the building design stage.

Initial indicators	Harmonised indicators
1. Bill of quantities, materials, and lifespans [16]	1. Bill of quantities, materials, and lifespans
2. Use of renewable resources other than primary energy [18]	2. Use of renewable resources as raw material
3. Use of renewable primary energy resources used as raw materials [17]	
4. Use of non-renewable primary energy resources used as raw materials [17]	3. Use of non-renewable resources as raw material
5. Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials) [17]	
6. Amount of non-renewable resources consumption by type (natural raw materials and non-renewable energy) [17]	
7. Materials for recycling [17]	
8. Components for reuse [17]	4. Components for reuse
9. Non-hazardous waste to disposal [18]	5. Non-hazardous waste production
10. Non-hazardous waste disposed [18]	
11. Construction and demolition waste [16]	
12. Hazardous waste to disposal (other than radioactive waste) [18]	6. Hazardous waste production
13. Hazardous waste disposed [17]	
14. Radioactive waste to disposal [18]	7. Radioactive waste production
15. Radioactive waste disposed [17]	
16. Amount of waste generation by type (hazardous and non-hazardous wastes) [19]	Already covered by harmonised indicators 5–7
17. Amount of non-renewable resources consumption by type (natural raw materials and non-renewable energy) [19]	8. Use of non-renewable primary energy
18. Use of non-renewable primary energy [17]	
19. Use of non-renewable primary energy, excluding non-renewable primary energy resources used as raw materials [17]	
20. Use of renewable primary energy [17]	9. Use of renewable primary energy

(*continued*)

Table 1. (*continued*)

Initial indicators	Harmonised indicators
21. Use of renewable primary energy, excluding renewable primary energy resources used as raw materials [17]	
22. Use of renewable secondary fuels [17]	10. Use of secondary fuels
23. Use of non-renewable secondary fuels [17]	
24. Materials for energy recovery [17]	11. Energy recovery
25. Materials for energy recovery [18]	
26. Use of freshwater resources [18]	12. Freshwater consumption
27. Use of net freshwater [17]	
28. Amount of freshwater consumption [19]	
29. Acidi cation potential [17]	13. Acidi cation potential
30. Acidi cation of land and water resources [18]	
31. Abiotic depletion potential for non-fossil resources [17]	14. Abiotic depletion potential
32. Abiotic depletion potential for fossil resources [17]	
33. Eutrophication potential [18]	15. Eutrophication potential
34. Emissions to outdoor air, soil, and water [18]	16. Emissions to outdoor air, soil and water
35. Formation of ground-level ozone [18]	
36. Climate change [18]	17. Global Warming Potential
37. Global Warming Potential [17]	
38. Global warming potential [19]	
39. Life cycle Global warming potential [16]	
40. Ozone-depleting potential [17]	18. Ozone Depletion Potential
41. Destruction of the stratospheric ozone layer [18]	
42. Change of land use [19]	19. Change of land use
43. Design for adaptability and renovation [16]	20. Adaptability potential
44. Change of use or user needs [19]	
45. The ability to accommodate individual user Requirements [18]	
46. The ability to accommodate the change in user requirements [18]	

(*continued*)

Table 1. (*continued*)

Initial indicators	Harmonised indicators
47. The ability to accommodate technical changes [18]	
48. The ability to accommodate the change of use [18]	
49. Maintainability [19]	21. Maintainability
50. Maintenance operations [18]	
51. Resistance to climate change [18]	22. Adaptability for climate change
52. Adaptability for climate change [19]	
53. Design for deconstruction [16]	23. Deconstruction potential
54. Life cycle costs [16]	24. Life cycle costs
55. Life cycle costs [19]	
56. Economic performance expressed in cost terms over the life cycle [18]	

Considering that indicators 26–28 refer to measuring the amount of freshwater consumption, all were merged. Since the indicator of "global warming potential" was more frequent than "climate change" in the reviewed sources, and climate change is one of the consequences of global warming [23], therefore "global warming potential" was chosen as the final indicator. Additionally, the indicator "global warming potential" measures the greenhouse gas emissions associated with the building at different stages along the life cycle [24], and because ground-level ozone (Tropospheric ozone) is the third most important anthropogenic greenhouse gas after CO_2 and CH_4 [24], hence this indicator was merged with the indicator of "Global Warming Potential". On the other hand, indicators 40 and 41 refer to the measurement of Ozone Depletion Potential and were unified. Lastly, "Change of land use" had no identical indicator and was considered separately.

As explained earlier, based on EN 15643-3, indicators associated with adaptability and maintainability are considered under the umbrella of the social aspect [26], so indicators 43–48, which all refer to the adaptability of the building, were unified. Additionally, indicators 49 and 50 both refer to Maintainability. Indicators 51 and 52 refer to the ability to withstand and recover from adverse events or stresses, such as natural disasters and climate change [25], which indicates how buildings are resilient to climate change. Since indicators 54–56 refer to the same issue, they were unified as "Life cycle costs".

3.3 Categorising the Final Circularity Indicators

The classification framework provided by Kubbinga *et al* [20], which classifies the CE indicators based on two general impact areas (social & technical) and seven classes as seven pillars of the CE, was employed to categorise the indicators (Table 2). As some extracted indicators were not included in the speci ed categories in the above-mentioned framework due to the nature and impact areas of the indicators, this study made amendments to the mentioned categories and presented a different categorisation.

Table 2. Categories of CE Indicators

Class (Kubina et al. 2018) [20]		Categories developed by this study
Technical	1-Material cycle	1-Material and resources
		2-Waste Management
	2-Energy cycle	3-Energy cycle
	3-Water cycle	4-Water cycle
	4-Biodiversity & ecology	5- Ecosystem
Social	5-Human culture & society	6-Social
	6-Health & well-being	
	7-Multiple forms of value	7-Economic

The 24 indicators were organised into seven categories based on their impact area (Table 3). R2-Reduce was the most frequently extracted indicator, and R7-Repurpose was the least repeated one.

Table 3. The nal circularity indicators of the building design level.

Material and Resources	Waste Management	Energy Cycle	Water Cycle	Ecosystem	Social	Economic
Bill of quantities, materials, and lifespans	Non-hazardous waste production	Use of non-renewable primary energy	Freshwater consumption	Emissions to outdoor air, soil, and water	Adaptability potential	Life cycle costs
Use of renewable resources	Hazardous waste production	Use of renewable primary energy		Global Warming Potential	Maintainability	
Use of non-renewable resources	Radioactive waste production	Use of renewable secondary fuels		Ozone Depletion Potential	Design for deconstruction	
Components for reuse		Energy recovery		Acidi cation potential	Adaptability for climate change	
				Abiotic depletion potential		
				Eutrophication potential		
				Change of land use		

For instance, in this study, the material cycle class is divided into two subclasses of materials and wastes for a more accurate review of the material cycle. Additionally, based on "EN 15643-3, Social aspects [18] indicators associated with Accessibility, Adaptability, Health, comfort, and maintainability are considered under the social aspect and impacts, and therefore this study classi ed them under the social class.

4 Conclusion

The rapid urbanisation brings challenges like increased waste, resource use, and greenhouse gases. In response, policymakers and scholars are investigating the (CE) model, which aims to enhance resource management and ef ciency while reducing waste, addressing these urgent concerns.

This study aimed to analyse the international sustainability frameworks in construction and provide a list of circularity indicators for the building design stage. The ndings revealed that among the 107 analysed indicators, more than 50% of them, which count for 56, were directly associated with circularity within the building design stage, which ultimately were summarised into 24 nal indicators following uni cation. Results also revealed that although the reviewed references mainly refer to sustainability indicators and none of the approaches fully address or directly mention the CE concept, they align partially with CE principles, demonstrating an interconnecting relationship between circularity and sustainability that shows CE cannot be fully separated from sustainability. Additionally, among all 9Rs, R2-Reduce was the most frequent one, followed by R0-Refuse and R3-Reuse, respectively, for the most frequent strategies, while R7-Repurpose was the least important one. This led to the conclusion that the provided reviewed indicators mostly emphasize "design out waste and pollution" and "keep products and materials in use", which are respectively 1st and 2nd principles of EMF circular design principles.

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