Towards Circular Building Key Performance Indicators

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Abstract. The concept of circular economy (CE) nowadays garners considerable attention as strategy for resource management and waste reduction. The principles of circular economy have emerged as a promising framework for minimizing environmental impacts while maximizing resource efficiency across the entire life cycle of a building. To effectively assess and monitor the progress towards circularity in buildings, the development and implementation of appropriate key performance indicators (KPIs) are crucial. This paper provides a comprehensive overview of circular economy KPIs in the building sector, aiming at supporting industry professionals, policymakers, and researchers in understanding and implementing effective measurement and evaluation frameworks. The study identified several indicators related to circular buildings and categorized them based on building types and layers. The study findings indicate lack of robustness to comprehensively evaluate the circularity and socio-economic impacts of circular practices that highlight the need for more comprehensive and universally accepted KPIs. Such indicators could guide stakeholders, enabling them to assess progress towards circularity, identify areas for improvement, inform their decisions, and actively promote the transition towards more circular building practices.

Keywords: Circular Economy · Key Performance Indicators · Buildings

1 Introduction

The construction industry plays a crucial role in fostering economic development. However, the construction sector's linear economic model is accountable for greenhouse gas emissions, natural resource depletion, and waste production [1]. In response to these pressing concerns, the concept of CE attracted significant interest as a solution to address environmental and economic issues as the concept offers an alternative to the traditional linear economy of "take-make-use-dispose".

According to the Ellen Macarthur Foundation [2], CE is defined as "*An industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business*

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models". CE encourages the design of buildings that have a circular flow of materials throughout their lifecycle, involving procurement, utilization, deconstruction, reutilization, recycling, and resource recovery. Leising et al. [3] described CE for buildings as *"a life-cycle approach that optimises the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank"*.

Monitoring and evaluation tools are crucial for effectively transitioning to CE, as it enables organisations to track progress and make informed decisions for achieving circularity goals [4–7]. According to the Organisation for Economic Co-operation and Development (OECD) [8], an indicator is defined as "a *quantitative or qualitative factor or variable that provides a simple, and reliable, means to measure achievement, to reflect the changes connected to an intervention, or to help assess the performance of a development actor*". Megevand et al. [9] added that indicators play an important role in simplifying information, as they condense complex phenomena into measurable and quantifiable metrics and are capable of effectively communicating and raising public awareness about significant issues. In addition, Indicators contribute to decision-making by offering a simplified and accessible representation of relevant information, allowing decision-makers to make informed choices without requiring extensive details and analysis [7, 10]. Developing successful indicators for policymaking involves finding a balance between several factors. This includes considering the need for conceptual simplicity, the cost of evaluation, and the alignment of the indicator with existing policy targets [11].

This study presents a systematic review focused on the KPIs for circular buildings. The main objective of the study is to identify KPIs for assessing progress toward circular building practices and compare their level of effectiveness in terms of source data and applicability to different layers of buildings. The research questions formulated for this study are:

1. What are the KPIs related to the circular design and construction of buildings?
2. How are the KPIs currently used in the evaluation of circular building practices?

2 Methodology

The primary objective of this study is to undertake an extensive literature review to identify circular buildings' KPIs. To achieve this objective, a thorough search was conducted using two prominent academic databases: Scopus and Google Scholar. The aim of this research is to investigate the KPIs of CE in buildings. To conduct this investigation, a set of key words were employed including "Circular Buildings", "Key performance indictors", "Circular Indicators", "Circular Economy Indicators", "Circular Construction" OR "CE", "KPIs". The search focused on articles published in English from 2013 to 2023. To fully understand the current state of the field, the study employed both qualitative and quantitative research methods. This review synthesizes a wide range of research methods, from case studies to mixed methods and theory development.

The search results were initially transferred to an Excel spreadsheet. Following, full-text access was obtained for the most relevant studies, and titles, and abstracts were examined for shortlisting, applying specific search criteria to include or exclude papers based on their alignment with the research topic. To evaluate the quality and relevance of the articles, the following questions were posed:

1. Does the article align with the review's objectives
2. Is the article clearly focused on KPIs for CE?
3. Could the identified KPIs be implemented in the building sector?

Finally, a comprehensive full-text evaluation was conducted to assess the quality and relevance of the remaining articles which resulted in 40 articles being included in this study. Figure 1 shows the phases completed for processing published papers.

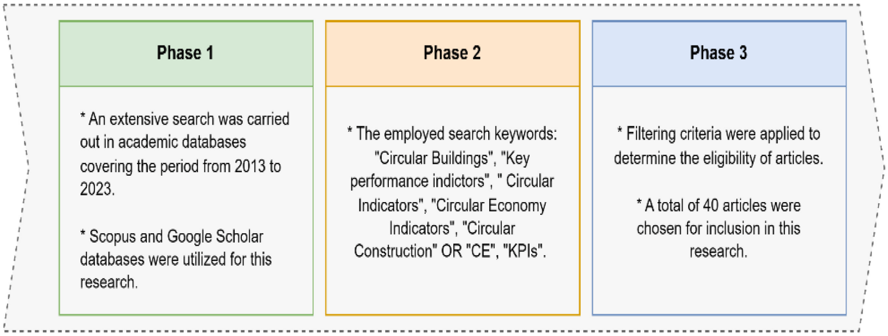

Fig. 1. Phases in processing published papers.

3 Circular Economy Indicators

Circularity can be evaluated through the utilization of various circular indicators. Moraga et al. [12] defined a circular indicator as *"a variable (parameter) or a function of variables to provide information about circularity (technological cycles) or the effects (cause-and-effect modelling)"*. Indicators for measuring the circular economy can be categorized into three levels: macro (global, national, regional, city), meso (industrial symbiosis, eco-industrial parks), and micro (individual firm, product) [6, 13, 14].

Saidani et al. [15] identified a set of 55 indicators developed by scholars, governmental agencies, and consulting companies and clustered them into 10 categories of taxonomies. The Ellen MacArthur Foundation and Granta Design [16] published Material Circularity Indicators (MCI) which is a micro level index that allows companies to evaluate the degree to which the material flows of a product are restorative, indicating how efficiently resources are circulated and reused within the product's lifecycle. Kristensen et al. [6] reviewed 30 circular indicators at the micro level and stated that most indicators focused on recycling, end-of-life management, or remanufacturing. Parchomenko et al. [17] used Multiple Correspondence Analysis (MCA) to evaluate 63 CE metrics based on 24 elements relevant to CE, such as recycling efficiency, longevity, and stock availability. The study's findings indicated that the most prevailing CE perspectives focus on waste disposal, differentiation between primary and secondary resource usage, resource efficiency and productivity, as well as the efficiency of recycling processes. Oliveira et al. [18] examined a total of 58 indicators and indicated that many of these metrics are environmentally driven indicators at the nano level, emphasizing material and resource recovery strategies and rarely address social aspects. However, Moraga et al. [12] claimed that determining the specific indicators and metrics to assess progress toward a CE can be challenging due to the ambiguity of the concept which could lead to incoherent conclusions.

4 Circular Buildings KPIs

According to Pomponi and Moncaster [19] buildings can be considered at meso level, while building components at micro level, as shown in Fig. 2. Circularity indicators can help to evaluate buildings and products during three phases of their lifetime: construction, use, and end-of-life [20]. Several authors have identified a range of CE indicators for buildings, for example, Khadim et al. [7] conducted an extended systematic literature and identified a total of 24 distinct building circularity indicators. The authors claimed that the most widely adopted KPIs are material loops, disassembly, adaptability, and reusability. Bilal et al. [21] completed a detailed literature review and consulted 21 experts from 14 different countries to select and rate the most important indicators related to CE. The results were then used to identify the top 24 indicators. Verberne [22] developed the Building Circularity Indicator (BCI) for the construction sector which focuses on identifying and evaluating KPIs designed to measure CE aspects within the built environment.

According to Brand [23], building can be divided into six shear layers (6 S's): site, structure, skin, services, space, and stuff, based on the rate they experience change and their role in keeping the building alive. Most KPIs identified in Table 1 measure circularity across structure, skin, services, and space, as their life cycle is less or equal to the life cycle of the building. Some of the indicators follow a more holistic approach and include the site in the calculation of building KPIs. For instance, FLEX 4.0 indicator [24], considers multifunctionality, expandability, and area coverage efficiency of the site in calculating building KPI, which is based on design for adaptability considering 44 flexibility performance indicators. Another indicator: RIPAT 1.0 by Valdebenito et al. [25] also included site geology and seismic characteristics in calculating the circularity of building sites.

Circularity in building structures is assessed through various KPIs, with a primary emphasis on optimizing space, improving accessibility, and minimizing obstacles posed by structural elements, to align with circular design principles [24]. Building skin is also covered by almost all the KPIs. A few of the metrics related to building skin in these indicators include the level of efficiency of façades, windows, and daylight facilities [26]. The level of circularity in services is usually measured in terms of measures and control of services, and their modularity and abundance [26]. The distribution, accessibility, and independence of user facilities are also gauged to quantify circularity in building services [24]. Lastly building space is gauged in terms of circularity based on its effective functionality and accessibility [26], the ease of dismounting, and the flexibility of units like infill walls, ceilings, and floors [24]. The stuff is items like furniture and electronics, that move around the building frequently are usually not included in the calculation of the building circularity KPIs. Their circularity is usually gauged by product circularity indicators.

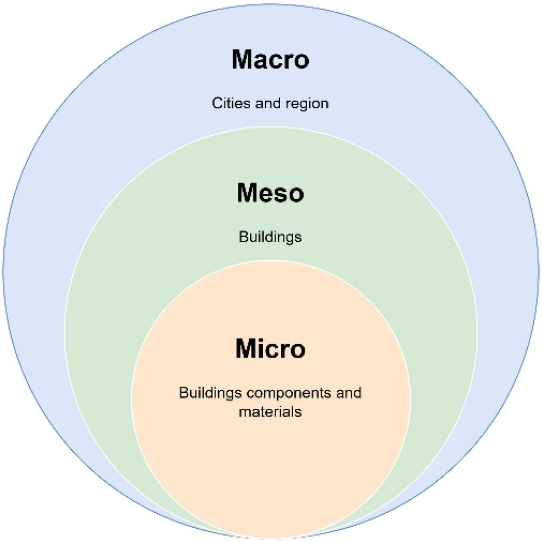

Fig. 2. Circular economy indicator levels.

The application of various KPIs suggested in the literature also varies depending on the size of measurement (material, product, or building), the kind of building (residential, commercial, or historical), and the stage of study (existing or new buildings). Tables 1 and 2 show the identified indicators that apply to all types of buildings with few of them limited to be used for certain types of buildings only. It's important to highlight that certain elements in Table 1 are not explicitly formulated as indicators; instead, they are presented in the form of frameworks. These frameworks are based on studies that have demonstrated their effectiveness in developing building indicators. For instance, Dodd et al. [27] illustrated how 'Levels,' essentially a framework for assessing and reporting sustainable performance, can be utilized to create specific building-level indicators.

Some of them directly use the Building Information Modelling (BIM) [28, 30, 32], while others are reported in the form of quantitative measures [29, 37–39]. Whole-Building Circularity Indicator (WBCI) by Khadim et al. [38] uses only quantitative data that can be processed in any spreadsheet tool. WBCI considers 4 material flow phases of the building: manufacturing, construction and assembly, use/operation, and end of life. Lei et al. [39] used reliability theory to create an overall CE index that includes circularity and sustainability indices. Cottafava and Ritzen [14] proposed a Predictive Building Circularity Indicator (PBCI) which helps understanding how design for disassembly criteria impact on circularity. Zhai [28] developed a BIM-based framework that conducts the circularity assessment throughout the building's design phase using Autodesk Revit and Dynamo for Revit. Within the same framework, BIM may be used to automate the circularity assessment due to its capabilities in parametric modelling, data classification, and visualization.

Table 1. Analysis of Circular Building KPIs.

Study	Building KPI	Type of Building	Building layer applicability				
			Site	Structure	Skin	Services	Space
Dodd et al. [27]	Level(s)	Residential and office buildings	✓	✓	✓	✓	✓
Zhai [28]	BIM-Based Building Circularity Assessment	All buildings (design phase only)		✓	✓	✓	✓
Schaik [26]	Modified Alba Concept (For Foundations)	Building foundation only		✓			
Cottafava and Ritzen [14]	Predictive Building Circularity Model	Residential buildings	✓	✓	✓	✓	✓
Madaster [29]	Madaster Circularity Indicator	All buildings	✓	✓	✓	✓	✓
Geraedts [24]	FLEX 4.0	General and office, school	✓	✓	✓	✓	✓
Di Biccari et al. [30]	Circular Business Models (CBM) Based Circularity Indicator	All buildings			✓		✓
Sreekumar [31]	Integrated Energy Performance and Circularity	New buildings		✓	✓	✓	
Akanbi et al. [32]	BIM-based Whole-life Performance Estimator	All buildings		✓	✓		✓
Fregonara et al. [33]	Synthetic Economic Environmental Indicator	Existing buildings		✓	✓		

(*continued*)

Table 1. (*continued*)

Study	Building KPI	Type of Building	Building layer applicability				
			Site	Structure	Skin	Services	Space
Valdebenito et al. [25]	RIPAT 1.0	Heritage Buildings	✓	✓	✓		✓
Kubbinga et al. [34]	Framework for Circular Buildings	All buildings		✓	✓	✓	✓
BAMB [35]	Circular Building Assessment Prototype	All buildings		✓	✓	✓	✓

There are different ways of using the circular building KPIs reported in the literature.

There are also specialized software tools available to analyse the level of circularity of a building, for which the user is essentially required to input both quantitative and qualitative data. C-CalC [36] is one of those which uses both quantitative and qualitative data to calculate a building's circularity and compares it against other structures. It emphasises the method, the degree of adaptability, and the utilization of materials. In contrast, Oliveira et al. [18] argued that the analysed indicators primarily concentrate on material and resource recirculation, lacking the robustness needed to effectively assess the overall sustainability performance of a circular system.

Table 2. Analysis of Circular Building KPIs (continued).

Study	Building KPI	Type of Building	Building layer applicability				
			Site	Structure	Skin	Services	Space
Cenergie [36]	C-CALC	All buildings		✓	✓	✓	✓
Dams et al. [37]	Circular Construction Evaluation Framework	All buildings		✓	✓	✓	✓
Khadim et al. [38]	Whole building circularity indicator	All buildings		✓	✓	✓	✓
Lei et al. [39]	Probabilistic circular economy assessment of buildings	All buildings		✓	✓		✓

According to Di-Maio and Rem [11], policymakers continue to face challenges in finding an effective key performance indicator, and the existing indicators often fall short in properly capturing the broader socio-economic impacts of circular practices. Mesa et al. [40] argue that indicators for measuring CE are currently in the early stages of development. According to Khadim et al. [7] circular indicators in the construction sector are not well-established yet. As a result, current indicators do not raise confidence or trust among construction practitioners and policymakers.

5 Conclusions

CE offers promising solutions to the unsustainable "take-make-use-dispose" model currently prevalent in the building industry. The shift to CE is largely dependent on monitoring and assessment instruments such as KPIs, which allow decision-makers to evaluate circularity and make well-informed decisions. Notwithstanding, the creation and implementation of these KPIs in the framework of circular building practices present various difficulties often linked to conceptual clarity, evaluation cost-effectiveness, and compatibility with current policy objectives.

The purpose of this investigation was to examine KPIs pertinent to circular building practices, aiming at assessing the extent to which circularity is integrated into the built environment. The study identified several KPIs that can help to gauge the level of circularity in buildings. These indicators, once categorized according to building type (residential, commercial, or historical), stage of existence (existing or new buildings), and number of building layers (structure, skin, space, etc.), provide valuable insights into diverse aspects of circular building practices.

Despite valuable findings, we recognise persistent limitations for the full implementation of CE being the main one that current indicators lack robustness to comprehensively evaluate the circularity and socio-economic impacts of circular practices. This concern raises questions about the effectiveness of current assessment frameworks, therefore suggesting the need for a more holistic understanding of the broader implications of circularity in building practices. Finally, to effectively drive the shift toward circular building practices, more comprehensive and widely accepted KPIs are required, as the identified gaps limit the level of confidence and trust placed by practitioners and policymakers regarding the effectiveness of current indicators.

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