Obstacles and barriers for measuring building’s circularity

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Abstract. Applying circular economy principles in the built environment at different levels is considered as a future vital approach to reducing its environmental impacts along with huge economic benefits, which is generally explained by “decoupling resource consumption from economic development”. At the meso-level of the built environment, circular buildings have arisen as a more holistic approach to embrace circular economy thinking. This novel practice requires flexible and adaptable strategies to enable alteration and adjustment while avoiding material loss and keeping the value of products at the highest levels. Evaluating buildings circularity by means of standardized indicators is therefore primordial to implement a common language between all involved actors and monitoring the progress towards an eco-design. Still, the complexity of putting together such a methodology is far from being a mere task. To date, several studies have been more focused on assessing circularity for short-lived products while disregarding assessing long-lived products as buildings and their ability to be deconstructed andreassembled in a so-called “reversible design”. Unfolding a set of robust indicators to measure building circularity promises to be challenging in order to set up a flawless assessment tool which can summarise different aspects of the application circular economy at a building level. This paper intends to put an emphasis on the potential obstacles that can be encountered while developing metrics to quantify building circularity.

Keywords: Circular economy, built environment, circular buildings, Assessment tool, challenges.

1. Introduction

Building sector is among the largest consumers of resources and natural capital with about 40% of resource consumption and waste generation [1,2]. The general assumption of building’s end-of-life plan is demolition and in best case scenarios recycling generated wastes. With the new promise of managing natural resources and reducing negative externalities, the Circular Economy (CE) stands out as a paradigm that aims at reaching sustainable development goals by preserving natural capital and generating economic value. Merging buildings and CE principles offers considerable benefits to keep assets cycling in loops at their
highest values. Recently, Circular Buildings have emerged as long-lasting structures, modular and able to be disassembled after their end-use, to overcome current environmental issues [3].

Various world known tools are available to assess Sustainability in buildings, however, as CE implementation in buildings remains a fresh approach, there is no standardized tool to gauge circularity due to the intricacy of establishing a common tool for this concept. Still, measuring CE is highly praised, it plays a key role in informing different parties about progress and development of the concept, while facilitating the transition by revealing flaws that should be settled. Once the Circular Buildings gain in reputation, the assessment model can be used as a benchmark to compare between buildings’ CE performances.

The following study goes one step ahead by addressing future potential obstacles that could slow the development of an assessment tool to measure buildings’ CE.

2. CE principles in the built environment
The CE is rooted in many schools of thoughts (e.g. Cradle to cradle, regenerative design, performance economy) and has been sharpen throughout the last decade to encapsulate different practices related to industrial ecology and sustainable development. Applying CE principles in the built environment implies multiple approaches that are closely bonded to sustainability. Nevertheless, there is still a lack of research on the implementation of the CE into the construction industry.

One of the main features of CE is closed-loop systems, which once embraced in buildings could be translated into construction materials flowing in circles via different strategies into technical or biological cycles [4]. Resource efficiency is another aspect of CE, which stands for “doing more with less”, whereas in construction it refers to using fewer inputs sustainably (energy and materials) to design buildings with less outputs (wastes and emissions) [1,5]. Long-life and durable buildings based on eco-friendly materials are also desirable to reduce the need for additional natural resources [6–8]. Stahel and Reday-Mulvey [9] highlighted the positive impact of durable buildings on the social dimension which could offer better life quality [1]. Braungart et al. [10] described the benefits of “sharing” building stocks to enable a better use of resources. The 3R’s principle: Reduce, Reuse, and Recycle, is a well-established action plan in the construction sector as a sustainability strategy to lower harmful environmental impacts and design out wastes [11]. However, the 3R’s was appraised as insufficient for a CE transition, and hence expanded to the “R-List” which includes additional actions arranged by a priority order as follows: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover [12].

Designing buildings in a CE manner also englobes other strategies such as: modularity, adaptability, flexibility, and deconstruction or disassembly. These design strategies will enable a higher use-performance while maintaining the value of building materials and components.

3. Circular buildings
Given the limitations of green and sustainable buildings, which mainly focus on design and use life-stages of buildings and merely on their end-of-life scenarios, Circular Buildings have arisen and put forth as a more holistic approach to CE in the built environment. Academia and non-governmental institutions promoted the reliability and efficiency of Circular Buildings to ensure a better transition towards CE [3, 13, 14].

Still, research and scientific contribution related to Circular Buildings is barely scratching the surface in terms of producing buildings that match the Sustainable Development Goals. Pomponi and Moncaster [14] set out a framework for Circular Building research and defined it as “a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles”. The authors positioned the “Buildings” at the meso-level of the built environment and acknowledged that this research area is poorly investigated. Six dimensions were described as relevant to Circular Buildings: Environmental, Technological, Economic, Societal, Governmental, and Behavioural.

Likewise, Leising et al. [13] claimed that stakeholders recognize the challenges ahead and defined the CE in the building sector as a “systemic view on the whole life cycle of buildings and by using new
technologies and design approaches” in order to generate financial, social and environmental benefits. The authors go further on and define the circular buildings as “A lifecycle approach that optimizes the building’s 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” and states that their definition is more explanatory than the one given by Pomponi and Moncaster.

4. Potential obstacles to measuring circularity
Gauging building’s circularity is essential to the well-development of the CE paradigm while unlocking its potential benefits at the building level. However, measuring progress towards a CE practice is a challenging task, a set of indicator is required to seize the main factors of CE in buildings, inter alia lifecycle of involved materials, inputs/outputs (e.g. environmental impacts, toxicity, economic benefits), and building’s end-of-life scheme. The indicators aim at assessing, improving, and disseminating CE performance. The following paragraphs will further discuss the main factors that could influence developing a new tool to measure circularity in buildings.

4.1. Plethora of CE definitions
CE is described as a fuzzy defined concept and needs a clear and unified path [26]. Haas et al. [27] critically examined current literature and unveiled a gap in defining the concept to assess and improve its practices. Homrich et al. [28] reviewed 327 research papers and concluded that the CE concept lacks of common focus and definitions which may lead to future challenges in bringing out circularity. Moreover, Kirchherr et al. [29] systematically analysed 114 definition of circular economy in order to provide transparency to its current comprehension and concluded that the concept of CE may face incoherence and eventually breakdown or “remain in a deadlock” as many conflicts were found in those definitions. While, Preston [30] argued that a lack of an acknowledged definition may challenge future international cooperation. The inability of clearly defining such concept makes its implementation hard and its monitoring even harder and challenging, which is considered as a first obstacle that requires a clear definition and fixed principles beforehand.

4.2. Building’s complexity from a CE perspective
The prevailing notion of buildings as single entities with indefinite lifespan makes CE assessment in buildings quite intricate. While measuring sustainability is more straightforward, building’s circularity mainly considers building’s end-of-life, where different materials are involved with different life cycles and a blurred service-life for each component that once assembled, they form a unique structure which is considered as irreversible unless demolished. Akanbi et al. [24] claimed that establishing an estimation model to the whole building recovery/reuse is not achievable due to different lifespans of each building’s component and therefore the authors narrowed their work on analysing materials of building’s structure. To overcome the circular design barrier. Several studies [2, 13, 14, 24] suggested the adoption of Brand’s model: Shearing layers [25], to decompose each building’s component according to its expected lifespan. It will enable designers to consider buildings as dynamic structures that englobes adaptability and flexibility for future potential deconstruction. However, when it comes to assessing the eventual scenarios of building’s end-of-life, the different time frames of these layers could complicate the assessment as some layers have longer life-cycles and others shorter which will create uncertainty and unpredictability around the assessment method.

4.3. Assessing Sustainability vs. circularity
CE is considered as a means or strategy, or even as a national policy (e.g. China [20, 23]) to attain sustainable development goals at different scales [22, 32]. In that context, and based on the CE principles, Circular
buildings may offer a pathway towards sustainability more efficiently than Sustainable buildings. Nevertheless, when it comes to assessing circularity in buildings, some overlapping may be faced due to common indicators between sustainability and circularity; for instance, indicators that imply both of the concepts, as: use of solar energy (regenerative design and renewable energies), materials reuse and recycled content (Recycle and Reuse principles to extend products lifetime while minimising negative externalities). Still, the issue may be solved out by prioritising some indicators than others by attributing higher weights.

Assessing Sustainable buildings essentially cover the construction process and the use stages while Circular buildings rely on design for adaptability and flexibility through materials sourced sustainably that prioritises more suitable solutions for buildings' end-of-life plans. It is noteworthy that both approaches share the same goal of promoting sustainability in buildings.

4.4. Unrelated, Obsolete, and Arbitrary indicators

Circularity indicators form the core of the assessment methodology. They provide meaningful measurement of the main elements of Circular buildings. CE-related indicators for buildings should cover four points: 1) Measure building’s impact on the environment, economy and social aspects whether it is positive or negative; 2) Improve buildings performances from early stages to the end-of-life by closing materials loop; and 3) Evaluate and gauge building’s development towards CE in an objective manner. These indicators should address various issues and goals to be achieved from a CE perspective to attain sustainability.

Recently, the Ellen MacArthur Foundation put in complementary indicators to cover the social gap in CE measurements [4]. However, given the need of precise indicators to quantify the social aspect, some “opportunistic behaviour” may be encountered [16]. Linder [16] suggested to minimise subjective decisions when assessing CE as a key to overcome “opportunistic behaviour”. Objective indicators should measure the CE development based on reliable data to avoid arbitrary decisions that eventually will bias the results and benefit certain parties rather than attain CE goals. Subjectivity might arise by showing higher figures of a Building’s aspect to persuade a costumer, which will eventually reduce credibility and trustworthiness of the assessment method.

Moreover, CE indicators should be updated and reflect progress over time intervals, while identifying changes using data that is updated as well. Obsolete or outdated indicators may lower the accuracy and impede the soundness of the assessment methodology. The CE-indicators should aptly describe the complex cyclic, closed-loops and other Building’s performances that are in line with CE principles, while being constantly updated to match the pinned goals of CE practices in Buildings without exposing them to subjective and thus arbitrary assessments.

4.5. Data collection/management

Any assessment tool requires large amount of data to provide an outcome that matches its purpose. However, there is a huge need to objective data with reliable quality to supply the selected indicators and avoid hypothetical assumptions that could false the results. At first, the use of energy indicators were the only ones included in the environmental assessment mostly due to data scarcity related to raw materials. For instance, the C2C® Methodology for Materials Health assigns a “Grey” rating to materials that demonstrate a lack of data which could heavily obstruct the assessment. Data availability will enable accurate assessments and identify different lifecycles of the materials involved in a building. At the moment, there is a shortage of publically available data, some industries prevent the data collection due to confidentiality which will challenge the research process.

On the other hand, some experts suggest that material flows, circular design and maintaining assets in a CE will engender a considerable amount of Big Data, that if used effectively, it could reveal benefits for CE measurements [34], while Internet of Things (IoT) can offer additional insights on material flows and energy consumption (e.g. smart sensors and connected technologies). Big Data in combination with IoT can be
advantageous by influencing the use-efficiency of assets and their maintenance and durability. The overload of data when collecting information requires a supplementary tool to back the assessment, the Building Information Modelling (BIM) can offer the endorsement needed at building level to gauge its circularity.

4.6. Social measurements
The current CE indicators mainly monitor environmental and economic aspects and disregard the social dimension. Nevertheless, extending building’s lifetime and altering its end-of-life plan from demolition to deconstruction or disassembly must have a distinct impact on users. The issue that lies with assessing the social effects is generating qualitative data that in some cases cannot be quantified.

Generally, while assessing building sustainability, the environmental and economic dimensions imply a large amount of tools used as benchmarks or incentives (e.g. LCA, LCC), however the social aspect remains complex and involves subjectivity which could impede the weighting system and overall, the assessment tool. Janda [35] argued that the buildings users are usually neglected while addressing energy use, though, they play a substantial role in managing energy.

The building will lose its purpose if users are not pleased of its performances. The post-occupancy evaluation (POE) offers a useful benchmark that shows the potential of improving building performance. The POE is defined as assessing building performances at the operation stage [36], the assessment aims at matching the user’s expectation on life quality within buildings once occupied. Still, closing the building’s loop by stock re-use and embedding recycled components can affect the life quality which might impact the user’s perception on buildings performances.

Among the available tools dealing with sustainability, it has been noted that the social aspect is not fully covered [37]. In a CE assessment, the social effects of lifecycles extension should be addressed by establishing suitable indicators to monitor and meet the user’s satisfaction. The indicators should be based on objective data whilst avoiding opportunistic behaviour and arbitrary measurements, as the social dimension remains a fragile aspect for measurement.

4.7. Ambiguity in weighting and scoring
As a final step of the assessment, a score is obtained to translate the CE in buildings. Most of the tools available that explore CE at the industry level or sustainability in buildings adopt a single scoring approach to manifest the studied concept as simply as possible. In general terms, the building sustainability assessment methods rely on a single score or rating (e.g. BREEAM, SBTool, LEED) through categorising the main covered aspects of buildings along with various weights in accordance to their importance within that context. Similarly, methods to evaluate CE at micro, meso or macro level (products or companies, eco-industrial parks, and regions or provinces respectively) follow the approach of single scores. For instance, the Material Circularity Indicator (MCI) developed by Ellen MacArthur Foundation and Granta [4] attributes a score ranging from 0 to 1 to a product’s or a company’s circularity. Su et al. [23] described CE performances in four pilot cities by scores assigned to each selected indicator. While they reviewed several CE assessment studies, the authors stressed the issue of weighting indicators and listed six of the most used methods: Average weighting, Principal component analysis, Analytic hierarchy process, Fuzzy synthesis appraisal, Grey correlation degree, and the Full permutation polygon synthetic indicator method [23]. The weighting system may fit the local circumstances which implies financial state, social and cultural aspects, climate, policies. Considering the local conditions may lower the ambiguity of the weighting system. The adjustments of weights adopted by the SBTool are noteworthy considering the respect given to the local context.

The following question should be asked when it comes to aggregate a set of defined indicators: which indicator/category is more important to consider in the CE context among the set? Which indicator/category influences more the circularity of buildings?
Kajikawa et al. [31] argued that ambiguity in scoring and weighting is one of the main issues encountered while assessing environmental aspect of buildings. As the CE is broader and englobes several other dimensions, weighting indicators/categories, and then providing a single index to Circular Buildings could be injudicious. Linder [16] claimed that aggregating “circularity values” of a product in order to assign a circularity score is not recommendable. Likewise, buildings cover miscellaneous aspects which make the importance level of CE in each layer not suitable for a single score to translate all their performances.

5. Summary
This paper intends to briefly address some of the main obstacles and barriers that could be encountered while developing an assessment tool for Circular Economy (CE) in Buildings. Several studies emphasized the benefits of applying CE in the built environment. The Circular buildings emerge as a novel concept that fully embrace the CE principles by adopting various design strategies to enable reversibility and toggle the building end-of-life from demolition to stock re-use.

To track and gauge the development of CE in buildings, a proper assessment tool must be established to accurately evaluate the improvements and flaws of the concept towards a sustainable built environment. Nevertheless, the inherent complexity of the paradigm can complicate the assessment and hurdle the progress. The following points sum the main findings of this paper:

- **Plethora of CE definitions**: Various of CE definitions are being stated which may let the concept undergo vagueness in adopting a pathway to achieve the primary endpoint.
- **Building’s complexity from a CE perspective**: Buildings require the right planning at the early stage to embrace circular design. The “unique structure” practice of a building may complicate the assessment.
- **Assessing sustainability vs. circularity**: CE and Sustainability are two overlapping concepts that share the same goal of preserving environmental capital, generating economic benefits, and establishing social welfare. The assessment model requires a narrow scope which focuses mainly on CE progress in accordance to its principles.
- **Unrelated, Obsolete, and arbitrary indicators**: The main component of an assessment tool is the indicators. The CE related indicators must be selected carefully and updated as time goes while keeping the outcomes objective.
- **Data collection/management**: The necessary data to supply the CE tool may either be scare or overabundant which may consume time and resources to gather and manage it. At the building level, a secondary tool as BIM could facilitate the assessment, while setting up standards for data collection to smooth data access.
- **Social measurement**: The social aspect is usually overlooked when assessing building sustainability. Measuring this dimension generally implies subjective assessment which eventually weakens the overall methodology.
- **Ambiguity in weighting and scoring**: Aggregating the assessment results following a predefined weighting system may reveal some limitations. The weighting must clearly match the purpose and scope of CE in buildings while remaining “open” to adapt local scenarios.

Finally, this study superficially explored some of the hurdles for establishing an assessment method for Circular Building, while at some extent, attempted to bypass some of the obstacles, as a step ahead for developing a monitoring tool for circular economy to smooth the implementation.

6. References

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