#24: BIM-based building circularity assessment: conceptual framework

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Abstract: The construction sector contributes substantially to the consumption of raw materials and the production of waste. Traditional building design strategies are based on an unsustainable economic linear model. Transition to the circular economy (CE) paradigm aims to reduce the consumption of raw materials and minimise waste. To achieve the promises of CE, it is crucial to assess sustainability aspects early. In the final design decision-making process, both technical circularity and sustainability strategies must be implemented. However, the existing building circularity assessment (BCA) models and tools are not comprehensive and fail to cover all the critical factors that affect circularity and sustainability in the built environment. Technical circularity and sustainability assessments are often conducted in isolation. There is a need for practical comprehensive assessment tools for use during the early design stage of construction projects, where crucial decisions are made as opposed to the late design stages, in which changes are more costly and complex. Since BCA requires a large amount of data, it requires the use of a supplementary tool to conduct the assessment effectively. Building information modelling (BIM) can serve as a useful tool to facilitate BCA. This paper proposes a framework that integrates technical circularity and sustainability aspects, such as environmental impact by life cycle assessment (LCA) and economic aspect by life cycle costing (LCC) within the BIM environment to achieve a sustainable circular-built environment. The framework is a promising step toward developing a prototype tool that assesses circularity and sustainability aspects simultaneously and helps decision-making for designers in the context of building design and material selection and trade-offs between the different aspects and selects more circular and sustainable alternatives. The proposed framework aims to contribute positively to reducing global warming and decarbonization in the building sector and the shift toward a sustainable circular-built environment.

Keywords: Building Circularity Assessment, Sustainability, Building Information Modelling, Circular Economy, Sustainable Construction

1. INTRODUCTION

The construction industry consumes 30% of raw materials and generates 25% of waste globally (Benachio et al., 2020). Traditional design strategies are based on the linear model of consuming the resources, in other words, “take-make-dispose” which is a cradle-to-grave approach. On the other hand, the new sustainability paradigm of a circular economy (CE) is based on the closed-loop of consumption and regeneration with materials efficiency through reuse and recycling, which is a “make–use – reuse/recycle” and it is considered the cradle-to-cradle approach. The shift toward a circular building and assessing the building’s circularity is not limited to the technical aspect of circularity. Pomponi & Moncaster, (2017) defined six research aspects within the built environment that relate to the concept of CE. The study states that there is a need for a holistic approach and research studies in each of these aspects it is essential to integrate the utilization of different disciplines to successfully meet the sustainability research goals. However, in practice, not all research aspects may be required, some of them such as two or three aspects may be included such as environmental, economic, and technological.

Building circularity indicators should measure the building’s impact on the environment and economy (Rahla et al., 2019). Zhang et al., 2021 define Building Circularity (BC) as “a building property that describes the circular capability, including its construction activities to create environmental quality, economic prosperity, and social equity” by R strategies such as reuse and recycling. Both the methods for building circularity assessment (BCA) and life cycle sustainability assessment depend on the life cycle perspective and advocate life cycle thinking. Despite the sustainability and circular economy terms becoming popular, the differences and similarities between both remain unclear. The relationship between them is not clearly outlined in the literature (Geissdoerfer et al., 2017). Each of them (i.e., sustainability and circularity) is considered complementary to the other as they do not have the same meaning (Blum et al., 2020). The new Level(s) framework for the building sustainability assessment includes six macro- and objective 2 linked to circularity by 4 indicators (Dodd & Donatello, 2021). Therefore, the final design decision-making process depends on implementing both circularity and sustainability. Thus, there is a need for the utilization of decision support systems (DSS) to select the most appropriate design option that aligns with the set objectives among different alternatives. Moreover, various researchers have suggested integrating circularity with sustainability when assessing building design (Pomponi & Moncaster, 2017) (Akanbi et al., 2018) (Blum et al., 2020) (Zhai, 2020) (Zhang, et al., 2021) (Zhang, Han, et al., 2021). However, Rahla et al., (2019) addressed the main obstacles and barriers that could influence the progress of creating an assessment tool for a building’s circularity such as assessing circularity versus sustainability and data collection/management.

BCA requires a large amount of information to conduct its assessments, and BIM can facilitate this (Rahla et al., 2019). Several studies state the need to leverage technology and digitalization to improve CE (Verberne, 2016) (Braakman et al., 2021) (Khadim et al., 2022). Due to the increased complexity and volume of data at a building level, a BIM-based tool should be developed to automate the building circularity assessment calculation. Data required for circularity assessment may be extracted from the BIM model. The BIM-LCA integration is used in building sustainability studies which could be expanded to circular assessment research (Feng et al., 2022). Such as analyzing LCA and LCC within the BIM environment as a data repository (Santos et al, 2019). The BIM-based end-of-life research theme is a connection between three trending issues in the building industry: digitalization, circular economy, and sustainability (Akbarieh et al., 2020). This research aims to integrate these three existing trends by proposing a framework for assessing building circularity and sustainability using BIM.

After the Introduction in Section 1, this paper is outlined as follows: Section 2 discusses current efforts and approaches to integrate BIM and circularity and sustainability assessment; Section 3 outlines the research methodology; Section 4 Overview of the proposed framework; Section 4 Conclusion and future work.

2. RELATED WORKS

Over the past few years, several researchers have tried to use BIM in BCA. There are three main streams or approaches of integrating BCA with BIM: 1) External Online platform; 2) Link BIM and external database; 3) Creating custom parameters. In the first approach, processing an exchange file such as Industry Class Foundation (IFC) and uploaded to an external platform and processed in the external platform for assessment. This approach is used by Building as Material Banks (BAMB), Madaster, and One Click LCA. The limitation of these external online platforms is requiring manual procedures to upload to the online platform. These manual steps decrease the efficiency of work and are time-consuming, particularly in the design phases which may require multiple assessments (Zhai, 2020); (Zhang et al., 2021). Hence, designers need a simplified approach that enables continuous assessment throughout the entire design phase instead of the end of the design phase that works within the BIM environment and enables a quick and real-time assessment of the building's circularity.

The second integration approach establishes a link between the BIM model and external databases that include data required for the assessment. Some studies used this integration approach (Zhai, 2020); (Zhang et al., 2021). However, the limitations of these two tools are not considered the sustainability aspects. Christian et al. (2021) and Heisel and Nelson (2020) proposed a BIM tool for building circularity indicator assessment based on the circularity indicator (CI) proposed by

Madaster and embodied carbon. However, it does not consider the economic aspect. In the third approach, users are required to create shared parameters for each building element and material-specific data containing the required information to conduct the assessment. Akanbi et al., (2018) developed a BWPE add-in for the parameters influencing recycling and reusability using Revit and C#. The limitation of BWPE it does not consider the sustainability aspects. However, this integration approach is time-consuming as users are required to manually create parameters for each necessary information and subsequently input the data into those parameters. Di Biccari et al. (2019) designed a tool to assess the circularity of the building level only based on a circular indicator proposed and the LCC. However, it is a semi-quantitative method and includes the environmental impact inside the calculation of their proposed indicator to assess circularity.

However, in previous studies, BIM tools are related to the fact that they do not cover all aspects of building circularity and sustainability. There is an essential need to explore BIM to assess building circularity considering the sustainability aspects and improving the decision-making in a simplified approach. Thus, integrating circularity with sustainability aspects within the BIM environment will establish a robust system for assessing the sustainability of building materials selection and design options (Akanbi et al., 2018). However, to the knowledge of the authors, this integration within the BIM environment as a data repository is still missing from the literature. Therefore, additional research and development in this field are required. Our proposed framework leverages BIM as a data repository to model the technical circularity, environmental, and economic sustainability aspects to assess buildings and inform design decisions.

3. METHODOLOGY

The research methodology comprises two steps: i) identifying the technical circularity and sustainability indicators by literature review, and ii) adopting the design science research methodology for developing the proposed conceptual framework for BIM-based building circularity assessment based on identified indicators.

4. IDENTIFYING THE INDICATORS

The proposed framework will integrate the technical circularity aspect with sustainability aspects, i.e., the environmental impact by using LCA, and the economic aspect by using LCC to conduct a comprehensive assessment.

4.1 Technical circularity indicators

Creating a new circularity assessment method is considered challenging (Jiang et al., 2022). WBCSD, (2018) recommended building upon existing frameworks. Moreover, academia also recommended that the improvements in the future must be standardized and aligned with previous literature (Khadim et al., 2022). However, the Material Circularity Indicator (MCI) for product level (Ellen MacArthur Foundation & Granta, 2015) and the Building Circularity Indicator (BCI) proposed by Verberne, (2016) are the most popular indicators. Many researchers and companies built their indicators on MCI and BCI. Therefore, they will be adopted in this research to develop the circularity assessment model. However, they should be adapted to be a form of life cycle perspective because they do not consider materials required for the use phase, and material wastage during the construction (Khadim et al., 2023).

4.2 Environmental impact indicators

The Life Cycle Assessment (LCA) method is widely utilized within the building and construction sector for environmental impact assessment (Lu et al., 2021) based on ISO 14040 & 14044:2006 series (ISO, 2006). These standards provide general guidelines for LCA. BS EN 15978 is a specific LCA standard for construction projects and buildings (BS EN, 2011). LCA covers different environmental impacts, and the global warming potential (GWP) is considered the biggest environmental impact contributor to climate change. GWP is caused due to emissions of greenhouse gases and carbon dioxide (CO2) represents the largest percentage of GHGs that are released into the atmosphere, and the GWP of all other greenhouse gases over 100 years is calculated using the carbon dioxide equivalent unit (CO2e) (RICS, 2017). Among LCA indicators, the most common environmental impact assessment of buildings is carbon emissions, and embodied carbon is the main factor that assesses the overall environmental impact of a building (Lu et al., 2021) (Fregonara et al., 2017).

4.3 Economic indicators

The economic factor is crucial in promoting circularity (Braakman et al., 2021). One of the key goals of circular buildings should be to generate economic value (Pomponi and Moncaster, 2017). The correlation between an increase in product circularity and the potential business benefits is not a straightforward one (Ellen MacArthur Foundation & Granta, 2019). Unknown relationship between circularity and life cycle costing (LCC) (Braakman et al., 2021). LCC is the most widely accepted technique for economic sustainability assessment, and it is one of the indicators of the new Level(s) framework for building sustainability assessment. Life-cycle costing includes construction cost, operation and maintenance cost, and end-of-life cost (ISO 15686-5, 2017).

5. A PROPOSED CONCEPTUAL FRAMEWORK

The proposed conceptual framework aims to reflect the technical circularity and sustainability aspects of buildings. In this research, technical circularity will be integrated with environmental sustainability and economic sustainability within the BIM environment as a data repository. The proposed framework is based on a modified version of the circularity assessment model BCI (Verberne, 2016) to assess the technical circularity, LCA to assess environmental sustainability and use LCC to assess economic sustainability. The proposed conceptual framework uses BIM for integrating technical circularity, LCA, and LCC by benefitting from BIM-LCA/LCC integration frameworks (Lu et al., 2021), as illustrated in Figure 1, the proposed framework involves four steps, described below.

5.1. Define the goal and scope of the assessment

In the first step, the goal and scope of the assessment need to be clarified for each aspect. The indicators (technical circularity, environmental impact categories, and economic), the scope of life-cycle stage (A, B, C, D) modules and building components should be defined. The determination of the order of importance for the three aspects.

5.2. Inventory analysis and define the basic assumption

Step 2 includes analysing the material flows and building design information. Establishing the basic assumptions such as lifespan or the study period, inflation, and discount rate. Defining the calculation standard and formula. Creating a semantic enrichment of the BIM model that takes into account the level of details (LOD) and information including disassembly potential. To perform the BCA, LCA, and LCC it is essential to identify the information required for the assessment.

5.3. Conduct the assessment

In the third step, start conducting the assessment within the BIM environment. The circularity for each product will be calculated, and then they will be grouped according to building Brand, (1994) layers to calculate the SCI. Then, BCI will be calculated. For LCA/LCC, assessing the environmental impact and costs for each stage, and then accumulating these results to obtain the whole life cycle.

5.4. Interpretation and analysis of the results

In the last step, it is essential to perform an uncertainty analysis for both LCA and LCC due to various factors such as the uncertainty of the database, potential risks, and parameter settings (Lu et al., 2021). Moreover, due to the life span of buildings that may reach 50 years, uncertainties in the scenarios of the end of life could pose a risk of unsatisfactory CE performance (Lei et al., 2022). Defining the percentage of unrecoverable waste from the many materials used in building construction is hard because of the uncertainties surrounding the treatment of these materials at their end of life (Lei et al., 2021). Hence, uncertainty analysis is required. On the other hand, there is no simple correlation between technical circularity, LCA, and LCC. Therefore, it is essential to consider their trade-offs by developing a decision support system based on technical circularity and sustainability criteria by adopting optimization methods to enable the selection of optimal materials and design alternatives.

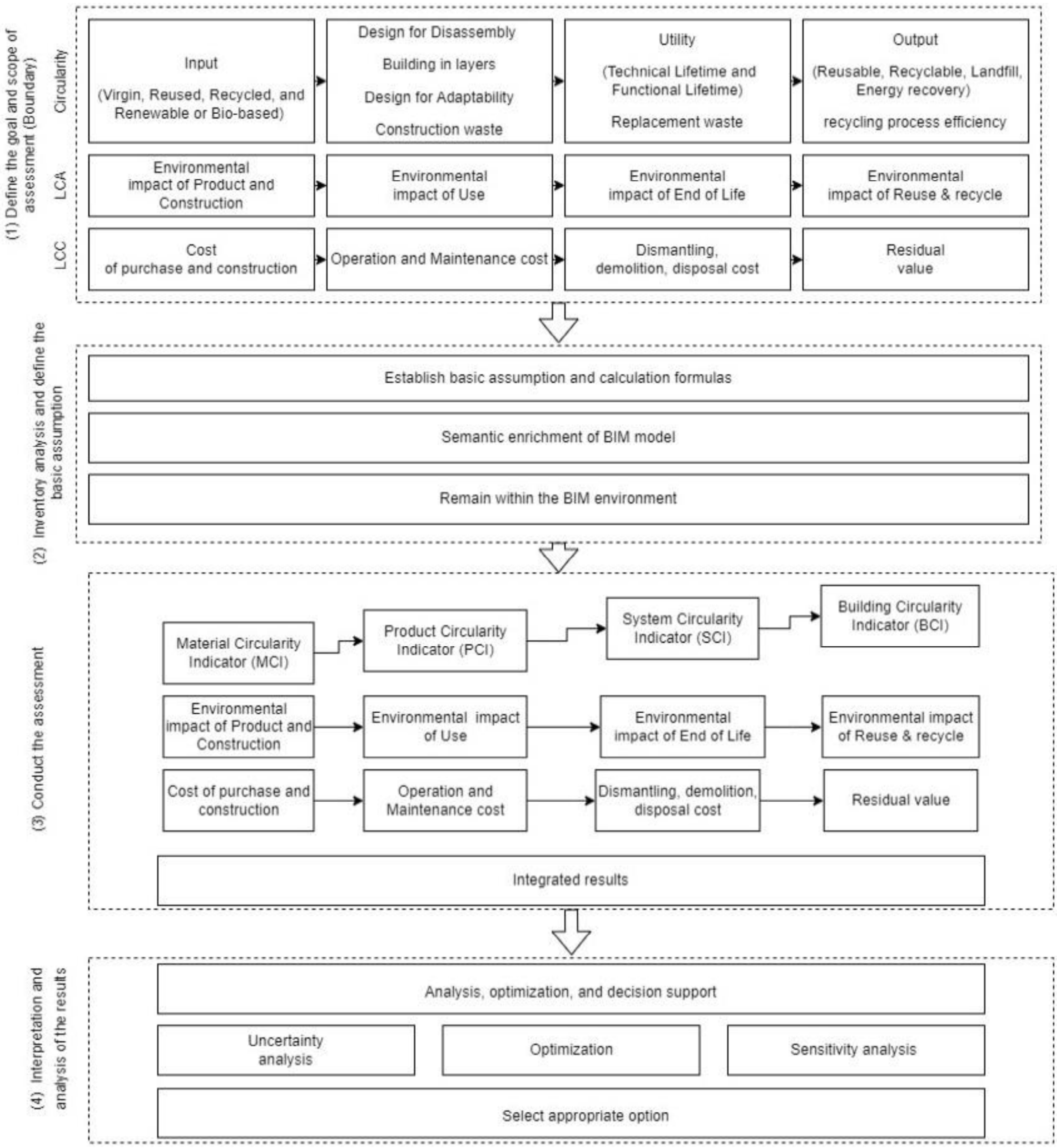

Figure 1 Proposed conceptual framework

6. THE PROTOTYPE DESIGN

A prototype tool will be developed based on the developed conceptual framework following the preliminary proposed system architecture to demonstrate the framework's functionality. The preliminary architecture is divided into three parts: input, process, and output as shown in Figure 2. The system takes inputs from the enriched BIM model including the information required for the assessment and the project data such as disassembly potential. The integrated assessment model embedded in BIM software calculates BCA, LCA, and LCC considering the uncertainty. The expected outcomes from the calculation and the optimization methods are to determine the best material and design alternatives for achieving a sustainable circular-built environment. In addition, the system outputs the results in a visualisation model.

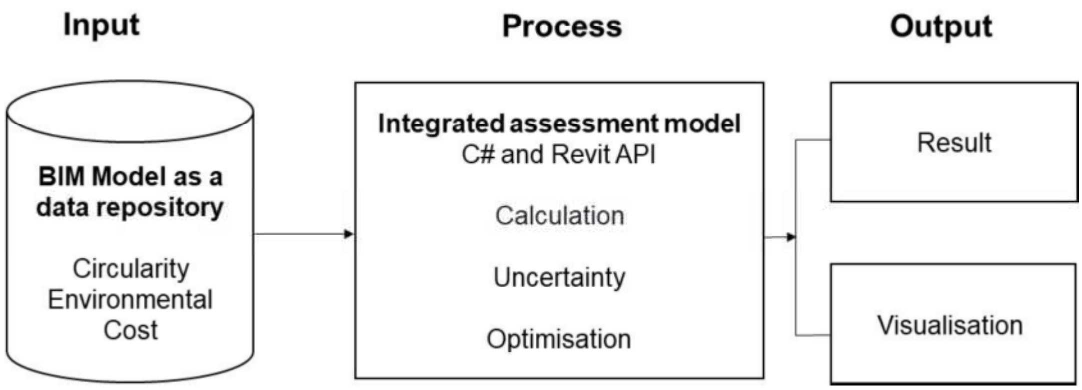

Figure 2 Proposed system architecture

7. CONCLUSION AND FUTURE WORK

An integrated framework to assess the circularity and sustainability of the building within the BIM environment at the early design stage is proposed in this research. It integrates the assessment of three key indicators: circularity, LCA, and LCC measures. The first indicator accounts for technical circularity while the other two give a measure of environmental impact and economic sustainability. Concepts of these indicators and aspects have been presented in this paper. The directions for the implementation of the BIM-integrated framework in the form of a prototype tool have been stated. The next step of this research will be implementing the developed conceptual framework in a BIM-based prototype tool and the framework will pave the way to develop a plugin within Autodesk Revit. To shift toward a circular and sustainable built environment, this paper presented a proposed BIM-based framework for assessing technical circularity with sustainability and using it to inform design decisions of buildings and serve as a decision support system and design tool.

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