The opportunities and challenges of using LCA-based BIM plugins in early-stage building design: an industry expert perspective

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Abstract. The integration of Building Information Modelling (BIM) and Life Cycle Assessment (LCA) has gained importance in decision-making processes of building design, and various approaches have been developed. Nevertheless, in moving towards a circular economy (CE), current integration approaches still face limitations in the implementation of CE principles into building design. This paper focuses on LCA-based BIM plugins and investigates through a series of semi-structured interviews with expert practitioners in the field, the opportunities and challenges associated with the process for achieving robust integration between BIM and LCA platforms as an approach to enhancing the incorporation of CE principles. Findings reveal the considerable potential of using LCA-based BIM plugins at early design stages as a decision-making tool. The results in particular highlight the importance of the accuracy in both BIM and LCA modelling; and thus, the need for (i) effective management relating to both time and work, (ii) clear guidance for BIM modelling, and (iii) increased knowledge regarding the proper implementation of LCA and CE concepts.

1. Introduction

In the context of the response to the growing threat of global warming, there is an immediacy to act on significantly mitigating greenhouse gas emissions with ambitious reduction targets [1, 2] and a need for a fundamental shift towards a circular economy (CE), as a potent contributor to achieving zero-carbon prosperity, across all sectors [3]. The architecture, engineering, and construction (AEC) sector accounts for 36% of global energy use and nearly 40% of total direct and indirect CO_2 emissions [4]. It is therefore a major target of mitigation efforts [5] and an area where there has been the increased attention directed towards exploring the way of incorporating the CE principles into the design practice [6]. In this context, Life Cycle Assessment (LCA) has allowed the holistic evaluation of environmental performance of buildings throughout their entire lifespan. However, it is a complex, data-intensive process as buildings consist of various elements and components and have a long-life span [7]. As Building Information Modelling (BIM) tools offer the opportunity to overcome data management difficulties, recent work has focused on integrating BIM and LCA in both academia and industry to reduce the time required for data input to support automatic implementation of multiple analyses in early design stages [8-10]. However, technical limitations, such as complexity of data interoperability, lack of data exchange standards and inadequate levels of knowledge and expertise in both areas still

exist [11, 12]. LCA-based BIM plugins are one of the most cutting-edge integration strategies. They support automated data input and the minimisation of practitioner effort and thus have considerable potential with this context [9, 13]. To address the current gap in knowledge, the key aspects of current practice, needs and requirements within the implementation of LCA-based BIM plugins, this study, through the undertaking of in-depth industry interviews, aimed to gauge the perspective of industry practitioners to:

- Identify current opportunities and challenges associated with the process,
- Highlight solutions for achieving the practical application of the plugins,
- Investigate opportunities for the inclusion of CE principles during early design stages.

2. Methods

A qualitative research approach involving a series of semi-structured interviews with expert practitioners in the field was adopted. In the relevant literature, the number of participants in 'expert voices' studies is rarely defined, whereby the quality of the analysis is deemed more important than the quantity of interviews [14]. Saunders [15] proposes a range of 4 to 12 participants chosen from a homogeneous population to achieve data saturation. Given this, a study sample size of 4 was deemed as appropriate and in line with similar work in the field.

A non-random purposive sampling approach supported by snowballing strategy was employed to select participants. The interviewees were selected based on the criteria which aimed to ensure relevant industry experience and expertise, where they were expected to be LCA practitioners with experience in the implementation of both LCA and BIM in sustainability practices across Europe. Potential interviewees were identified via their organisational LinkedIn profiles, then contacted via email.

The main topics covered in the interview were: (i) actions in the design process at early design stages, (ii) influence of LCA tools on the decision-making process, (iii) issues in the application of the tools, (iv) analysis process of sensitivity and uncertainty in LCA results, (v) opinions about the efficiency of LCA tools in terms of the ability of the tools to provide accurate enough results, and (vi) future development in the tools considering the circularity context.

2.1. Data analysis method: thematic analysis

A "thematic analysis" approach was used for data analysis where key information from interviews was identified and encoded; then sub-themes and main themes were derived and interpreted [16], using the systematic guideline proposed by Braun and Clarke [17, 18]. Theme generation was based on an inductive and a data-driven approach. The qualitative analysis software NVivo 20 was used to support the analysis and a participant coding system was used to enable cross-referencing (e.g., P1 denoting Participant 1).

3. Analysis results

The interviews provided feedback on how the LCA-based BIM tools are used within the design process and the way in which influence the decision-making process. In addition, more comprehensive information about the specific actions taken by practitioners in each life cycle stage to reduce overall environmental impacts of design alternatives within the consideration of circularity context was derived. The three themes discussed below were identified.

3.1. Theme 1: Integrating LCA in building design practice

This theme covers the barriers and enablers in the implementation of LCA in the design process as a part of the effective decision-making mechanism. Participants were asked to determine drivers and constraints to the influence of LCA in the design process and these were identified as:

- The lack of regulatory enforcement to undertake LCA was indicated as the main constraint. As an example, one interviewee stated that "*…the challenges that there is 'no' regulation that forces anyone to do it…as a less serious thing to solve…(P4)*".
- Building certifications and planning applications were considered to be main drivers "*…the driver is all the certifications; BREEAM, LEED, DGNB…those LCAs are …part of the planning application…(P2)*".
- The time demanding LCA process and unrealised potential of LCA as an effective decision-making tool were also highlighted by interviewees, in statements such as "*It is more like a just 'do it'. Doing the assessments is not kind of used for any meaningful design tool…(P3)*" "*…Then, that is time-consuming…(P2)*".
- The knowledge gaps within the design team, which were mostly attributed to a lack of familiarity with LCA were identified as the most common barriers in the implementation of LCA during the design process. Several statements supporting this included "*…people could just use them in the design process, and not needing me to come at the end of the process and tell them what is good. This does not have so much sense…(P1)*" "*…the architects themselves should do the calculations early stages…(P3)*" "*…it takes time and time before my team to get involved and by that point maybe the point of influence has already been passed…it would be really helpful to allow them to do their own quick analysis…(P4)*". This was in part due to the unclear sequence of data transfer involved and subsequent resistance to implementing design changes in response to analysis outcomes.

3.2. Theme 2: LCA-based BIM plugins

This theme aimed to explore the benefits and main difficulties in using LCA-based plugins in the decision-making process and requirements in achieving a robust integration between BIM and LCA plugins. The benefits of using LCA-based BIM plugins were identified as:

- Provision of time-efficient assessment and the ability of the tools to conduct a quick analysis of the design alternatives e.g., "*…it is reasonably fast to do different iterations and test different reduction opportunities…it is quick…(P4)*".
- Supporting the decision-making process and the ability of the tools to conduct simultaneous calculations for various iterations to reduce building impacts. Examples given include "*…you can get very good information…(P1)*" and "*…it allows you to again do a hotspot analysis of where the biggest chances of making the building more circular…(P4)*".
- The suitability of using the tools in the certification process; the interviewees stated that "*…It will work for BREEAM as well…(P4)*" and "*…it has all the tools you need in order to a BREEAM assessment…(P1)*".

Difficulties in achieving a robust integration between BIM and LCA plugins were identified as:

- The larger size of model data and the unsuitability of the early-stage BIM models to performing an LCA in most cases where "*…larger projects might get a little bit hard to handle because of the size of data…early-stage models don't have anything useful for LCA…they're not really useful…(P3)*".

Two similar and often compatible discourses emerged in relation to the lack of suitability of BIM models:

- The lack of useful data at early-stage models and the inaccuracy stemming from the modelling simplifications. Examples of reported issues included "*…the main constraint is getting good and accurate data on which to base the LCA…at the earlier stages of the projects…the BIM models and drawings just really were not accurate enough for us to rely on for any materials, quantities, all types…(P4)*" and "*…especially in the early design stages you don't have much information…*(P1)".

In regard to these statements, the main requirement in achieving a robust integration highlighted was having a "well-built" model to perform an LCA. This requirement was associated with two main factors:

- Harmonisation: Standardising naming conventions across tools to enable the recognition of materials when assigning the relevant data to the building elements "*…It was very difficult for me to understand which material they have corresponds to what material in Revit. Because they have different names…(P1)*",
- Minimising user errors during modelling: Through training and provision of an LCA/BIM modelling, e.g., "*…training…so, they can be overcome*…and…*a BIM guide on how to prepare BIM models for LCA that lists all the things should be integrated into the BIM process…(P2)*".

3.3. Theme 3: Circularity in building context

Within this theme, the following issues were identified: (i) the barriers to transitioning to circularity in building design, and (ii) the difficulties in the use of LCA-based plugins to aid the selection of building materials with a focus on their reusability and recyclability. Similar constraints as those discussed in Theme 1 were highlighted, where the main barriers were:

- The lack of regulatory enforcement, clear standards, and metrics to assess the circularity in building "*…there is 'no rules'…and… 'no standards' around…circularity score…all of these make it challenging to do circularity assessments as part of LCAs…there is no clear metrics around building circularity...(P2)*"
- The lack of proper understanding of the concept of circularity and a lack of motivation to assess circularity; "*…in terms of assessing circularity or level of circular economy, the materials efficiency calculation…is 'kind of' doing that. It is rating proportion of the material is virgin against recycled or reusable…(P4)*" and "*…module D like we reported but then we don't really measure it, we don't really summarise all together. We just reported somewhere…(P1)*".

Since findings illustrated that LCA was not properly adopted in the current building design practice, the difficulties in implementing CE principles via LCA-based BIM plugins were not particularly prominent in the interview data.

4. Discussion and conclusion

Based on the practical assessment of LCA-based BIM plugins by the practitioners, this study provides insights into the enablers and constraints relating to the implementation of LCA in building design, the parameters relating to effective use of LCA plugins and finally the main barriers in the transition to the circularity in building practice. The insights gained and discussed are as follows:

4.1. The enablers and constraints relating to the implementation of LCA in design practice

The analysis revealed four groups of insights. First, a regulatory requirement to undertake LCA as a part of the application was identified as one of the main enablers; therefore, since LCA remains non-compulsory, this constrains the potential benefits achievable through widening its utilisation in the industry. Second, even though building certification requirements to earn credits, such as BREEAM Mat 01 and LEED MR, have helped drive increased utilisation, the influence of LCA in design practice was limited to that particular process. As a result, LCA practice was in most cases not utilised as a decision-supporting tool during the design process. Likewise, it was found that the LCA 'knowledge gap' and absence of required skills to perform it have further constrained its potential as a powerful decision-making tool. Mechanisms to overcome barriers included increased engagement particularly between architects and other members of the design team with the LCA process and the incorporation of LCA tools and consultants as early as possible within the design process. Given the frequency of design changes and the laborious LCA process, effective time and work management are required to organise the unclear sequence of data transfer. To further enable the implementation of LCA within design practice, it is important to upskill the workforce with LCA training as well as provide clear guidance for the assessment process.

4.2. The parameters relating to effective use of the LCA plugins

Findings demonstrate that the use of LCA-based BIM plugins at early design stages as a decision-making tool can potentially help to assess the overall environmental impacts of the building and identify the reduction potential during the design process. The quality of LCA undertaken and the effectiveness and reliability of LCA plugins were closely associated with the accuracy of BIM models where the maturity of BIM models was identified as a key aspect for accuracy. The need for well-built models was one of the main priorities highlighted; therefore, modelling guidance that clearly specifies the requirements for well-built models is crucial.

4.3. The main barriers in the transition to the circularity in building practice

As a highly novel topic in the AEC industry, the absence of regulations, standards, and clear metrics to guide the assessment process as well as inadequate motivation on both organisational and individual levels were the main barriers noted. Given the difficulties identified in current LCA practice and the limited capabilities of current tools in assessing the uncertainties associated with the impacts and benefits of reused building materials, the implementation of CE and circular design principles currently requires substantial effort.

4.4. Conclusion

These key messages which can be concluded from this study are:

- The use of LCA-based BIM plugins can play a considerable role in aiding the transition towards a net-zero carbon built environment.
- Due to the lack of regulatory enforcement and sectoral motivation, the use of LCA plugins is in most cases currently limited to supporting building certification rather than as part of a design process that aims to improve the environmental performance of buildings.
- Therefore, the potential of LCA as a powerful decision-making tool is unrealised and considerable efforts are still required to make its use widespread.

In considering the wider scope of the environmental impact agenda, the findings related to the circularity in building practice indicates that the important role of regulations, standards, and metrics to assist and encourage the practitioners to implement CE principles. Moreover, insufficient knowledge

regarding the conceptual foundations of CE were identified as further barriers to the wider adoption of circular design principles in the sector. The interview findings suggest the following solutions which can be used to overcome these challenges and to facilitate the inclusion of CE principles to the building design process: (i) effective time and work management, (ii) clear guidance for BIM modelling, (iii) increasing knowledge levels regarding the proper implementation of LCA, and (iv) the improvement of workforce skills.

It should be noted that the study findings provide a view of the "current use" of the LCA-based BIM plugins in the practice, which was limited to, and reflective of the European context and thus may vary from the more global view. Given this, an extended study with a more international scope might reflect on the varied role of the regulations may play within these different contexts. As such, further research intends include a wider group of practitioners and investigate extending the use of these plugins to support the implementation of circular design principles.

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