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Comparative analysis between a complete LCA study and results from a BIM-LCA plug-in

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ABSTRACT

Early and precise decisions can help the process of sustainable design to become much more efficient and cost-effective. Life Cycle Assessment (LCA) enables a scientific assessment, which facilitates locating possible changes associated with different stages of the cycle which results in improvements in its environmental profile. Although LCA is increasingly present in the demands of the building sector, professionals continue to seek new ways to incorporate such a methodology into the building design and construction processes as seamlessly and straightforwardly as possible. A promising possibility is the integration of building components LCA data in the Building Information Modelling (BIM) platform. This paper discusses the consequences of the simplifications of LCA data and methodology in the main existing tools that integrates LCA in the BIM platform using a simulation on wall systems performed in a BIM plug-in. The consistency of the results is compared to a full LCA on Gabi 6 software. The results were not consistent, despite the research efforts towards equalizing the scope of the studies to provide a fair comparison. The reasons are probably the simplifications and shortcuts necessary for developing a simpler BIM-based tool to be applied during the design process, by any building designer with no particular expertise in LCA.

1. Introduction

The design of sustainable buildings that meet all sustainable requirements is often a challenge to building professionals and designers [1]. New building design and construction are an opportunity for reducing the impacts on the natural environment and operational costs and concerns regarding energy scarcity. Environments that meet users' economic, utility, durability, and comfort needs and are environmentally conscious and resource-efficient throughout their life cycle can be potentially created [2].

Informed and precise decisions in the early stage can help the sustainable building design process to become more efficient. Traditional design environments usually provide less support for visualization of the feasibility of early design decisions. Connecting Building Information Modelling (BIM) to a sustainability-based decision-making tool enables detailed environmental trade-off analyses at the early design stages [3].

Life Cycle Assessment (LCA) enables a scientific assessment, which facilitates locating the possible changes associated with different stages of the cycle, which results in improvements in its environmental profile. Although it is increasingly present in the demands of the building sector, professionals still seek new ways to integrate it into the building design and construction processes as seamlessly and straightforwardly as possible. The integration of building systems LCA data per functional unit in the BIM platforms is a movement towards solving such issues.

2. Literature review

This literature review provides an overview of Life Cycle approach implementation within BIM-based sustainable design, and the existing software tools towards the BIM-LCA integration during the building design process. Such review is an important basis for further discussion on the potentials and limitations of the simulated software plug-in.

2.1. BIM-based sustainable design and life cycle approach

Integrating sustainable data into the early design stages is significantly important for decision-making, as this is when most sustainable decisions are made. The challenge is to find a way of using sustainable BIM-based tools even during the early design stages when many of the variables for the building's systems are not yet available, and to provide quantitative performance predictions [4].

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BIM software is still not well integrated with sustainability databases and, in most cases, a team may need to use considerable time and effort to import the information from an outside source [4].

Ilhan and Yaman [4] presented a framework for this integration in order to build environmental assessment processes in the BIM platform, which would also help the provision of documentation for green building certification. The authors state that the shifting approach to the building design, construction and maintenance needs an interdisciplinary collaboration. BIM for integrated sustainable design would simplify the certification process in terms of time and cost due to early stage interactions [4].

Oti et al. [5] also said that integrating sustainability decision modelling into BIM is still at the initial stage. These authors classified the main challenges into two categories: a) the complexity of the sustainability definition and the difficulty of including it in the initial modelling process stages, and b) the difficulty related to the techniques for mapping objects, data and rules from holistic sustainability definitions into BIM. Those authors proposed a sustainability modelling framework which targets combining sustainability requirements with systems implementation in order to ensure that both are not carried out separately 5]. Typical aspects of planning, construction, operation and end-of-life of materials involved in the building life cycle have been considered, and the approached implementation is limited to economic and environmental dimensions of sustainability [5]. They proposed a BIM extension which provides support for sustainability-based decision-making on structural solutions, that comprises a modelling framework and which combines three key indicators – namely, life cycle cost, carbon footprint and ecological footprint measures – to assess the sustainability of buildings [5].

Krygiel and Nies [6] summarized the different ways BIM can support the design of building sustainability as follows: i) assessing the building's orientation; ii) analyzing the buildings massing; iii) conducting daylighting analysis; iv) investigating the water harvesting potential; v) modelling building energy performance; vi) examining the suitability of sustainable materials, and vii) designing site and logistics management.

LCA was developed in the mid-1980s and it has become a widely-used methodology because of its integrated way of treating topics, like framework, impact assessments and data quality, and the use of a life cycle perspective avoids shifting a problem from one part of the life-cycle to another [7,8].

The LCA methodology has developed and somewhat matured over the last decades. Current activities regarding databases, quality assurance, consistency, and harmonization of methods have contributed to this process and the development of new application areas has indicated the need for the assessment and communication of environmental impacts of products [9].

Standard bodies, such as ISO, have avoided the standardization of more detailed methodological choices. Presently, international activities have aimed at providing such recommendations, including characterization models and operational characterization factors for important substances [7].

The review conducted by Ortiz et al. [10] systematically explored and evaluated the different ways of using LCA for building materials and components combinations (BMCC) and for the whole process of construction (WPC). The results showed the LCA of BMCC and WPC represents an innovative methodology that improves sustainability in the construction sector throughout the building life cycle stages. Over 90% of the LCA case studies have focused on the evaluation of environmental impacts and decision-making process assistance in the building sector [10].

Although LCA has been used predominantly to retroactively estimate building impacts [11], it can be useful during the building design [12], as it can help environmental-based design decisions [13]. The LCA methodology can quantify, during the design process, a product's impact over its entire life cycle and its most impactful components [14], however, it has often been avoided due to the complexity of the required data and available tools [15,16].

The recent advent of BIM represents an approach towards LCA integration in the construction industry and this expansion is moving towards more engineering analysis techniques and several construction business functions [17]. The BIM competencies to be learned and measured for performance improvement must be identified for the development of BIM capabilities [18,19].

Wang et al. [20] reported that previous research have mainly approached three aspects, namely advanced intelligent technologies, performance assessment methodologies and investment evaluation analysis. The LCA integration in the BIM platform is a combined field that comprises all the above-mentioned aspects and could support the spreading of environmental assessment and conscious choices of building materials in the design process [20,21].

However, the BIM-based LCA has several constraints, such as the complexity of LCA tools and data input on such programs, and the concerns regarding data interoperability among different software [21,22]. Improvements in the data exchange and the implementation of LCA tools in BIM software are still requirements to be met [21,23].

Several studies have addressed the use of BIM for LCA as summarized by Ajayi et al. [21]. For instance, Wang et al. [20] demonstrated how BIM supports the implementation of LCA and an easy file transfer between BIM tools though a simulation using Revit Architecture, Autodesk Ecotect and a combination of other external analysis tools and databases. Stadel et al. [24] highlighted that although recent BIM platform development has enabled material take-off and estimates, disaggregated individual materials must be under the same family, which may act as a limitation for some analysis.

The need for proposed methodological simplifications for an uncomplicated LCA implementation led some studies to neglect some of the five main stages in the whole building life cycle coverage [20,21,25]. Due to a large number of environmental assessment software tools currently available, a combination of LCA and other external analysis tools, as various databases, have been used in several studies [21,26].

Azhar et al. [27] concluded, using a case study, that BIM-based sustainability software provides very quick results, in comparison to traditional methods, however, some discrepancies have been found in the results due to the inaccuracy of the building information model developed.

New forms of integration between design tools and building performance simulation (BPS) tools at runtime-level provide environmental performance feedback directly in the design tool and open new design scenarios at early design stages [28], changing the building design into a faster performance-aware process, and easing the development of multiple design alternatives [28].

Negendahl et al. [28] discussed the modelling method best suited to the early design stages, specifically for designing high performance buildings, and concluded that the most important aspect is regarding how much the operator can benefit from the model, rather than being limited by it.

Design tools, such as Rhino, Revit and SketchUp blur the distinction of being exclusive CAD software, as they support many BPS environments either as services or plugins. While plugins offer extension capabilities beyond the design tool, the latter require an exclusive operator to use such extensions [28].

Despite the growing understanding of BIM and its potential for sustainable environmental design in academic research, the development of green BIM has also been criticized by Wu and Issa [29] as ‘immature, *ad-hoc* and unsystematic’. These authors argue that the adoption rate of BIM in green building projects is still very low and its full potential is yet to be explored due to the practitioners' limited knowledge on this evolving technology [29].

Wong and Zhou [3] concluded in their review that there is a lack of all-inclusive green-BIM tools that provide a ‘cradle to grave’