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Using BIM for Assessing Buildings Life Cycle Impacts

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Abstract. Facing the recent implementation of the Building Information Modelling (BIM) process in the construction industry, several potentialities have not been fully explored yet. Among them, is the integration of BIM in Life Cycle Assessment (LCA) analysis in order to automate the assessment of the potential environmental impacts. To date, despite the existing studies on the subject, there is still a need to define and establish a recommended assessment framework and software tool for LCA purposes when BIM methodology is used. This research analyses the current state of the implementation of the LCA analysis in the BIM process. Additionally, it compares the results from the use of two LCA software. For this purpose, a case study was modelled in the Autodesk Revit BIM platform and exported to two LCA specific BIM tools: Athena Impact Estimator and Tally. The life cycle impact results from both BIM tools, as well as the required workflows, are discussed and compared in order to validate results and identify the advantages and disadvantages of each. The results show that the implementation of the LCA method can be optimized in time and reliability by using the BIM process. Concerning the selected software, Tally has a better interoperability capability, user-friendly interface and a wider range of possible locations for the building. On the other hand, Athena Impact Estimator requires a detailed building characterisation to perform a comprehensive environmental impact assessment and has a broader materials database.

1. Introduction

European buildings are responsible for about 40% of the European Union (EU) final energy consumption, where 60% of this consumption is electricity-related [1]. Extraction and processing of natural resources create environmental burdens, related to material or water extraction or land-use change, as a result of socio-economic activities. Thus, waste and emissions are released into nature, causing environmental impactss on the planet [2]. The environmental issues concerns the reduction of use of non-renewable materials and water, and the reduction of emissions, wastes and pollutants [3]. The EU's buildings sector needs to develop and deploy more innovative solutions to enhance the building stock energy efficiency and help to reach the energy and climate policy targets [4]. Therefore, an assessment and multi-objective optimisation at the building level is an opportunity for further research [5]. Life Cycle Assessment (LCA) allows to estimate the cumulative environmental impacts, resulting from the whole life cycle stages of a product (e.g., raw material extraction, material transportation, ultimate product disposal, etc.) [6].

Following this approach, Building Sustainability Assessment (BSA) methods have been developed to support designers in achieving the most appropriate balance between the different dimensions of sustainability, as well as to create apractical, transparent, and flexible enough sustainability assessment method [3][7]. Currently, with the theoretical BSA framework, it is necessary to create improved tools to meet designer's needs, by looking for new platforms to facilitate the connection from different sources, covering as many building aspects, criteria, processes and life cycles stages as possible [8]. LCA software has the potential to simplify the complex and time-consuming task of assessing buildings life-cycle impacts. Besides that, even when inputs are matched as closely as possible, implementations of a common methodology in different LCA software systems can provide different results [9].

Building Information Modelling (BIM) tools and their associated processes can support building design and construction procedures to answer to the increasing societal and political demand for higher quality buildings, faster development, and improved sustainability while reducing costs, time and resources. The use of the BIM process in the Architectural, Engineering and Construction (AEC) industry may be an essential path to optimise buildings performance and reduce the environmental impacts of the industry in the future [10]. Because BIM is a data application with the inherent ability to associate data fields with the 3D model, it promotes a wide range of capabilities that include: quantity take-offs, cost estimating, space and asset management and energy analysis, along with other applications [11]. Given the demand for better and sustainable buildings, it is important to create ways to integrate and automate the BSA methods within the BIM context [12].

The integration of BIM with LCA has delivered a fast and reliable way to produce material quantity take-offs and has enabled the automated mapping of materials with the associated environmental impact factors [13]. Röck et al. [14] have presented a workflow, showing that it is possible to accomplish an integration of LCA in BIM, when using a common granularity in both LCA data and BIM-based bill of quantities, as well as specifying a common naming convention. Emami et al. [15] have demonstrated, with two existing buildings, how the estimation from the two most widely used LCA tools (SimaPro and GaBi) are incompatible when studying all the impact categories, other than Climate Change. Nwodo et al. [16] claim that it is required a real-time BIM-LCA framework/prototype for sustainable construction, which may be robust enough to have the following qualities: 1) establish milestones for other researchers in the field; 2) has the potential to successfully evolve into a commercial software; and 3) has the potential to be adopted by the AEC industry.

Given the potential of interoperability between BIM and LCA, this study intends to optimise and test the evaluation process of two LCA tools (Athena Impact Estimator and Tally) by using a 3D architectural model created in Autodesk Revit. The BIM model was exported to those LCA tools by using the existing plug-ins.

2. Materials and Methods

This study aims to analyse the feasibility of implementing an environmental life cycle analysis by the use of the BIM process A residential building case study was modelled in Autodesk Revit and exported to two different LCA tools: Athena Impact Estimator (AIE) and Tally. Autodesk Revit was selected to create the building architecture and structural model due to its vast library of parametric models, allowing its potential use in many fields. After that, a research analysis about LCA software platforms was made to understand their practical applicability and which were the most recommended for the present research. Tally plug-in was chosen due to its interoperability capabilities, user-friendly interface and a wide range of available locations. On the other hand, AIE was also chosen because of the broader materials database and free access, which allow comparing different market solutions. AIE requires a detailed building characterisation to perform a comprehensive simulation.

To conduct the research methodology, EN 15978 was followed. According to this standard, the life cycleanalysis entails the material production stage (Modules A1 to A3), the construction stage (Modules A4 and A5), the use stage (Modules B1 to B7), the end-of-life stage (Modules C1 to C4) and Module D, which allocated the benefits and loads due to recycling, recovery or reuse of materials, corresponding to a cradle-to-grave analysis [6]. The bill of materials is highlighted in ISO 14044 [17] mentioning that LCA studies shall include the goal and scope definition, inventory analysis, impact assessment and interpretation of results.

The selected environmental impact indicators for the study are: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Smog (POCP), Ozone Depletion Potential (ODP), Primary Energy (PE) and Non-Renewable Energy (Non-Energy). These indicators were selected according to the adopted software capabilities, and also because they are the ones that are normally considered when implementing the LCA and BSA methods at the material, building and urban scales[18]–[21]. According to Figure 1, an essential step to quantify the potential environmental impacts of a product is the inventory analysis. In this process, the inputs and outputs (e.g. energy and materials) of the system under study are quantified.

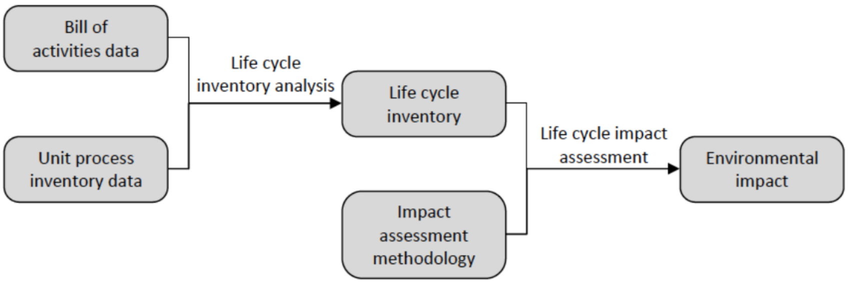

Figure 1. Steps to convert the inventory data into environmental impacts [22]

In order to analyse how BIM can facilitate the implementation of the LCA method, the architectural and structural plans of a two-floor house was modelled in Autodesk.. As a first step of the research methodology (Figure 2) all the quantities were exported from Autodesk Revit model to AIE. Moreover, in AIE, three scenarios of an expected lifetime were tested – 40, 60 and 90 years – and reported for each life cycle stage. At this level it was possible to identify two negatives points about this process, namelly the necessity to introduce the the materials quantitative take-off manually and the restriction in the definition of the building location. In this software it is only possible to define cities from Canada or from the United States of America. Thus, Atlanta, Georgia was chosen. After that, the same Autodesk Revit model was exported to Tally (via plug-in) and it was necessary to input the detailed materials characteristics manually the location (set as in AIE), , the expected building lifetime (60 years) and the construction and operational energy inputss. With all the simulations data, a comparison was made concerning the results from the AIE and Tally and considering alifetime of 60 years.

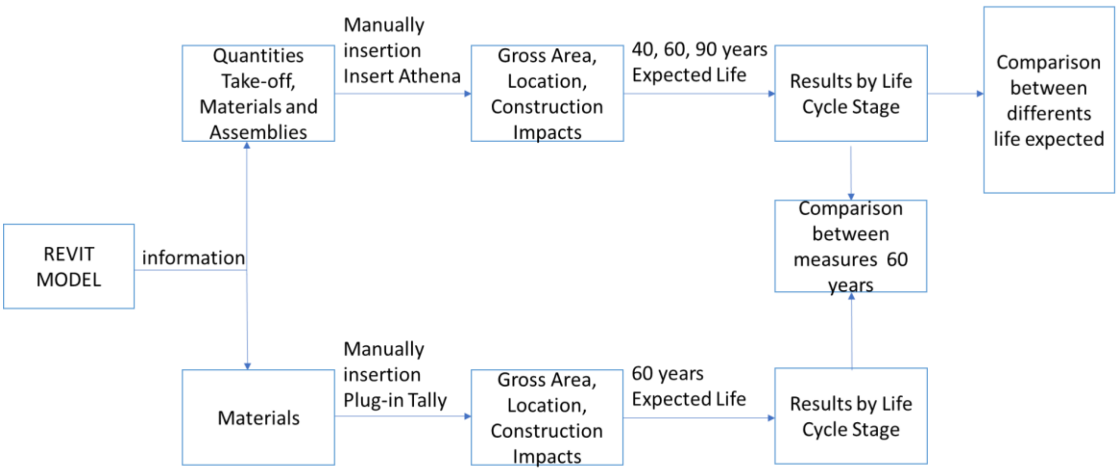

Figure 2. Research methodology

The Autodesk Revit model was carefully checked to avoid duplicated quantities of materials and wrong interpretations. The model and the main characteristics are presented in Figures 3 and 4.

Figure 3. Building Model

Gross Area	108 m²
Ceilings	Metal Stud Layer and Gypsum Wall Board
Windows and Doors	Wood Framing and Double Glazing
Floors	Pre-stressed precast concret structural
Roof	Clay roofing tile with rigid isulation with XPS
Structural Columns	Precast concret column with rebar reinforcement
Footing Foundation	Structural Concrete 35 Mpa
Structural Beam	Precast concret retangular beam with rebar reinforcement
Wall	Brick with XPS cavity fill, air, Autoclaved concret block and Gypsum Wall Board

Figure 4. Main characteristics of the building model

3. Results

The results from the application of the Athena Impact Estimator (AIE) are presented in Figure 5, 6 and 7. Figure 5 and 6 presents the results by life cycle stage. The cumulative life cycle impacts for different lifetime scenarios (40, 60 and 90 years) are presented in Figure 7. The production stage (A1 to A3) has the highest impact. Over the life type there are only changes in the potential impacts related to the use stage (B2, B4 & B6), namely due to the operational energy use.

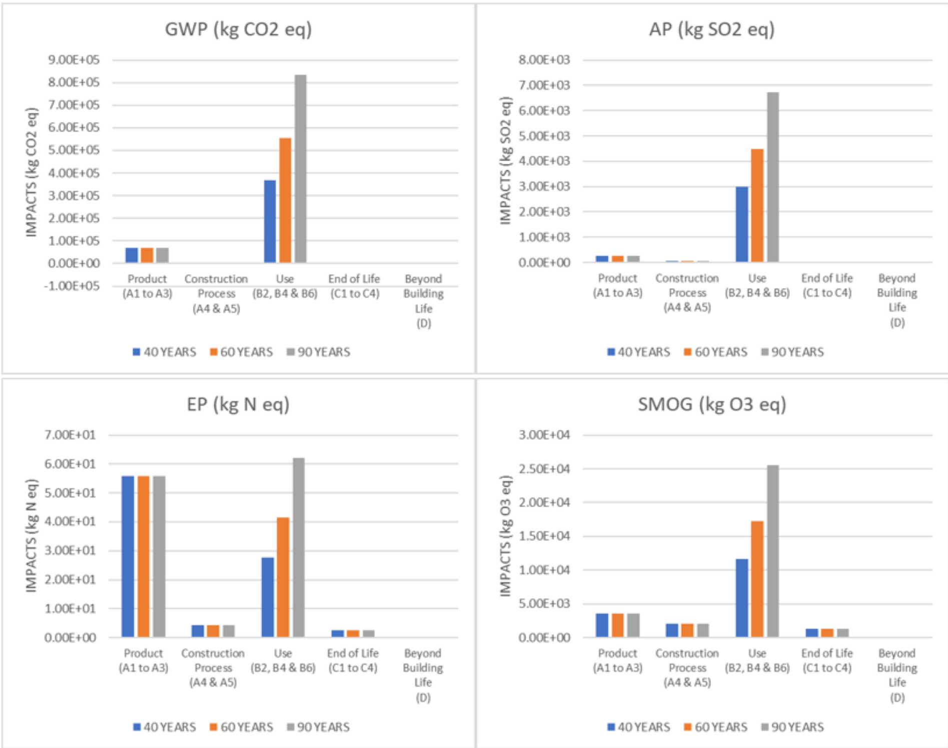

Figure 5. Results from AIE for each life cycle stage for GWP, AP, EP and SMOG impact categories

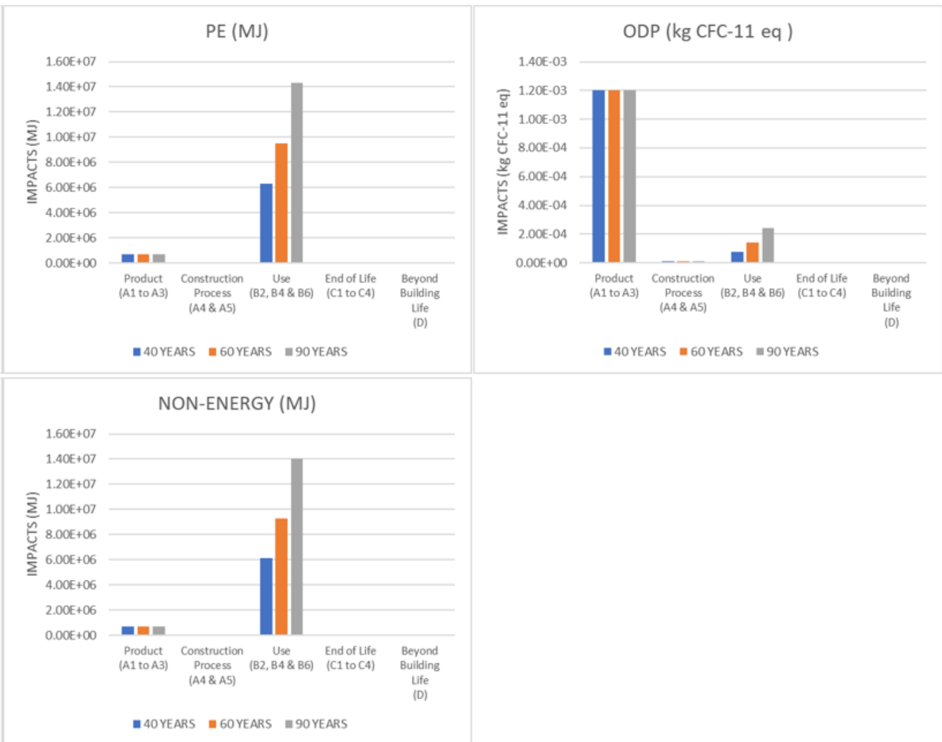

Figure 6. Results from the AIE for each life cycle stage for PE, ODP and NON-ENERGY impact categories

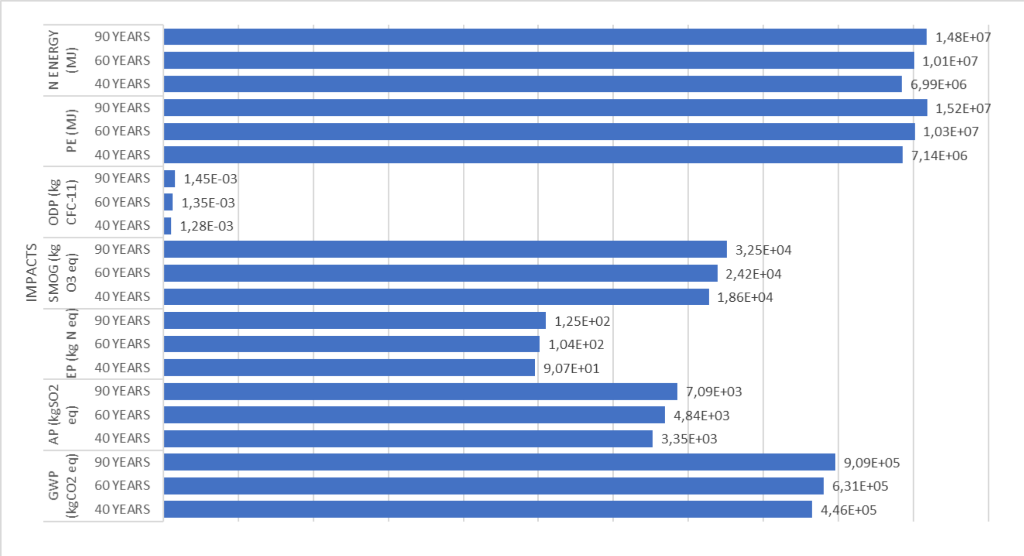

Figure 7. Cumulative environmental impact per category for a lifetime 40-years, 60-years and 90-years

The results from the use of Tally software are presented in Figure 8, showing the contribution of each life cycle stage -product stage (A1-A3), construction stage (A4-A5), use stage (B2-B6), end-of-life stage (C1-C4) and benefits and loads beyond the system boundaries (D) – in the cumulative lifetime impacts. According to Table 1, the most significative impacts were registered in Energy (Primary Energy and Non-Renewable Energy) and GWP. The lowest impacts were obtained for the ODP.

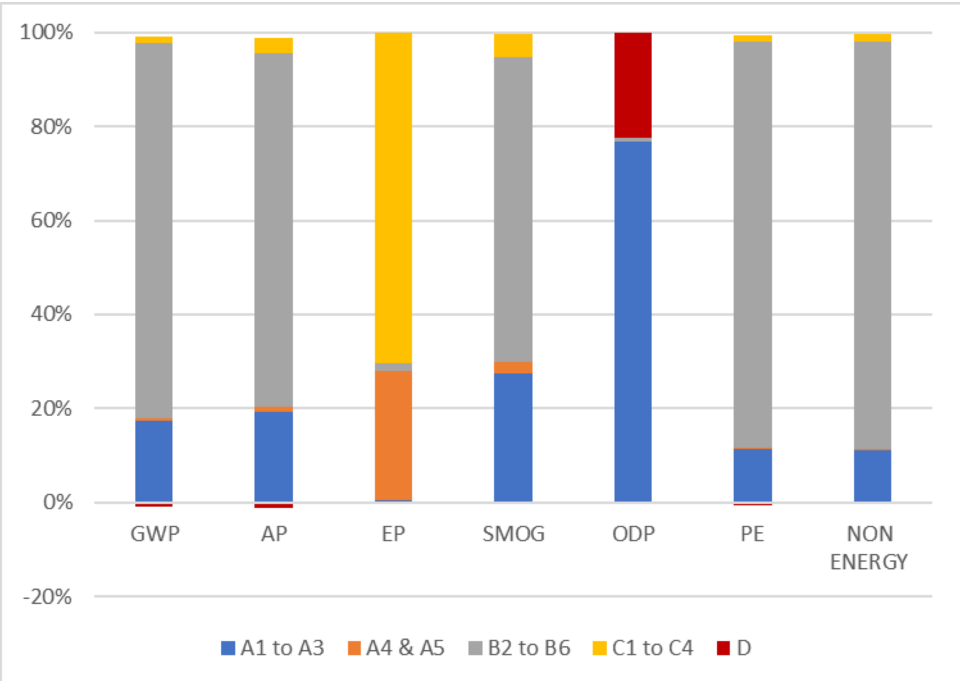

Figure 8. Results from Tally software, presenting the contribution of each life cycle stage to the considered impact categories within a 60-year lifetime

Table 1 and Figure 9 compares the cumulative results for the 60-year lifetime, between Tally and AIE. Results show that the lowest differences were obtained for the NON-ENERGY, PE and GWP indicators. The highest differences were noticed for the ODP, AP and EP. Overall, the results from AIE are higher than the results from Tally, except for the EP and PE indicator. The differences are above all related to the use of different life cycle inventory databases. Results show that it is impossible to have similar results from the use of different LCA software tools when the background data (e.g. life cycle inventory and material bill) is different.

Table 1. Cumulative 60-years lifetime impacts – Athena Impact Estimator (AIE) *vs* Tally

	AIE	Tally	Difference (%)
GWP (kgCO_2 eq)	6.31E+05	6.26E+05	1
AP (kgSO_2 eq)	4.84E+03	1.38E+03	71
EP (kg N eq)	1.04E+02	3.93E+03	97
SMOG (kg O_3 eq)	2.42E+04	1.82E+04	25
ODP (kg CFC_{-11})	1.35E-03	1.07E-04	92
PE (MJ)	1.03E+07	1.05E+07	1
NON-ENERGY (MJ)	1.01E+07	9.83E+06	3

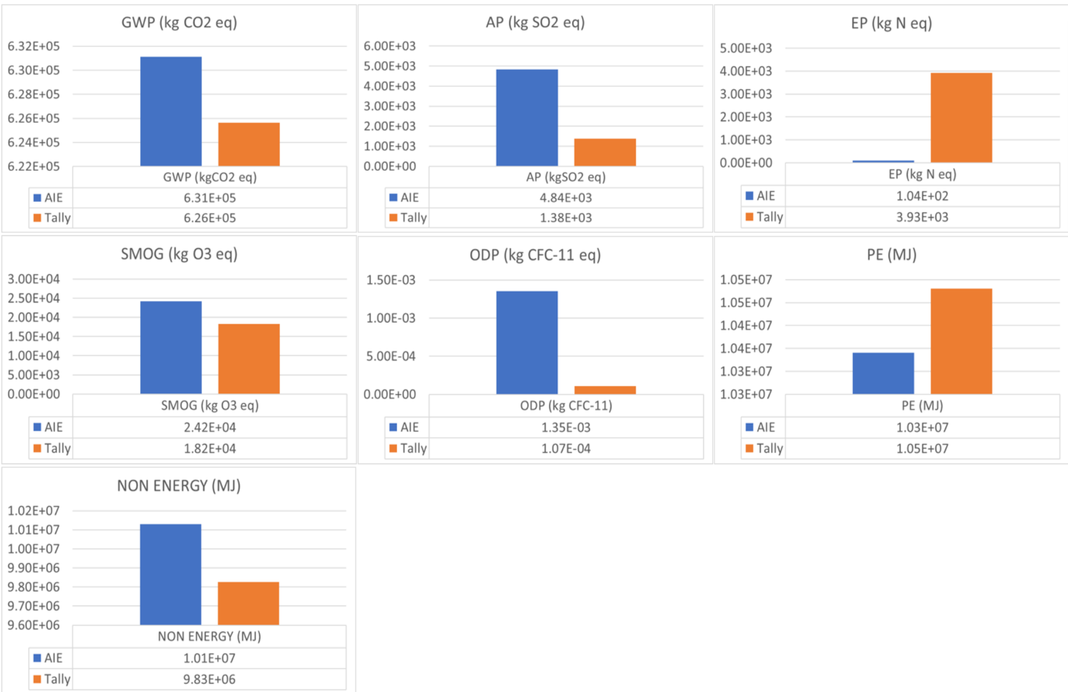

Figure 9. Comparison between AIE and Tally results

4. Conclusion

Building Information Modelling has high potential to promote the use of the LCA method since the preliminary design stages, since it simplifies all the necessary steps for the implementation of an LCA study.. BIM is the first step of a digital revolution, which is taking place in the construction industry, making easier to define and compare the performance of different design scenarios. The use of BIM to promote the practical use of LCA should be faced as an important study topic to improve and foster new results, to assist a holistic view for the built environment, considering a cradle-to-cradle approach in the design of a more sustainable built environment.

This study presented the results from the use of two different BIM integrated LCA software. This comparison intended to increase the knowledge about BIM application on LCA as well as to understand how much the LCA assessment process can be optimised.

Tally brings a betterinteroperability capability, a user-friendly interface and a wider range of possible locations for the building. On the other hand, Athena Impact Estimator (AIE) requires a detailed building characterisation to perform a comprehensive simulation and has a broader materials database. Due to the use of two different databases, the discrepancy between the results was very evident. Differences between the results of the two methods ranged between 1% to 99%. Overall, Tally results are higher than the ones of AIE.. These differences highlight the need to develop country-specific life cycle inventory data for building materials, energy and transportation to be adopted by the different LCA software.

Important conclusions can be drawn in the performed analysis. The implementation of the LCA method in the BIM process is easily learned and performed. Nevertheless, there are some interoperability problems and therefore it is necessary to repeat some processes and double check some information, like e.g. the materials bill. At this level, Tally has better interoperability than AIE. It was also found that the use phase (B1-B6) is where there are more impacts. In contrast, the end-of-life phase is where there are fewer impacts.

Based on the capabilities of the BIM process, it is important to recognise the evolution that digitisation brings to the AEC industry. New trends that allow for more efficient construction processes and buildings are being developed. Despite the existing benefits of using BIM for LCA studies, there is still space for improvements. For instance, there is a need to overcome important interoperability problems, to establish a framework and accurate parametric tools for this type of analysis within the BIM context, and to improve the LCA tools by integrating country-specific life cycle data instead of average one.. Additionally, updates to reduce the number of necessary software to perform an LCA study is of utmost importance for the practical implementation of the LCA method within the BIM process.

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