An Alternative Approach to Material and EPD Mapping in The Development of BIM-based LCA and LCC Tools

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Abstract
Building and construction industry is being criticized for losing oversight and strategic planning of its environmental and economic impacts. As a response, Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) methods are increasingly being studied, evolved, and carried out during design processes of building projects. A practical approach to automate building LCA/LCC is using BIM software to automatically map materials in a Building Information Modeling (BIM) model to Environmental Product Declaration (EPD) and cost databases. However, these approaches often produce unreliable results due to using the material names in the BIM model to match in databases. That leads to inaccurate LCA/LCC analysis. This paper aims to propose a bottom-up material mapping approach, ensuring fast and accurate mapping of the materials. A tool will be developed in collaboration with two Danish sustainability consultants in architecture and engineering, and is empirically evaluated on a large Danish housing project in Aarhus, Denmark.

Keywords: Life Cycle Assessment (LCA), Life Cycle Costing (LCC), BIM, Decision-support

1 Introduction
The world today has inherited a massive inherent global environmental and economic crisis, where buildings play an essential role. Buildings are responsible for 30% of worldwide waste as a result of the construction process and demolition (Herczeg et al 2014). They are responsible for a third of the total Green House Gas (GHG) emissions, and present a 40% portion of global energy use (Sbci 2009). With energy production shifting to renewable sources and buildings becoming increasingly more energy-efficient, policymakers are now looking at including material embodied impacts into building regulations. In Denmark, the government began testing a Voluntary Sustainability Class (VSC) to have a more holistic building design process (Planstyrelsen 2020). In 2021, the ministry of interior and housing announced new regulations regarding the CO2 impacts of buildings, including the embodied impacts of materials, setting a carbon budget for buildings bigger than 1000m2 of 12 kg CO2eq/m2/year, to be implemented in 2023, and it proposes a further reduction every two years and to include buildings under 1000 m2 from 2025 until 2029 (Boligministeriet 2021).

Building designers have to adapt fast to these new strict regulations, which will add a new layer of constraints to the building design. The most popular method that building designers use to measure and improve their carbon footprint over the whole life cycle of a building is Life Cycle Assessment (LCA), which is a methodology used to quantify the environmental impacts of a system or a product (Crawford 2011). LCA is regulated by ISO 14040 and has been adapted for buildings in the EN 15978 standard. Furthermore, it is important to keep in mind that construction companies run on strict budgets, and usually, they would not choose only based on environmental impact. Therefore, a measure of the design cost over its life cycle is important to consider, and the main method used is Life Cycle Costing (LCC) which is regulated for buildings by the EN15643-4 (CEN/TEC 2012)

LCA/LCC requires a large database of all the building materials within a project. Manual input of this data would be very time-consuming and is not feasible for rapid early design assessments. Therefore, Building Information Modeling (Eastman et al 2011) models are significantly beneficial to LCA/LCC analyses. BIM can be used to track project variables such as costs, time, and design efficiency from the early design stage (Kamari et al 2018a,b) to maximize the project's value (Saridaki et al 2019). While the focus on LCA/LCC has been increasing in the literature, data storage in BIM appears to be a substantial barrier; there are issues with the creation of stable, accurate, and flawless frameworks for BIM and LCA/LCC integration (Chiurugwi et al 2015). More importantly: interoperability problems that arise from the interaction of multiple individual technical systems are a significant barrier to performing LCA/LCC analyzes (Hooper 2015).

The use of BIM-based tools (Kamari et al 2019, 2021) in building LCA/LCC has been increasing in the last decade (Potrč Obrecht et al 2020). Researchers use BIM for these analyses because they are data-intensive methodologies. BIM in the context of LCA/LCC is considered as a data hub, containing most of the necessary information for streamlined LCA/LCC analyses. BIM models contain the geometric information of the building elements and materials (2D and 3D). They can also contain data concerning time and life of the elements (4D) and costs (5D). 6D should be recognized as an energy or sustainability dimension (Montiel-Santiago et al 2020).

Although numerous studies consider BIM 6D as the sustainability dimension, BIM models do not currently contain all the data for comprehensive economic and environmental sustainability assessments in the form of LCA/LCC. BIM models need to embed EPD data, end-of-life scenarios within the elements for any LCA analysis, and at least discounting and inflation data for LCC analysis. For this reason, most BIM-based LCA/LCC use extracted material quantity data from a BIM model such as (Jrade & Abdulla 2012).

While (Santos et al 2019) Integrated life cycle sustainability data within BIM objects, arguing that using BIM as a quantity extraction tool contradicts BIM methodology of containing all the building's information under one database. However, with no standard IFC properties for such data, integration is still limited, and data must be standardized by a standardization organization such as buildingSMART (buildingSMART 2021).

Most BIM based LCA tools rely on accurate naming of BIM objects in order to map these objects to their correspondent EPDs. However, BIM models obtained from architectural companies show that the model lacks data, and the objects are named in a way that makes it difficult to map them to their EPD. The other approach was to embed EPD data in BIM objects, however, this approach is still experimental and is seen to be complicated for designers to rely on, and high level of BIM and sustainability expertise is needed for this to be applied. An alternative approach is to create a customizable Excel database created by the company's sustainability consultant that contains EPDs of materials used by the company in their design and search the BIM model for these materials for rapid LCA/LCC analyses. This way will ensure accurate mapping of the materials and is an easier approach for companies with lower BIM and sustainability competencies.

2 Methods

The main aim of this paper is to proposing a bottom-up material mapping approach, ensuring fast and accurate mapping of the materials. We exploit a hybrid qualitative and quantitative approach, beginning with literature review. In collaboration with two Danish sustainability consultants in architecture and engineering (AART, and MT Højgaard) a tool is programmed and empirically evaluated on a large Danish housing project in Aarhus, Denmark.

2.1 Requirements for developing a BIM-based LCA/LCC

Based on challenges early stage BIM-based LCA/LCC from the literature (Meex et al 2018) and interviews, several requirements can be listed, as follow:

- R1. The approach must allow instant feedback to the designer during the designer process, for this the approach must be simple, rapid and does not require LCA/LCC knowledge or experience by the designer.
- R2. The approach should be able to deal with the un-conventional naming of BIM materials in the early design stages.
- R3. Flexible databases.
- R4. The presentation of the results should be easy to understand, allow for feedback and hotspot detection.

Uncertainty is another big issue found throughout the literature. To identify which data is more difficult to obtain for early stage LCA and which areas of the LCA have knowledge gaps (Schlanbusch et al 2016) conducted interviews with 57 construction industry practitioners, all from Nordic countries (Denmark, Finland, Sweden, Norway). Respondents were asked, *"In your opinion, what are the most important knowledge gaps in building LCA."* The top answer to this question was the lack of values used for a screening LCA, which is, is important in the initial design phases of a built environment if the life cycle inventory is not established.

The LCA approach needs comprehensive details on the studied material. It is a common dilemma that LCA is challenging to implement when decision support is more appropriate and most required in early design phases. Solutions to these problems involve sensitivity analysis of various design scenarios. However, due to the complexity of these solutions that appropriately deal with uncertainty, designers are unlikely to use or understand the function of these methods. Therefore, uncertainty and sensitivity are seen to be out of the scope of this study. And it will mainly focus on rapid calculations of LCA/LCC based on what objects exist within the BIM model.

2.2 System boundaries

(Malmqvist et al 2011) Suggested to simplify LCA methodology, the difficulty and uncertainty of LCA results are often viewed as the major obstacles to the increased use of LCA. If inconsistent data is being used, inconsistent results will inevitably be achieved. However, imperfect environmental assessments across the development cycle are often safer than ignoring such impacts. The main challenge is the need for an enormous quantity of detailed data. In general, these types of data are not accessible in the early stages, and the correct database Life Cycle Inventory (LCI) is not always accessible. A quantitative LCA is involved with many assumptions, estimates, and interpretations (Alberto & Ignacio 2018).

The European standard for building LCA EN 15978, created four categories to describe different stages of the life cycle of the building A, B, C, D with some stages several containing sub-stages as can be seen in Figure 1, stages to be included are highlighted in red and the optional stages are highlighted in green.

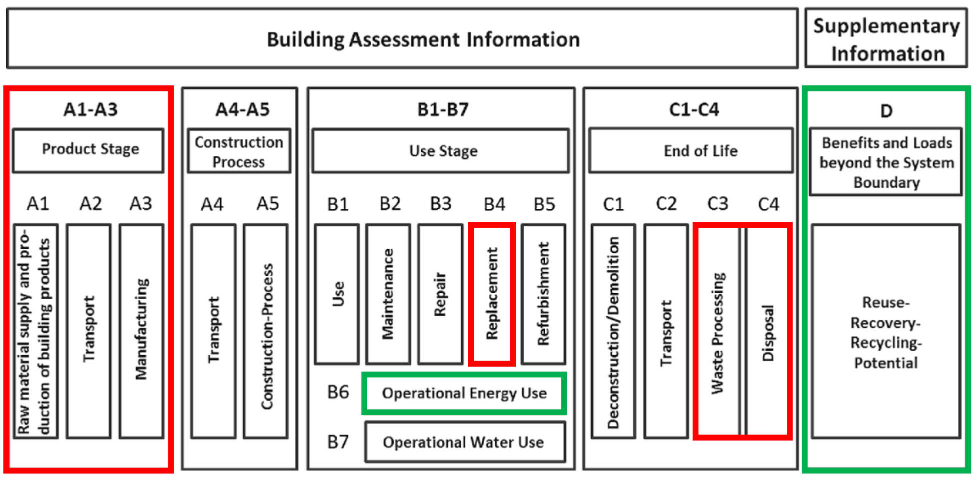

Figure 1. Buildings life cycle stages (EN 2011).

"A1-A3" is the most critical stage to include representing the direct impact of the construction materials, and it is considered the minimum requirement for any building LCA/LCC. "A4" is vital to include and can have significant impacts on the case study (Kellenberger & Althaus 2009); however, it would complicate the calculation for the designer, and it is to be excluded from the calculation. "A5" is not included in most building LCA studies, mainly because data from this stage is challenging to obtain, and also studies show it represents a small percentage of the life cycle environmental impacts estimated at 2%-3% (Devi & Palaniappan 2014) in an Indian case study. It is expected to have less impact when prefabrication is used, as shown in a Chinese case study (Cao et al 2015).

From the use stage, "B4" can easily be included since standard values for the service life of elements and materials is widely available (Aagaard et al 2013). "B6" is optionally included if operational energy use simulation software is used. This data can be used to calculate the impact of this stage. Other use stages are not included due to the limited amount of data available, and since the use phase is set in the future, it is difficult to predict future building use. (Wittstock et al 2009) state that it is important to include a building's water use in an LCA, however as building material choices do not influence optional water use (Hollberg & Ruth 2016) it is neglected.

From the End of Life (EoL) stage, "C1-C2" are neglected due to the difficulty of obtaining this data. However (C3-C4) are included if this data is available in the material's EPD. And the “D” stage is included optionally depending on the availability of data. The inclusion of "A1-A3", "B4, “B6" and "C3-C4" are the necessary stages to include in an LCA for EN 15978 (EN 2011), DGNB (DGNB 2008), and BNB (BBSR 2015b) compliance (Hollberg & Ruth 2016). It also allows results from the tool to be compared to the Danish building LCA tool LCAbyg (CPH 2021).

2.3 Environmental and Cost Data

According to ISO 14040, LCAs follow a 4 step approach. The first step is defining the goal and scope, where the functional unit and the system boundaries are defined. The second step is building a Life Cycle Inventory (LCI). The third step is Life Cycle Impact Assessment (LCIA). And the last step is the interpretation of the results. However, building LCA relies on pre-defined LCIs in the form of EPDs, thus combining the LCI and LCIA steps of an LCA (Lasvaux et al 2013).

EPDs contain a functional unit that describes the function of the material or element. If it cannot be determined, a declared unit (e.g. piece, kg, m, m2, and m3) can be used instead according to EN 15804. It also provides the LCA results based on the functional or declared unit for each impact category (e.g. 1 kg of concrete causes 75kg CO_2-eq) included in the EPD. These documents also contain several other information such as location, company, system boundaries, and performance metrics. This study will only use data available in these EPDs for embodied impacts calculations in order to simplify data input as much as possible.

Denmark does not yet have a comprehensive EPD database for construction materials. EPD Denmark (Denmark 2021) contains several EPDs of construction material and elements and should be used for Danish LCAs. However, for materials or elements missing from this database, ÖKOBAUDAT (BBSR 2015a), the German EPD database, can be a valid alternative to EPD Denmark. ÖKOBAUDAT is also used in several EU building LCA tools and it is also used in combination with EPD Denmark by Denmark's own tool LCAbyg. One of the requirements of this approach was to be as flexible and scalable as possible, so the tool will not rely on a database but will allow the user to input data based on preference or availability using an Excel sheet.

As for LCC data, material and element costs can be obtained from the Danish database Molio price data (Prisdata 2019). Information on discount rates and inflation rates is used from the Danish LCC from the Danish Ministry of finance's report on discount rates (Finansministeriet 2021). The information is added in a flexible Excel sheet that allows users to change this data based on their requirements. Other data such as the standard service life of building elements in Denmark can be obtained from (Aagaard et al 2013), The study includes an Excel sheet with all the information of expected service lives of elements in a Danish context.

2.4 Calculation methods

Based on the LCA/LCC calculations in (Santos et al 2019), the approach considers the chosen system boundaries discussed in section 2.2, including "A1-A3", "B4, B6", "C3-C4", and "D". The streamlined LCA is shown in equation 1, as follows:

$$LCA = \sum_{a=1}^{i}(\mathrm{Q}_a \times \mathrm{EI}_a^{A1-A3}) + \sum_{b=1}^{l}\left((\mathrm{Q}_b \times \mathrm{EI}_b^{B4} \times \frac{RSL_B}{RP_b}\right) + [(\mathrm{Q}_e \times \mathrm{EI}_e^{B6}) \times T] + \sum_{c=1}^{q}(Q_c \times Q) \times EI_c^{C3} + \sum_{c=1}^{r}(Q_c \times (1-Q)) \times EI_c^{C4} + \sum_{d=1}^{s}(Q_d \times Q) \times EI_d^{D} \quad (1)$$

Where:

LCA is the total streamlined environmental impact. Q_a is the quantity of material. EI_a^{A1-A3} is the impact of the material as a result of "A1-A3". Q_b is the quantity of materials to be replaced. EI_b^{B4} is the impact as a result of material replacement. $\frac{RSL_B}{RP_b}$ is the service life of the building over the replacement rate the material b. Q_e is quantity of estimated energy consumption over a one year period in kWh/year. EI_e^{B6} is the impact as a result of 1 kWh consumption based on local energy grid. T is the study period in years. Q_c is the quantity of material at the EoL phase. Q is the percentage of material to be reused, recycled or recovered. EI_c^{C3} is the impact as a result of "C3". EI_c^{C4} is the impact as a result of disposal "C4". Q_d is the quantity of material obtained from demolition. EI_d^{D} positive impacts as a result of reuse or recycle "D".

The streamlined LCC equation is shown in equation 2, as follows:

$$LCC = \sum_{a=1}^{i}(\mathrm{Q}_a \times \mathrm{MC}_a^{A1-A3}) + \sum_{b=1}^{l}\left((\mathrm{Q}_b \times \mathrm{MC}_b^{B4} \times \frac{RSL_B}{RP_b} \times \frac{1}{(1+d)^T}\right) + \left[(\mathrm{Q}_e \times \mathrm{EC}_e^{B6}) \times \frac{1}{(1+d)^T}\right] + \sum_{c=1}^{q}(Q_c \times Q) \times MC_c^{C3} \times \frac{1}{(1+d)^T} + \sum_{c=1}^{r}\left(Q_c \times (1-Q)\right) \times MC_c^{C4} \times \frac{1}{(1+d)^T} + \sum_{d=1}^{s}(Q_d \times Q) \times MP_d^{D} \times \frac{1}{(1+d)^T} \quad (2)$$

Where:

LCC is the total streamlined economic impact. Q_a is the quantity of material. MC_a^{A1-A3} is the cost of the material as a result of "A1-A3". Q_b is the quantity of materials to be replaced. MC_b^{B4} is the cost as a result of material replacement. $\frac{RSL_B}{RP_b}$ is the service life of the building over the replacement rate the material b. Q_e is quantity of estimated energy consumption over a one year period in kWh/year. EC_e^{B6} is the energy cost as a result of 1 kWh consumption based on local energy grid. T is the study period in years. Q_c is the quantity of material at the EoL phase. Q is the percentage of material to be reused, recycled or recovered. MC_c^{C3} is the cost as a result of "C3". MC_c^{C4} is the cost as a result of disposal "C4". Q_d is the quantity of material obtained from demolition. MP_d^{D} is the material profit as a result of "D". d is the discount rate.

3 Tool demonstration

3.1 Data and plugin structure

Based on requirements in section 2.1 the tool was designed to be simple, needing as little input as possible from the designer. The tool uses an Excel file containing two datasheets, the first sheet containing LCA data and the second containing LCC. Table 1 presents the information in LCA and LCC excel sheets. The Excel file can be seen in EA-A (EA 2021).

Table 1. Data in LCA and LCC Excel sheets.

LCA	LCC
Material Name	Initial costs and Residual value of building after study period
Functional unit	Operation, maintenance and repair costs per year
Replacement rate	Material cost, cost of recycling material, and cost of disposal of material
Density	Declared unit per cost
Recycle percentage	Cost of energy and water
Impact of (A1-A3, C3, C4 and D) for each impact category (GWP, ODP, AP, EP, POCP, APDE, and ADPF), and data sources	Discount, Escalation and Inflation rates, Study period, and data sources

For generating a rapid LCA database, a simple python script was developed to read a CSV file obtained from ÖKOBAUDAT. The user inputs the Universally Unique IDentifier (UUID) of the material's EPD found on the ÖKOBAUDAT website or LCAbyg. The script can be found in EA-B (EA 2021). The plugin creates a new tab in Revit, the tool will first ask the user to locate the excel files if it has not been chosen yet. The user can upload a different file by selecting the "Open Excel file" button. They can also input energy estimation if module B6 are to be included in the calculation. If there is a carbon budget for the project, the user can input the target CO2/m2/year value and the project's total floor area to quickly overview the design target's distance. These steps are shown in the plugin's workflow diagram Figure 2.

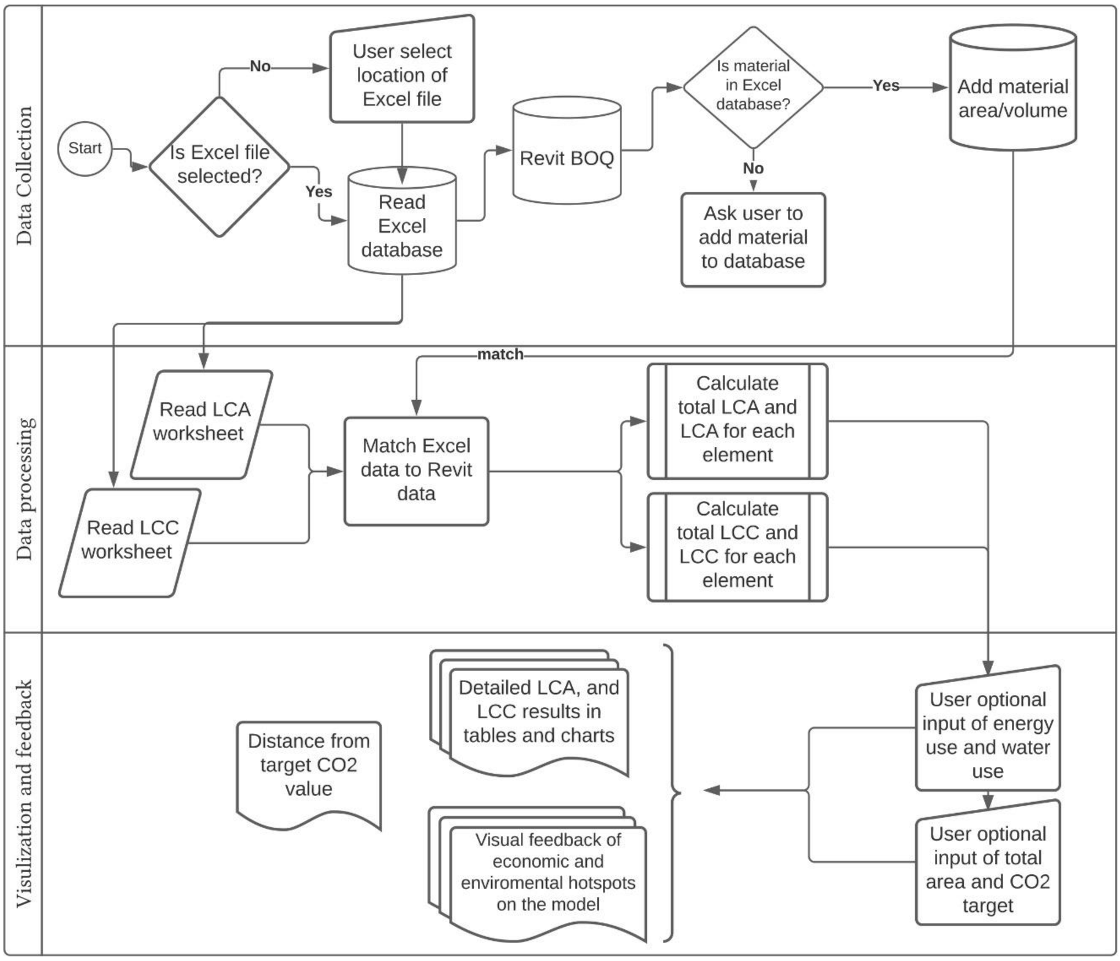

Figure 2. Plugin workflow diagram.

3.2 Case study – residential Danish dwelling

In this section, we present a case study where we empirically evaluate the plugin by applying it to a real BIM model of a Danish housing project. The BIM model was obtained through a research collaboration with Danish Architectural Company AART. AART's design for this project comprises a network of 46 housing units linking the city (Aarhus) to the northern cityscape. The topographic grid distributes the houses across the building area, bringing together the characteristics of the orderly and organic regions Figure 3.

Figure 3. Case study picture and BIM model.

3.2.1 LCA/LCC material screening

The first step was to build the LCA/LCC Excel dataset. LCA data was obtained from the German ÖKOBAUDAT EPD databased using the python script previously discussed in section 3.1. Material replacement rates were, recycle percentages were assumed. LCC data is also based on theoretical assumptions and not based on real data, due to lack of available cost data. In addition, due to confidentiality agreement with the company, we have used building elements material variants based on Hollberg & Ruth (2016), since the actual data cannot be published.

Figure 4 illustrates the results obtained from the plugin on the case study. Figure 4-a shows impact as a results of A1-A3, B4, C3, C4 and benefits as a results of recycling materials D, this method of presentation is essential for the designer to understand which life cycle stage is contributing the most to embodied impacts of materials. It also provides them with an idea on the importance of end of life scenarios, the possible benefits of recycling materials and how recycling rates effect the results. Figure 4-b highlights building elements that contain the material that contributes to the highest GWP value (Concrete 35/45). Figure 4-c shows a chart that combines both LCA and LCC this chart is essential to identify hotspots, designers can easily identify materials that are contributing to a high LCA/LCC. Figure 4-d demonstrates building elements that contain materials that contribute to the highest LCC in this case (XPS insulation).

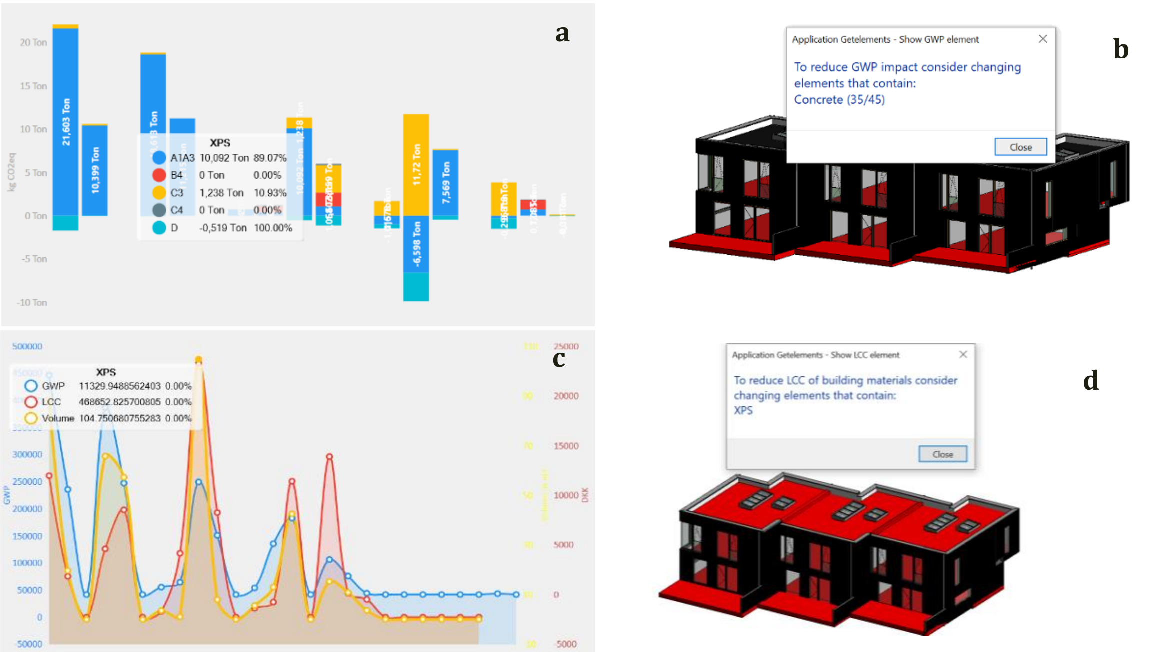

Figure 4. (a) GWP impact for each material from each life cycle. (b) Elements containing material with highest GWP highlighted in red. (c) GWP impact combined with LCC and volume for each material. (d) Elements containing material with highest LCC highlighted in red.

3.3 Validation and discussion

LCAbyg (AAU 2021) was chosen to validate LCA results because it is the most widely used LCA software in Denmark. According to the interviews conducted, it is the official tool from the Danish government developed at Aalborg University. The tool is used in different certification schemes such as DGNB, and voluntary sustainability class. Quantity material takeoffs from Revit were used to input the geometry data of the model to LCAbyg in m2 per element.

The developed plugin[1] and LCAbyg were applied to the case study on GWP impacts from building materials and the relative difference between the two values. The result can be seen in EA-C (EA 2021). As was expected, different types of concrete combined contributed to 49.6 tons of kg CO2-eq (i.e. 48 % of the total GWP impact). The model did not contain structural elements (i.e. columns, beams etc.); thus, the impact from concrete is expected to be higher in the final design. Insulation materials Extruded Polystyrene (XPS), and Rockwool have the second highest

[1] A video demo of the first prototype of the plugin: https://www.youtube.com/watch?v=nP4SXeNZeks

impacts at 22.4 tons and 11.2 tons. The results do not include benefits resulting from reuse/recycled materials (module D), as the end-of-life scenarios are unclear with the available data for the case study. Assuming XPS will be 100% recycled produced the 22.4 ton of CO2-eq and assuming 10% will be recycled (90% landfilled) results in 11.3 tons of CO2-eq, this is because impact as a result of recycling C3 (118,2kg CO2-eq/m3) is even higher than the impact as a result of producing A1-A3 (96,34 kg of CO2-eq/m3) and benefits from recycling D is (-49,51kg CO2-eq/m3). The inclusion of module D would impact the results significantly.

The validation of the study shows differences between the developed plugin and LCAbyg. Many factors impact these different results, one of the main ones being slight differences in the plugin's material quantity extraction and the automatic bill of materials obtained from Revit. Element areas/volumes with corners are not quantified precisely, leading to minor differences. In addition, most materials have the same error margin across different impact categories.

The third factor is about differences in LCA data between developed plugin and LCAbyg. The database building script uses the newest building material EPD database from OKOBAUT in CSV format. It is noticed that many EPDs in the version of LCAbyg 5 (1.0.5) were outdated. Although Custom EPDs can be added, it takes a considerably longer time to do so. Some EPDs used in the version of LCAbyg used were removed entirely from the 2021 ÖKOBAUDAT database, such as expanded polystyrene insulation (UUID: c5edec42-1921-46c6-a3aa-5cbd27685a74).

The fourth factor for differences in the results is due to the end-of-life scenarios. LCAbyg is clear on recycling percentages or landfill percentage per declared unit at the materials' end-of-life. Thus it is unclear if the exact percentages are used in the developed plugin. Different end-of-life scenarios (landfill, reuse, and recycling) directly impact C3, C4, and D modules and skew results significantly. It is also relevant for the used EPD database. Many materials either include C3-D or C4 in the EPD, assuming that the material is either 100% landfill or 100% recycled.

The plugin was designed for both sustainability managers and designers. The files needed for the plugin are found in EA-D (EA 2021). It is assumed that designers do not know the LCA/LCC methodologies. The process of using the plugin should ideally first allow the sustainability managers in a company to produce a comprehensive material EPD and cost databases (Excel). The designer would then use this excel sheet without needing any additional input. The sustainability managers can use the Excel sheet for multiple projects, adding new material to the database as needed. It can be assumed that the first project assessed using the plugin would require more time to build the databases, but the process will be faster after that. It was assumed that companies tend to use the same materials from the same suppliers over many projects. This would considerably reduce database building time over many projects.

The plugin is not considered to be a replacement for LCAbyg in the Danish construction industry but rather to be a complement to it. While LCAbyg must be used in certification schemes and reporting. The developed plugin does not allow for rapid structured reporting and is not accurate enough for certification purposes. Instead, it is developed for rapid early design stage LCA/LCC estimations and hotspot identification. The plugin is free of charge, allowing access to a wide range of users. The plugin can serve as an educational tool for companies to help build sustainability intuition in designers by exploring different design tradeoffs while designing.

4 Conclusion and future work

This study demonstrated the potential of developing early-stage BIM-based LCA/LCC analysis for the Danish construction industry. By combining data from Revit and Excel, the tool delivers robust solutions for the costly and time-consuming analysis at an early design stage. The tool allows for rapid LCA/LCC analysis of the low level of detail BIM models, thus influencing the design at an early stage where decisions have a higher impact. Changes at this stage save time and cost, rather than changes at later design stages which can be very time-consuming and costly.

The plugin includes the requirements laid out in section 2.1. R1 is achieved by introducing an external database that should be developed by a sustainability professional for each company based on their BIM-based objects (Revit families). The designer then receives instant feedback directly in the modeling software without prior knowledge in LCA/LCC analyses. R2 is achieved by linking the naming of materials in the Excel database to the material naming in Revit. This allows the tool to adapt to different terms used in companies to describe different materials. R2 is essential because it is noticed that BIM-based tools with automatic material mapping fail to map materials to EPDs correctly, especially when materials are named in local languages. R3 is achieved by using Excel as the database. It allows sustainability professionals to easily edit LCA/LCC data and send the Excel file to the design team to be used. If the designers have some EPD/cost knowledge, Excel is a flexible and popular software used across industries. R4 is achieved by combining different charts, tables, and visual feedback techniques. Charts that show impact from different life cycle stages for each material are used, allowing the designers insight into which material and life cycle stage can be improved. Tables that can be copied into other software allow for a quick and full summary of the results. If stored in other software, the results can be compared with other design scenarios. Furthermore, visual feedback directly on the model allows the designers to quickly identify elements that contain materials with the highest contribution to a specific impact category or LCC.

This study included a Danish housing project (a case study) where the plugin was demonstrated and validated, comparing the Danish LCA tool LCAbyg. The plugin calculated the total GWP impact due to A1-A3, B4, C3, and C4 to be 102 tons of CO2-eq and GWP from LCAbyg for the same model was 106 tons of CO2-eq, resulting in a -3.34% difference between the plugin and LCAbyg. The main reasons for differences in the results was identified as to be about the minor differences in material quantities and end-of-life scenarios.

The study needs further validation of results, using different case studies and to validate LCC results comparing to Danish LCC tool LCCbyg. The plugin in this paper was developed to extract the main building components (i.e. walls, floors, ceilings, roofs, and doors). The analysis should include more elements, starting primarily with the structural elements (i.e. beams, columns, and footings, etc.) and mechanical elements (i.e. HVAC, pipes, etc.). Also, the quantity extraction using Revit API can be significantly improved by using "CompoundStructure class" instead of the method used in the plugin (GetMaterialArea, and GetMaterialVolume). The can be improved to run faster by using lists and dictionaries.

Likewise, the material mapping method can be improved using more intelligent algorithms that can identify materials from the Revit database to materials in the Excel database even if there are small differences in the naming of these materials. Further analysis can be added to the plugin, such as sensitivity, uncertainty, and data quality analyses for a more comprehensive tool. Although adding too many analyses can render the plugin too complicated for industry use, design feedback can significantly be improved by incorporating automated and advanced machine learning algorithms towards generating rapid data-driven design alternatives.

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