IFC-based variant analysis considering multi-criterial sustainability analysis of buildings

Benjamin Lammers[1] and Kasimir Forth[2]

[1]Technische Universität München, Arcisstr. 21, 80333 München, Deutschland

[2]Lehrstuhl für Computergestützte Modellierung und Simulation, Technische Universität München, Arcisstr. 21, 80333 München, Deutschland

E-mail(s): b.lammers@tum.de

Abstract: Economic, social, and environmental aspects are the foundation for holistically measuring sustainability in construction projects. However, combining different indicators of these aspects is not common practice, yet. Especially not in early design phases. At the same time, Building Information Modeling (BIM) enables an interdisciplinary and integrated design approach for comparing variants and helping design decision support in early design stages. Therefore, this paper aims to enable a framework of an automated, multi-criteria sustainability assessment by combining the methods of life cycle assessment (LCA) and life cycle cost (LCC) with BIM. Using the open BIM approach and its data exchange format Industry Foundation Classes (IFC), the proposed method is applicable to all project stakeholders. Design variants can be compared by combining relevant information from the IFC model and several LCA and LCC databases. A combined database framework is created using relational databases and SQL to provide a single source for LCA and LCC data. As a result, an automated holistic assessment of sustainability using BIM and a component database is possible in an early design stage, without manually adding any LCA and LCC information to the BIM model.

Keywords: BIM, IFC, Life Cycle Assessment, Life Cycle Costs

1   Introduction

The building sector is responsible for 38% of the global CO_2 emissions, including the manufacturing, transportation and use of construction materials, which is the highest total level recorded until 2020 [1]. To assess the ecological and economical impact of buildings, standardized methods have been established, such as LCA and LCC.

At the same time, the building sector is in a transition phase of digitization. New processes and methods, such as BIM, are introduced and used. Combining BIM and the stated sustainability analysis has beneficial synergies. A wide variety of information can be stored in the semantic 3D building model.

Therefore, the extraction of cost estimates, and improvements in energy efficiency and sustainability with the help of design alternatives is an arising potential. Additionally, the early-design stages are getting more important, as more information is available using BIM. As the use of BIM is assumed to be very common for future building projects, automated assessments based on the information of a BIM model can present a huge chance [2].

This study tackles the challenge of combining multi-criteria sustainability analysis and automating the process based on BIM models as the data input.

2   State of the Art

For early design stages, different international standards and norms are available, which define building projects to phases or stages. The established methods are either focusing on organizing building project phases, like RIBA in the UK, or defining cost groups, like HOAI in Germany. However, conventional design processes are mainly linear, without enabling iterations for changes early into the project [3].

2.1   Building Information Modeling

In 2008, several committees of the American Institute of Architects (AIA) have adopted the concept Level of Development (LOD). The same standard was taken over by the BIMForum in 2013 and will be used for this study [4].

The standard itself consists of five basic LOD's, from Level 100 to 500. The early design stages are defined as the phases from the pre-draft or preparation to the first design draft [3]. Concerning the definitions of LOD's, these phases correspond to LOD 100 to 300. Despite being vague in an overall description of LOD, the standard defines precisely what information is included for the different object types, e.g. external wall, door etc. [4].

For the proposed methodology, the difference of open and closed BIM is relevant. The controversy describes the restrictions when relying on closed software systems and exchange formats. To make the process available for all stakeholders and independent of software systems, an open BIM approach is chosen. This corresponds to the exchange format of IFC, which can be written and read by every software product commonly used in BIM. Therefore, IFC is used as the exchange format for this study [5].

2.2   Sustainability Assessment

The process of calculating LCA is standardized in the ISO 14040 [6]. Because not all life cycle modules are considered as being representative for an early design phase estimation, the assessed modules encompass A1-A3, B4 and C3-C4. In this study, only the construction, but not the operation of buildings is considered. The use of module D is controversial and highly individual, since it relies on factors like the location of the building site and the recycling possibilities in the future [7].

To use an open and flexible approach, serveral environmental databases are linked together. Those encompass the Ökobaudat from Germany [8], the swiss KBOB [9] as well as the international Ecoinvent [10]. The environmental impact indicators, such as Global Warming Potential (GWP), Ocean Depletion Potential (ODP), etc., used for this study are limited to the lowest common denominator of the selected LCA databases. By combining theses databases, the overlapping, remaining indicators are GWP and Primary Energy total (PE).

Additionally, LCC is an established method to calculate the cost of a project over the whole life-cycle. In this study, only the construction phase is assessed. Similar to the environmental assessment, several databases are combined to assess the costs. These include the *DBD* [11] and *BKI* [12]. All used databases refer to prices in Euros (€).

In contrary to environmental data, which is mostly coherent on a material level, the cost data is assigned to components. To classify costs for building projects in Germany, the DIN 276 [13] has categories for all occurring cases. This system is used to group materials to building component categories and add the costs.

2.3 Literature Review of BIM-based LCA and LCC

The combination of sustainability analyses using BIM is not a totally new approach. An overview of the current research is given through the literature review made by Forth [14]. The aim of analyzed research encompasses the topics BIM, BIM-LCA integration and LCA. Several exchange formats for accessing building information through BIM are common, with IFC being the most adopted technology for open BIM applications. Additionally, the BIM-integrated LCC approach is investigated through the review by Santos [15]. It integrates several sustainability criteria, such as LCA and LCC. Information for combined analysis can either be stored in a specialized database or directly in the building model. A combination of both is often used as well. The first approach relies on exporting a Bill of Quantities (BoQ) from the model and combining that with cost and environmental data [16]. The second is enriching either the model or the resulting IFC-structure [7]. A third approach can be identified as adding an interface to an external software. This software uses the information for further calculations, but might also need separate inputs besides the model [16]. This leads to the existing gap, of using one combined database framework for LCA and LCC information to balance the often scarce information incorporated in an early-phase model.

3 Methodology

3.1 Framework

The goal of this paper is to propose a methodology, which combines two sustainability analysis methods with information input from an early design stage BIM model.

The methodology, including a bigger framework, is displayed in Figure 1. The red bounding box includes the complete project framework. Outside of the bounding box are either data sources or
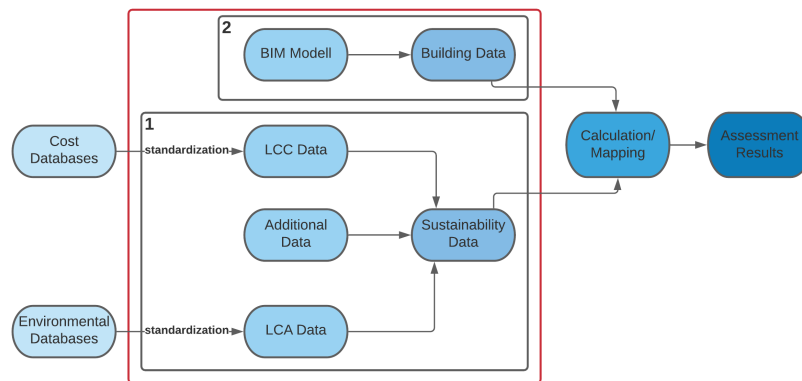
Figure 1: General framework represented as a flow chart, including the project boundary and the separation for first and second part.

additional steps for an automated calculation of design variants. For example, the mapping of building data to material data is not scope of this paper, but will be performed manually for the case study. The process inside the frame is split into two separate sub-parts. Both parts are described in more detail in the following sections.

3.2   Combined Sustainability Database

The first part is about transforming data from different databases and storing it in a useful way. Therefore, the input must be unified, and the structure must take all reference units into account. For cost data, building parts are mostly measured in square meters, which is why the environmental data is also transformed to this unit. That means materials have to be linked together to building parts before matching them with the cost data. The database structure is derived from different levels of complexity, moving up from single materials to whole building components. The material level contains the indicator information, in this case GWP and PE. On the component level, information like cost, replacement rates and layer thickness are added. By enriching the database with most of the calculation crucial information, the BIM-based model can be used without adding additional attribute information. The database is modelled in MySQL Workbench and then accessed and further processed through a python environment.

3.3   Model requirements and preparation

The challenge of using an early phase BIM-based model is the amount of information included. As previously identified, the model components have to be LOD 200 in early design stages. Therefore, the information for automatic matching of components or even materials might not always be included. The component classification is based on the DIN 276 cost groups. Subsequently, the BoQ is derived from the exported IFC-file with the help of IFCOpenShell, an open-source package for parsing IFC files in Python. For the multi-criteria calculation, model information is then matched manually with component information. Each cost group is mapped to a component group, e.g. outer walls, inner

walls or roof. Subsequently, the standardized calculation process regarding the LCA and LCC is used. This integrates the stated modules from production, end-of-life and the replacements in between.

4   Implementation and Validation

4.1   Case Study

To validate the proposed methodology, a case study is used to compare a conventional workflow with the proposed one. Figure 2 shows the model of the case study. The building consists of two floors, one of which represents a basement. The following component types are represented: load bearing and non-load bearing inner and outer walls as well as windows, inner doors, and one outer door on the ground floor. Windows and doors are essential for the example calculation because the LCC calculation is based on a different reference unit. Walls, floors, ceilings, and roofs are calculated by area, whereas the reference unit of windows and doors is the quantity. The maturity of the model is aimed to be LOD 200, which is neither at the beginning of the process nor does it stretch the definition of early design stages. A list of all building components is derived from the model, including their associated component type, cost group and the area. In this BoQ, the IFC-file provides the reference unit square meters, which is needed for the cost and environmental impact calculation.
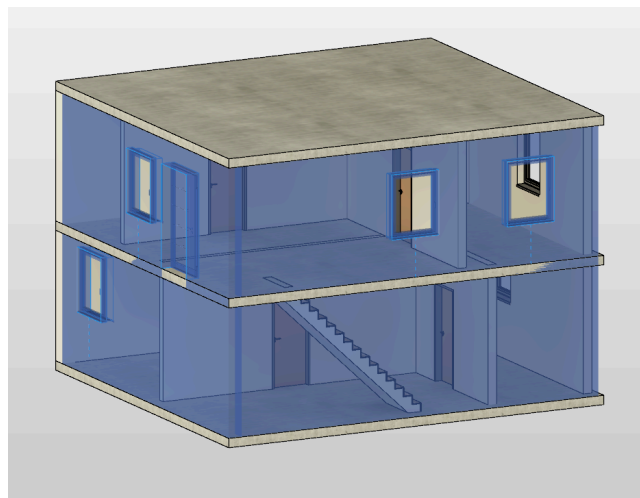

Figure 2: Case study building modelled in AutoDesk Revit.

Other reference units can be used by selecting different output parameters for the BoQ. This possibility is helpful if the LOD of the model changes. For example, thickness or other material information could be included, and therefore the pre-established template would not need to include this information separately. This flexibility ensures a robust methodology.

For each of the component types included in the model, several component variants are established. Components from the cost databases are used as templates, from which several alternatives are created. Different materials are selected as the core layer for different variants. Wooden, concrete and brick walls are chosen. The majority of material datasets is derived from Ökobaudat, with a few

representing KBOB and ecoinvent. Datasets from different sources are not combined to represent a single value, but modules can contain materials from different databases. Therefore, the benefits of several databases can be utilized without compromising their correctness. This enables to choose from a wider variety of datasets.

4.2 LCA and LCC Results

Three variants are established with the described materials and components to be compared to each other in both environmental and cost perspectives. Variant 1 (load-bearing concrete walls, non-load bearing wood and brick walls, all outer walls insulated) represents the thickest walls and overall most volume of materials. Variant 2 (core material bricks) is much lighter, concerning the number of different layers and materials. Variant 3 (concrete walls, no insulation) features similar materials to variant 1 but without insulation.

Additionally to the automated calculation of the proposed methodology, the three variants are calculated manually with an excel sheet to validate the results. The areas for the manual calculation are extracted directly from Revit. The components are established in a spread sheet which is linked to the environmental databases. The costs are added to the spread sheet manually from the cost databases.
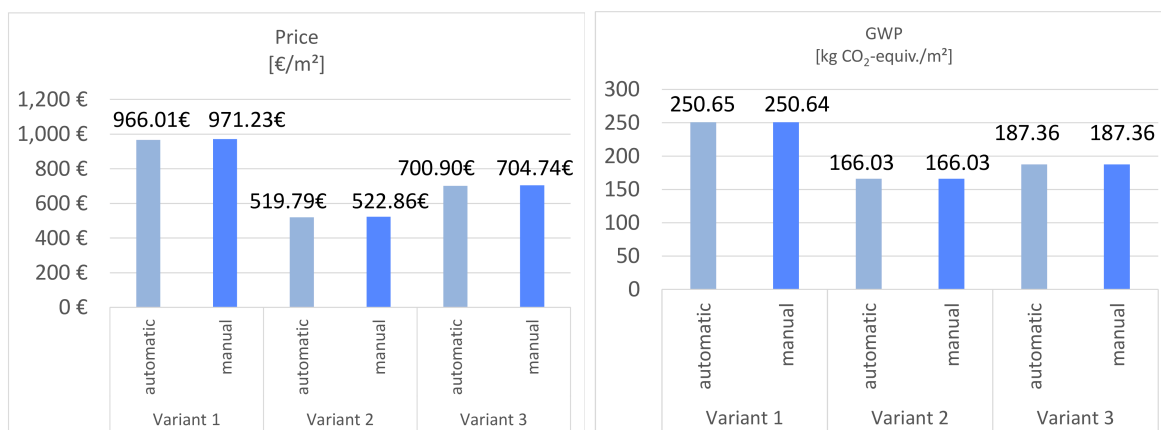

Figure 3: LCC and LCA calculation results per m².

Both automatic and manual calculation results are displayed in Figure 3. Apart from some minor deviations in the costs, which is due to rounding errors of currencies, the results are the same. The results are showing the correctness of the automatic calculation.

Comparing the calculation results to the different components, the outcome is reasonable. Basically, more material results in a higher price and higher GWP. Also, the variants differ similar to each other for all calculated variants. This calculation is comparing the whole building in three variants using different component settings. Nevertheless, the method can be used to compare different components on a building scale.

5 Discussion and Outlook

For early design stage building models, a method of using an enriched database to automatically calculate LCA and LCC without enriching IFC-files is proposed and verified. One requirement for the established method is to manually design a component catalogue. Once established, it is viable to be used in many projects. This compensates the work done manually once. Another requirement is that the component matching was done manually, because it is out of scope for this paper. The needed information could be included in the model, by providing model requirements beforehand.

Some challenges still remain about the implementation of the combined sustainability database, such as the high inconsistency of the input databases. Compensating these inconsistencies requires a high amount of manual work. If some values, e. g. for a specific concrete, are completely missing, the data-set cannot be used for a holistic calculation. Also in the second part some problems have occurred. Even though IFC is defined through a standard, exports from different modeling software products can vary strongly. This can be tackled by defining a robust quantity take-off algorithm, which adapts to the exporting software. Nevertheless, appropriate model requirements should always be defined beforehand.

As a conclusion, a multi-criteria variant comparison using the open BIM methodology is possible. However, further steps have to be taken for being applied in the decision process. First of all, to make a useful decision, it is not sufficient to only assess the construction and demolishing phases of buildings. Energy and costs during the operation phase have to be assessed as well and should be included in future research. Secondly, the shown case study aimed at a very rudimentary comparison. For real projects, the complexity of models and components will be notably higher, incorporating also a broader variety of component types. Nevertheless, the proposed methodology proved to be applicable. By extending this approach in the future accordingly, the goal of automated and holistic LCA and LCC analysis can be realized.

References

[1] United Nations Environment Programme, "Global Status Report of Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector", 2020.

[2] R. Sacks, C. Eastman, G. Lee, and P. Teicholz, *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*, 3rd ed. John Wiley & Sons, Ltd, 2018, ISBN: 9781119287568. DOI: 10.1002/9781119287568.

[3] P. Schneider-Marin and J. Abualdenien, "A framework to facilitate an interdisciplinary design process using BIM", Sep. 2019.

[4] BIMForum, "Level of Development (LoD) specification Part I & Commentary", Tech. Rep., Dec. 2020.

[5] T. Liebich, C.-S. Schweer, and C. Dubler, *Auswirkungen der Planungsmethode Building Information Modelling (BIM) auf die Leistungsbilder und Vergütungsstrukturen für Architekten*

Architekten und Ingenieure sowie auf die Vertragsgestaltung. Research Initiative ZukunftBAU, Federal Institute for Research on Building, Urban Affairs and Spatial Development, 2011.

[6] DIN EN ISO 14040, "Umweltmanagement – Ökobilanz – Grundsätze und Rahmenbedingungen", standard specification, Feb. 2021.

[7] C. LLatas, B. Soust-Verdaguer, A. Hollberg, E. Palumbo, and R. Quiñones, "Bim-based lcsa application in early design stages using ifc", *Automation in Construction*, vol. 138, p. 104 259, 2022, ISSN: 0926-5805. DOI: https://doi.org/10.1016/j.autcon.2022.104259.

[8] BMI. "Ökobaudat". (2021).

[9] KBOB. "Ökobilanzdaten im Baubereich 2009/1:2016". (2016).

[10] ecoinvent Association. "Ecoinvet.org". (Oct. 2021).

[11] DBD, "Dynamische BauDaten", 2021. [Online]. Available: https://www.dbd.de/ (visited on 07/13/2021).

[12] BKI, "BKI Kostenplaner", 2021. [Online]. Available: https://www.bki.de/ (visited on 07/13/2021).

[13] DIN 276, "Kosten im bauwesen", standard specification, 2018.

[14] K. Forth, J. Abualdenien, A. Borrmann, S. Fellermann, and C. Schunicht, "Design optimization approach comparing multicriterial variants using BIM in early design stages", Nov. 2021.

[15] R. Santos, A. Aguiar Costa, J. Silvestre, and L. Pyl, "Integration of LCA and LCC analysis within a BIM-based environment", *Automation in Construction*, vol. 103, pp. 127–149, Jun. 2019. DOI: 10.1016/j.autcon.2019.02.011.

[16] K. Lu, X. Jiang, J. Yu, V. W. Tam, and M. Skitmore, "Integration of life cycle assessment and life cycle cost using building information modeling: A critical review", *Journal of Cleaner Production*, vol. 285, p. 125 438, 2021, ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2020.125438.