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The coupling of BIM and LCA—challenges identified through case study implementation

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ABSTRACT To conduct an environmental Life Cycle Assessment (LCA) of buildings, the potential benefits of coupling LCA and Building Information Modelling (BIM) has gained a lot of attention among researchers recently. The expected efficiency gains, mainly coming from establishing the Life Cycle Inventory (LCI) in an automated way, can improve the process significantly. However, the application of BIM and building model's varying Levels of Development (LOD) have implications on how the LCI should be structured and which LCA datasets can be used. The structure and completeness as well as granularity of a building model have to be clarified before deciding for the assessment workflow and tools used. Aiming for an efficient yet complete assessment, the implications of a workflow of establishing the LCI in Revit are discussed, refining the inventory in Excel and finally assessing the complete building in SimaPro. The study discusses the potentials, challenges and learnings from two BIM-LCA case studies investigated as part of the PEF4buildings project and presents the workflow developed based on these case studies.

1 INTRODUCTION

The built environment plays a major role in reducing environmental impacts to mitigate climate change impacts.

To assess and improve the environmental performance of buildings over their entire life cycle the methodology of Life Cycle Assessment (LCA) is proposed in the relevant standards and recent policy guidelines. To assess the complex product systems of a full building several methodologies and standards are applied and results are often presented in ways difficult to comprehend and compare with little chance to replicate the assessment. Against this background recent developments in standardization and policy making aim to improve the situation by increasing transparency and comparability of results for individual construction products as well as full buildings (e.g. ISO 15804/15789, CEN TC 442, PEF Guidance).

To conduct LCA on buildings a variety of information on the building, components and materials used for construction as well as data on its operation, is required. To provide and manage the variety of information required recent studies support the assessment using digital building models.

Building Information Modelling (BIM) is expected to enhance the applicability of LCA throughout the design process. LCA of buildings, as well as the application of BIM for that matter, is under constant development and so far mostly applied in the academic context. The goal however is, to evolve the coupling of BIM and LCA and make its application feasible in everyday design practice.

This study presents the findings of using BIM to conduct LCA acc. to EN 15978/15804 as well as in particular, experiences from testing the application of the Product Environmental Footprint (PEF) methodology using a BIM-LCA workflow. The identified potentials and challenges are discussed and conclusions drawn on how LCA and BIM could be evolved to support integration of environmental assessment of buildings in the future.

2 POTENTIALS OF BIM-LCA

2.1 *State of the art review*

In order to identify generally applicable concepts of organizing building information, inventory and granularity of data used for assessments throughout the design process we reviewed literature, standards, and guidelines regarding conventions in LCA and BIM.

2.1.1 *Life cycle assessment (LCA)*

Several approaches for simplifying building LCA to enhance its applicability were found in literature.

Some studies proposed to conduct LCA tailored to the current level of information in a specific design stage – starting with screening LCA in the development stage, simplified LCAs throughout designs and eventually a full LCA for the final building (Lasvaux et al., 2016). An approach that is also recommended by the European Commission, as it is applied in their proposed 'Level(s)' assessment framework (Dodd, Cordella, Traverso, & Donatello, 2017).

To provide representative LCA data for such simplified assessment especially in 'early design stages' approaches for aggregating data on the level of building elements and sub-elements were investigated and proposed in a number of studies (Kellenberger & Althaus, 2009; Marsh, 2016; Passer et al., 2015; Trigaux, Oosterbosch, De Troyer, & Allacker, 2017). In their 2017 paper, Trigaux et al. propose a hierarchical and modular approach to aggregate LCA datasets on various levels, from macro-perspective building-level data down to micro-level data on construction materials and processes. To understand implications of simplification of building LCA some studies also investigated the related uncertainty of LCA results from e.g. modeling choices (Häfliger et al., 2017; Heeren et al., 2015; Hoxha, Habert, Chevalier, Bazzana, & Le Roy, 2013).

Regarding information on the environmental impact of construction products the use of Environmental Product Declarations (EPDs) provides aggregated data based on a standardized assessment methodology (ISO 15804) yet with varying granularity. For the LCA of buildings, the relevant standard ISO 15879 in its Annex 1 proposes to follow a hierarchical structure when establishing the Life Cycle Inventory (LCI).

2.1.2 *Building information modeling (BIM)*

As BIM implementation increased in recent years, efforts are made to increase the common understanding and definition of the at times vaguely used term "BIM". To enable the use of BIM models for the various potential applications (e.g. documentation, estimation, simulation, tendering, fabrication, etc.) it is generally agreed that the quality of a BIM model regarding its Level of Development (LOD) is a crucial factor. Following the generally accepted LOD approach, such a level is comprised of various definitions to describe e.g. the Level of Geometry (LOG) and Level of Information (LOI) of a BIM element's quality and reliability regarding geometric representation (LOG) and information specified (LOI). It is to note that international harmonization and standardization of terms and abbreviations as well as their translation is still in progress with currently several guidelines proposing similar yet different approaches (BIMForum, 2015; Egger, Hausknecht, Liebich, & Przybylo, 2013; Maier, 2015).

Generally, the LOD concept suggests to start the design process with generic but representative elements which are constantly refined and specified as decisions are made throughout the design process (Meex, Hollberg, Knapen, Hildebrand, & Verbeeck, 2018; Röck, Hollberg, Habert, & Passer, 2018). For detailed buildings models with respectively high LODs, the definition and application of so-called Product Data Templates (PDTs) is becoming a central element to achieve a harmonized structure and format for the specification and exchange of building related information e.g. during tender phase.

2.2 *Potentials for coupling*

Potentials identified show that implementation of LCA and BIM could be supported by:

- Organization of the inventory according to international standards (e.g. ISO 12006, national classification schemes) to support comparability in interpretation of results.
- Structuring building elements and sub-components hierarchically with specified levels of granularity, which should further support;
- Linking of BIM elements and quantities with respective LCA datasets and scenarios (e.g. maintenance, replacement, end of life) for an integrated establishment of the LCI, as well as;
- Parametric approach for establishing the LCI based on both BIM and LCA model to support easy changes – regarding e.g. element's material composition – and make the model adaptable to other building cases.

3 BIM-LCA CASE STUDY IMPLEMENTATION

3.1 *Description of case studies*

The coupling of BIM and LCA was tested as part of the PEF4Buildings project during the application of the Product Environmental Footprint (PEF) methodology on two office buildings.

The first office building is situated in a suburban region in Belgium finished in 2014. The building is an extension to a building and represents a business as usual office. The two-story building has a net floor surface of 3000 m^2 and has an inner patio around which the office and meeting rooms are organized.

The second office building is situated in a suburban region in Austria finished in 2013. The six story building has a net floor area of 2700 m^2 and was specifically designed to operate with an advanced building concept without active heating or cooling systems. Instead the building makes use of a high thermal mass and an advanced control system for natural ventilation.

3.2 *Description of assessment workflow*

As there was no established workflow to directly 'connect' the BIM model (Autodesk Revit) and the

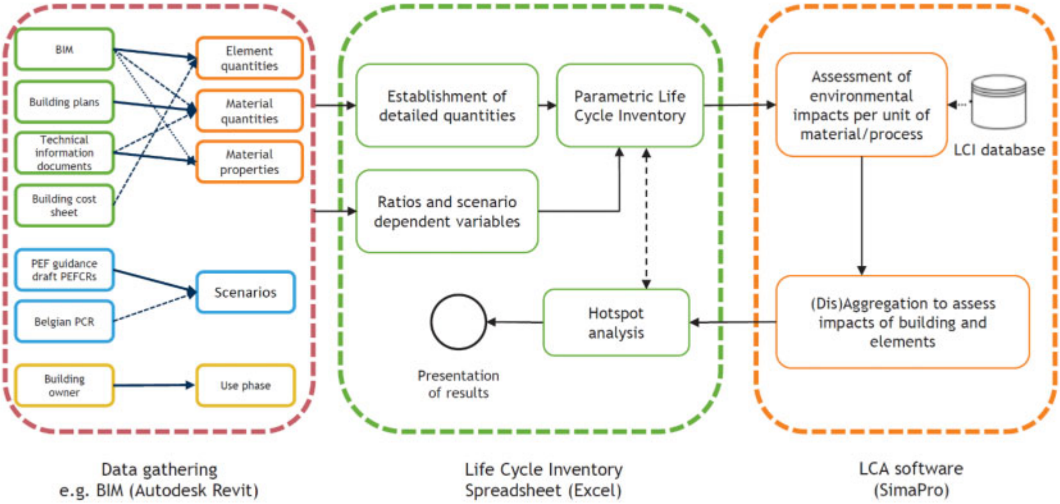

Figure 1. Overview of BIM-LCA workflow using different data sources and various tools in order to establish the LCI as well as assess and analyze the building's environmental impact.

Level 1: Building element				Level 2: Building sub-element			Level 3: Building material		
Building Element	Quantity element	Quantity sub-element	Unit	Building sub-element	Unit	Ratio sub-element / building element	Material	Material unit	Ratio material/sub element
Concrete floor on earth	1148		m^2						
		1148	m^2	Vinyl Tiles	m^2	1			
							Vinyl Tiles	*m^2*	*1.0*
							Butyl Acrylate	*kg*	*0.3*
		1148	m^2	Concrete Screed	m^2	1			
							Concrete In Situ	*m^3*	*0.1*
		1148	m^2	PUR	m^2	1			
							Polyurethane Flexible Foam	*kg*	*3.0*
		1148	m^2	Concrete Floor	m^2	1			
							Reinforcing Steel	*kg*	*22.2*
							Concrete In Situ	*m^3*	*0.3*

Figure 2. Hierarchical decomposition making use of ratios by example of a floor element.

LCA software (SimaPro) a workflow including a spreadsheet-based Life Cycle Inventory was established (see Figure 1).

This spreadsheet was used to collect element quantities, specify element compositions (for the different hierarchical levels) as well as to define and assign scenarios for transport, use stage and end of life. The structure of the spreadsheet is based on the **element method for cost control** (De Troyer et al., 2008) which was extended to LCA studies of buildings (Allacker, 2010). The element method subdivides a building stepwise in building elements (level 1), building sub-elements (level 2) and building materials (level 3). Each of these levels in the subdivision of the building are connected via **ratios** (see Figure 2).

To complete the LCI several sources of information were needed, with the BIM model being the main, but by far not the only source of information. As multiple data sources had to be used, transparency regarding aggregation and background data was challenging.

A parametrization of the LCI was implemented to support a step by step modelling of the LCA model in SimaPro as well as adaptation of the model in a later stage. Parameters were defined for ratios at material, sub-element, element and building level as well as for the method specific formula parameters and scenarios (e.g. transport and EOL scenarios).

4 CHALLENGES OF BIM-LCA IMPLEMENTATION

4.1 *Incompleteness of BIM model*

A first challenge in the BIM-LCA application was the **incompleteness of the BIM model**. This incompleteness is noticed in two ways: 1) in general some building elements were missing in the model (e.g. HVAC elements and sanitary elements); 2) for the modelled elements, often some sub-elements were not modelled (e.g. finishing plaster layers or other elements within a wall). In those cases of incompleteness, these objects were not included in the Bill of Quantities from the BIM model and had to be added manually to the LCI structure.

4.2 *BIM element's levels of development (LOD)*

A second challenge related to the use of BIM models for LCA were the **different Levels of Development (LOD)** of the various building elements in the model. For the BIM models of investigated case studies this varied significantly as most elements were modelled with LOD 100–200, i.e. on the building element or sub-element level (e.g. wall elements modelled with separate structural, insulating an external finishing layer). The 'Material' definition in the BIM model was used to obtain quantities on sub-element level but was not appropriate to describe the variety of base materials contained within one particular construction layer or sub-element. Thus a 'brickwall layer', which consists of bricks and mortar, had to be modelled with its individual base materials. As the quantification on building material (base material) level could not be derived directly from the BIM models, this level was thus specified in the Inventory spreadsheet using ratios.

4.3 *Modelling and allocation of scenario impacts*

A third challenge was to implement the modeling of scenarios for transport, cleaning and maintenance, replacement, and end of life. However, **different scenarios are applied on different levels** (e.g. maintenance on sub-element level while end of life on material level). In consequence, the dis/aggregation of assessment results and the allocation of life cycle impacts to a certain element, sub-element or material is challenging.

The implementation of LCA scenarios in BIM gets even more complex, as for some materials the deconstruction depends on materials and sub-elements it is attached to (e.g. EPDM foil fixed to concrete layer).

4.4 *Modeling structure in BIM and LCA*

Fourth, the **structure** of data in the **LCA model** (SimaPro) was challenging as it was aimed that the structure of the LCA model would reflect the structure of the element inventory following the element method combined with the OmniClass coding. For an office building with a lot of different building elements, such as the first case study, this would lead towards an enormously complex and rigid model.

Complexity of the LCA model was increased, as the described case studies were part of the pilot on application of the PEF methodology to buildings which includes application of the so called Circular Footprint Formula (CFF). As at the time of the study hardly any compliant datasets were available to apply this formula, which is applied mostly at the level of raw materials, an additional level of (dis)aggregation on level of raw materials and processes had to be introduced to the SimaPro model.

4.5 *Dis/aggregation of data and results*

Finally, the challenge was to handle these **different levels of granularity** of foreground and background data, i.e. input to the LCI from BIM as well as LCA background data modelled in SimaPro.

In order to analyze hotspots regarding most important life cycle stages, impact categories and processes a common definition of granularity was difficult to define. Difficult because on one hand results of the assessment should be presented on a level that can be influenced by designers while on the other hand elements of a building are produced, delivered and installed in a wide variety of aggregations (e.g. some walls may be built as individual bricks on site, while others arrive as precast or prefabricated elements). As this variety in granularity makes it difficult to compare the environmental performance of different building elements and products the need for transparent and dynamic aggregation and disaggregation became evident.

5 LEARNINGS FOR FUTURE BIM-LCA

Many of the problems identified in this study are highlighting the need for alignment regarding a common definition of several key aspects in LCA of buildings, e.g.:

a) Level of granularity – a hierarchical decomposition suitable to describe the elements of the building from aggregated building component down to its raw materials. Using common levels of granularity, a transparent documentation of building elements composition, down to construction materials (e.g. concrete) and actual raw materials/constituents (cement, gravel) can be achieved.

b) Organization of building information – For the study we used the element classification scheme of OmniClass, which can be used to distinguish between e.g. building sections, elements and sub-elements. As multiple classification systems are in use in practice it seems reasonable to try finding a common ground by applying a more general, comprehensible way of structuring the building elements. Defining a common structure applicable to the various building components and aspects relevant in the building life cycle requires the joint effort of researchers and practitioners across disciplines.

To advance the implementation of LCA in BIM-based design workflows there is further a need to push discussion on other crucial aspects, e.g.:

- Completeness and scope – i.e. what information has to be contained in a dataset with a certain level of granularity? Can all of this be provided through the BIM model? (How) do we add missing/non-modelled elements to make a complete dataset (e.g. ratios)?
- Data quality – definition and documentation when using primary or secondary data as this affects uncertainty in the datasets (method) as well as results and their interpretation on the building level.
- Data exchange – In order to achieve widely applicably BIM-LCA workflows with comparable results for buildings throughout design stages the standardized exchange of data between BIM tools and LCA tools and databases for varying granularity and completeness.

If we further assume that in the near future comprehensive EPDs and PEF datasets will be available for a majority of construction products, the difficulty then is the provision up-to-date assessment data for products and the aggregation of data to the sub-element and element level, which need to be consistent in order to achieve transparent and compare results throughout the design process.

6 CONCLUSION

To evolve the application of LCA to building as well as enhance the integration with BIM a common definition of: a) the **organization and structure** of information on buildings as well as; b) the levels of **granularity and scope** for both, **BIM** elements **and LCA** data is required.

Existing LCA and BIM standardization should be followed and evolved to support approaches for harmonized reporting of all aspects relevant to ensure transparent and reproducible LCA studies on materials, elements and buildings.

As LCA should further be applied during building design the aim is to be both more time efficient to improve applicability, and at the same time able to dynamically analyze comparable results on many different levels and throughout the design process. Thus, the varying levels of development of BIM elements during building design will have to be acknowledged through use of appropriate LCA/PEF datasets.

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REFERENCES

BIMForum. (2015). Level of Development Specification. *BIM Forum*, (April), 195. Retrieved from http://bimforum.org/lod/

Dodd, N., Cordella, M., Traverso, M., & Donatello, S. (2017). Level(s) – A common EU framework of core sustainability indicators for office and residential buildings – Part 3, (August), 1–68.

Egger, M., Hausknecht, K., Liebich, T., & Przybylo, J. (2013). *BIM-Leitfaden für Deutschland*.

Häfliger, I. F., John, V., Passer, A., Lasvaux, S., Hoxha, E., Saade, M. R. M., & Habert, G. (2017). Buildings environmental impacts' sensitivity related to LCA modelling choices of construction materials. *Journal of Cleaner Production*, 156, 805–816. https://doi.org/10.1016/j.jclepro.2017.04.052.

Heeren, N., Mutel, C. L., Steubing, B., Ostermeyer, Y., Wallbaum, H., & Hellweg, S. (2015). Environmental Impact of Buildings – What Matters? https://doi.org/10.1021/acs.est.5b01735.

Hoxha, E., Habert, G., Chevalier, J., Bazzana, M., & Le Roy, R. (2013). Method to analyse the contribution of material's sensitivity in buildings' environmental impact. *Journal of Cleaner Production*, 66, 54–64. https://doi.org/10.1016/j.jclepro.2013.10.056.

Kellenberger, D., & Althaus, H.-J. (2009). Relevance of simplifications in LCA of building components. *Building and Environment*, 44(4), 818–825. https://doi.org/10.1016/j.buildenv.2008.06.002.

Lasvaux, S., Achim, F., Garat, P., Peuportier, B., Chevalier, J., & Habert, G. (2016). Correlations in Life Cycle Impact Assessment methods (LCIA) and indicators for construction materials: What matters? *Ecological Indicators*, 67(August), 174–182. https://doi.org/10.1016/j.ecolind.2016.01.056.

Maier, C. (2015). *Building Information Modeling – Grundzüge einer open BIM Methodik für die Schweiz*. Retrieved from www.ebp.ch/files/publikationen/ki-leitfaden-open-bim.pdf.

Marsh, R. (2016). LCA profiles for building components: strategies for the early design process. *Building Research & Information*, 44(4), 358–375. https://doi.org/10.1080/09613218.2016.1102013.

Meex, E., Hollberg, A., Knapen, E., Hildebrand, L., & Verbeeck, G. (2018). Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design. *Building and Environment*, 133.

Passer, A., Lasvaux, S., Allacker, K., De Lathauwer, D., Spirinckx, C., Wittstock, B., . . . Wallbaum, H. (2015).

Environmental product declarations entering the building sector: critical reflections based on 5 to 10 years experience in different European countries. *The International Journal of Life Cycle Assessment*, 20(9), 1199–1212. https://doi.org/10.1007/s11367-015-0926-3.

Röck, M., Hollberg, A., Habert, G., & Passer, A. (2018). LCA and BIM: Integrated Assessment and Visualization of Building Elements' Embodied Impacts for Design Guidance in Early Stages. *Procedia CIRP*, 69(May), 218–223. https://doi.org/10.1016/j.procir.2017.11.087.

Trigaux, D., Oosterbosch, B., De Troyer, F., & Allacker, K. (2017). A design tool to assess the heating energy demand and the associated financial and environmental impact in neighbourhoods. *Energy and Buildings*, 152(Elsevier 2017), 516–523. https://doi.org/10.1016/j.enbuild.2017.07.057.