SEMI-AUTOMATED PROCESSES FROM BIM TO LCA

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According to the European Commission, European buildings account for 42% of final energy consumption, 35% of greenhouse gas emissions and 50% of materials produced in their production, use and dismantling [1]. Also, they are responsible for 30% of water consumption and a third of all waste [2]. This increases the need to identify and reduce the environmental, economic and social impacts of buildings through the use of calculation tools.

In a discussion proposal for the new "Building Energy Act" (GEG) from February 2018, the German Sustainable Building Council (DGNB) proposes that in the future CO_2 emissions should be balanced rather than primary energy consumption [3]. This approach, which has been extended to include grey energy, is intended to create a goal-oriented, holistic approach.

In the following, the focus will be on the integration of life cycle assessments (LCA) into the building information modelling (BIM) process and their advantages and disadvantages towards achieving regenerative design in practice. The major challenge is the semantic linking of the BIM model with the LCA model. BIM programs can be used to determine areas and masses automatically. The goal, however, is a fully automated LCA process that can be realised with the help of an integrated BIM and LCA model [4]. Therefore, in the first instance, a model analysis with different tools and workflows is investigated. In a second step, an optimised workflow is suggested by using a prototype with Autodesk Dynamo.

Keywords: Life Cylce Assessment (LCA), Building Information Modeling (BIM), Integration, model analysis, sustainability

Model analysis of BIM-integrated LCA workflows

For the model analysis, 25 case studies were investigated. The author created BIM-models for each case study both in Autodesk Revit and ArchiCAD and were exported as the open BIM exchange format Industry Foundation Class (IFC 2x3).

Form	F1	Ground floor	angular	F1e
			round	F1r
	F2	Multistorey	suspended ceiling	F2z
			galery with cloumns	F2g
	F3	Sloping walls	outside inclined straight wall	F3ag
			outside inclined round wall	F3ar
			inclined inside straight wall	F3ig
			inside inclined round wall	F3ir
	F4	Roof	saddle roof	F4s
			saddle roof with corner	F4e
			hip roof	F4z
			pent roof	F4p
Material	M1	Monolithic	reinforced concrete	M1s
			brick wall	M1m
			timber	M1h
	M2	Multi-layer	reinforced concrete + EPS	M2s
			brick wall + XPS	M2m
	M3	Construction	mullion-transom facade	M3p
			wood frame construction	M3h
	M4	Windows/ doors	wood frame	M4h
			aluminium frame	M4a
			plastic doors	M4k
	M5	Roof	warm roof (flat)	M5s
			brick covering (saddle roof)	M5z
			sheet metal cover (pent roof)	M5b

Table 1. Model catalogue for Case studies of the model analysis

The models are divided into two categories, one focusing on form, the other on material, for a systematic and various model analysis considering the basic features of BIM models. The first category distinguishes between different floor plans, multi-storey buildings, orientations of slanted walls and roof geometry. The material category is differentiated by monolithic, multi-layered components as well as different types of wall structures, windows and doors, and roof structures.

The software eLCA was used according to the conventional calculation workflow. Díaz et al. [5] state that BIM-integration of LCA can be implemented through a semi-automated or fully automated workflow. The Revit plug-in Tally was used for the semi-automated work process using the native exchange format of Revit and IFC export of Revit and ArchiCAD imported to Revit for the model analysis. One Click LCA was used for the fully automated process (Figure 1) using the native exchange formats of Revit and ArchiCAD and their IFC export models imported to Revit, ArchiCAD and simplebim.

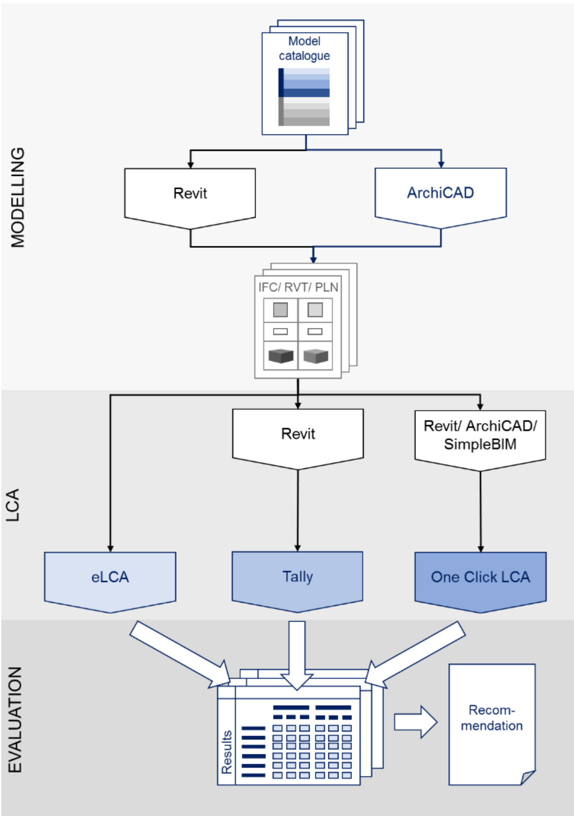

Figure 1. The procedure of the model analysis of BIM-integrated LCA workflows

The results show that even with simple models of the IFC files, from 200 LCA calculations based on IFC-exports 92 results had slight or strong deviations due to a number of reasons (Table 2). This shows that the "open BIM" approach has not been entirely developed yet for the fully automatic calculation of BIM-integrated LCAs. There were also problems with the correct material input with One Click LCA. This is because composite materials cannot be displayed correctly in the software export or import. Another major reason is the missing transparency of component-specific materials allocation to add additional or missing layers at a later stage. The calculation with the LCA-program Tally was only possible based on the LCA method of LEED v4, and the data sets were optimised mainly for the American market. There is no interface for importing your EPDs or data from the Ökobaudat database.

LCA-Software	Tally			One Click LCA										
LCA-Plug-In	revit	revit	revit	revit	revit	revit	simplebim	simplebim	archicad	archicad	archicad			
File-Format	RVT	IFC	IFC	RVT	IFC	IFC	IFC	IFC	IFC	IFC	PLN			
BIM-Software	revit	revit	archicad	revit	revit	archicad	revit	archicad	revit	archicad	archicad	●	◆	■
F1e	●	●	●	●	●	●	●	●	●	●	●	11	0	0
F1r	●	●	●	●	●	●	◆	◆	●	●	●	9	2	0
F2z	●	●	●	●	●	●	●	●	●	●	●	11	0	0
F2g	●	◆	●	●	●	●	●	●	■	●	●	9	1	1
F3ag	●	●	●	●	●	◆	■	●	●	●	●	9	1	1
F3ar	●	■	■	●	■	■	■	■	●	●	●	5	0	6
F3ig	●	●	■	●	■	■	■	◆	●	●	●	6	1	4
F3ir	●	●	■	●	■	■	■	■	●	●	●	6	0	5
F4s	●	■	■	●	●	■	●	●	●	●	●	8	0	3
F4e	●	■	■	●	●	■	●	◆	◆	●	●	6	2	3
F4z	●	■	■	●	●	■	●	●	◆	●	●	7	1	3
F4p	●	■	■	●	●	■	●	◆	●	◆	●	6	2	3
M1s	●	●	●	●	●	●	●	●	●	●	●	11	0	0
M1m	●	●	●	●	●	●	●	●	●	●	●	11	0	0
M1h	●	●	●	●	●	●	●	●	●	●	●	11	0	0
M2s	●	●	●	●	●	●	●	●	●	●	●	11	0	0
M2m	●	■	●	●	■	●	■	◆	■	●	●	6	1	4
M3p	●	■	■	■	●	●	●	■	●	●	●	7	0	4
M3h	●	◆	■	●	●	■	◆	◆	●	■	●	5	3	3
M4h	●	◆	■	●	■	■	■	■	●	◆	●	4	2	5
M4a	●	■	■	●	■	■	■	■	◆	●	■	3	1	7
M4k	●	■	■	●	■	■	■	■	■	●	●	4	0	7
M5s	●	●	●	●	●	◆	●	◆	●	●	●	9	2	0
M5z	●	■	■	●	■	■	◆	◆	■	■	●	3	2	6
M5b	●	■	■	●	■	■	◆	◆	■	■	●	3	2	6
●	25	11	11	24	16	10	13	10	17	20	24	181		
◆	0	3	0	0	0	2	4	9	3	2	0		23	
■	0	11	14	1	9	13	8	6	5	3	1			71

Legend: ● correct result ◆ slight deviation ■ strong deviation

Table 2. Comparison of the results of the model analysis

In general, a more precise nomenclature of materials with a qualitative name suffix is recommended to guarantee a correct, component-specific material assignment. This can be the minimum compressive strength class for concrete, the wood species for timber or the type and processing method of metals.

Although the promise of a fully automated LCA calculation sounds convincing, transparency and comprehensible adaptability suffer as a result. With an optimised BIM model, the results can achieve a high degree of accuracy. But skipping the step of material allocation or its control would be negligent since in complex projects with a lot of different component layers it often leads to considerable divergences. A check of the component-specific building materials for completeness and quantity is therefore highly recommended, as is a precise post-processing of the material take-off through correction and additions of missing layers and materials.

Most errors occur during the software-independent export into the IFC file format. Also, the IFC imports in the respective BIM programs cause deviations in the model about geometry and material assignment. There are major problems and thus optimisation potential especially with unconventional geometries, such as sloping walls, window and door components and multi-layer roofs.

Improved workflow with a prototypical implementation

The next step was to implement a prototypical LCA calculation tool using Autodesk Dynamo and Excel. The prototype solves the previously described problems by allocating component-specific materials and post-processing the material layers according to the specified component catalogue.

Tsikos and Negendahl [6] have already developed a method using Revit, Dynamo and Excel to calculate an LCA using an Integrated Dynamic Model (IDM). However, their aim is to achieve a fully automated work process. Material allocation is carried out with the aid of a "permanent link" between an external Excel database and the materials in Revit. Inaccuracies of the BIM model can be adjusted later in the model, but this way seems cumbersome, whereby a clear working method is not given. The present work is intended to make a specific contribution to optimising the compatibility between BIM models and LCA tools and to find a consistent and transparent calculation approach with a semi-automated workflow.

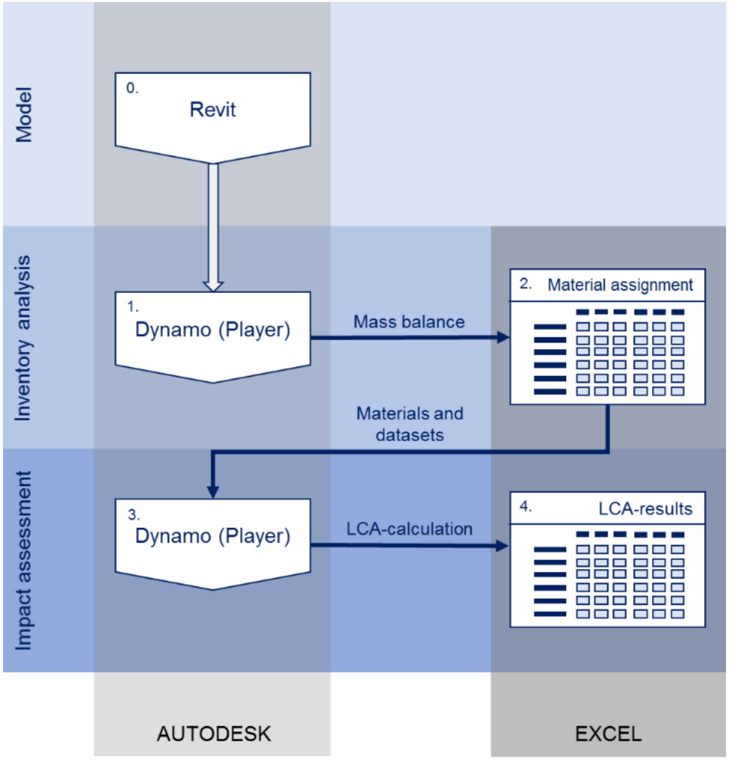

Figure 2. Prototypical approach for optimised workflow using Autodesk Dynamo and Excel

The aim is to enable complete transparency and the possibility to correct incomplete details in the LCA calculation process, in which the data for calculation and allocation are presented in a comprehensible manner. Adjustments for individual parameters can be made easily, quickly and precisely using Excel interfaces (Figure 2). Those include changes to layer thicknesses, composite proportions, lifetimes or end-of-life scenarios for building materials. The prototype uses the LCA calculation method of the DGNB system [7]. All components relevant for the LCA calculation are recorded via Dynamo and exported to Excel. However, in some cases, there are still problems with the geometric export of stairs, windows, façade elements and beams. These can be corrected by manual post-processing in Excel. An assignment for composite materials and different end-of-life-scenarios was also implemented.

With this approach, however, real-time calculation is still not possible for precise results. Also, this interface is only intended for models in Revit, but models of faulty IFC files can be adjusted by this post-processing correction step. Although the planned procedure is more cumbersome than the fully automated calculation, it can ensure a sufficient quality of the LCA with exact results.

The prototype was validated by comparing its results with existing manual tools. For this, the calculation method corresponds to the LCA calculation according to the DGNB system 2018 [7]. Fifty years were assumed as the service life of the building and the database used for the LCA impact factors of the construction materials is Ökobaudat 2013. The error deviation of 1.13%, which occurred in the evaluation process of the prototype, is the result from more accurate mass determination through BIM integration.

Conclusion

In general, BIM-integrated LCA are very well suited for a simple and fast method of operation. However, for a correct calculation, precise modelling requirements and recommendations for the quality of the BIM model must be communicated to the architect and planners in the beginning. Finally, a visual representation for the results is possible by using colour coding and Dynamo, although it is not implemented in the prototype yet. This enables a more intuitive and effective ecological optimisation of buildings. Interoperability between BIM and certification software must be further developed. The faster assessment will enable an increased demand for sustainable buildings.

In addition to energy and ecological aspects, the LCA can also be completed by an assessment of the costs (Life Cycle Costing – LCC) to take the economic dimension into account. Further BIM-capable holistic sustainability criteria are available in the areas of socio-cultural and functional quality as well as technical quality.

References (see next page for examples)

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