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Evaluation of BIM based LCA in early design phase (low LOD) of buildings

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Abstract. Building Information Modelling (BIM) is a convenient tool that is capable of collecting information throughout the whole life cycle of a building in one platform. The evolution in the digital BIM model in early design stages is not standardized, but Level of Development (LOD) is a concept that systematically structures the design processes divided into five levels. LOD is assessed in this paper as an opportunity to enhance the calculation of the environmental impacts in different early design stages more efficiently, using the methodology Life Cycle Assessment (LCA). Enlightening the building elements that contribute to highest release of CO_2 , permits early building material selection. This facilitates a pathway towards sustainable and environmentally friendly buildings. This study evaluates BIM based LCA in early design stages (low LOD) through literature reviews and a case study. This papers' case study executes LCAs at different LOD levels using the LCA software One Click LCA (OCL). Assessments in LOD 200, LOD 300, LOD 350 and an additional LOD 350 were utilized. The additional LOD 350 was deployed when LCA experts had implemented changes within OCL. Moreover, a concretized suggestion where today's unpredictable development of BIM becomes part of a LOD framework is proposed.

1 Introduction

There are several basic, well-established scientific links that constitute the background for this report. The UN Intergovernmental Panel on Climate Change (IPCC) states that the human fingerprint on greenhouse gases (GHGs) have risen to record levels not seen in three million years [1]. There are limitations to adaption and adaptive capacity for human and natural systems, but most adaptation needs will be lower for global warming of 1.5 °C compared to 2 °C according to the Paris Agreement [2].

The proposal of this report is to investigate which features that are required in an interaction between BIM and LCA in the early design stage (low LOD), to evaluate the environmental performance of a building. In addition, this paper research question is how an early design LCA framework corresponds to LOD.

The sustainability of buildings is depending on several aspects. This report is evaluating one of them, namely the environmental impact of buildings regarding CO_2 emission. This study focuses on the LOD in the design stage using BIM, and how a BIM based LCA can help improve the environmental impacts, limited to buildings. The study is illustrated by one case study, Valle Wood in Oslo (Norway), and one LCA tool, OCL. Cradle to gate processes for materials and services used in construction is considered as the system boundary for the study [3]. The embodied energy is the energy required to produce the building materials, and it is related to the production stage (A1-A3) of the life cycle stages. Furthermore, the in-use energy is energy consumption related to the use stage, and will not be considered in this report. Moreover, the incidence of embodied energy in building energy analyses account for the major part (50 %) of the whole primary energy demand, compared to the operational energy stages in the use stage [4–6]. The built environment have the highest potential to limit the global warming [7], and therefor an LCA framework regards to LOD is proposed.



2 Method

2.1 Conduction of LCAs

Qualitative and quantitative methods are the basis of this report's results. The qualitative methods investigate the findings regarding the interactions between BIM and LCA, as well as how BIM based LCAs can be advantageously rendered through comprehensive literature reviews. BIM models were deliberated this study through document reviews, received from NCC. The quantitative LCA calculations on the BIM models are based on using quantity take-off generated by BIM, as well as one LCA using input data retrieved from designers in Valle Wood, to obtain environmental impact in OCL.

All smc files were made available through NCC's own PortWise Access Manager 4.12. In the same portal, all relevant documents were available such as subcontractors' drawings and calculations. In addition, description of materials were listed. This study took advantage of three different smc files and distinguished the LOD levels based on [8, 9] requirements. The different BIM models (Figure 2, 3 and 4) express maturity in the design.

- (i) **.smc-file published February 2017 - LOD 200.** The model is represented with approximate quantities, size and shape. There are limited objects that are similar to the planned type of materials in the project description (Figure 1). It looks like elements are generic placeholders. See Figure 2.
- (ii) **.smc-file published July 2018 - LOD 300.** The model contains more specific and developed objects. Non-graphic information does also occur in this LOD level, but the size, shape and orientation of elements are located with respect to the project origin. See Figure 3.
- (iii) **.smc-file published December 2018 - LOD 350.** The quantity, size, shape, location and orientation of the element as designed, can be measured directly from the BIM model. Despite that there are existing non-graphical information to the model, the model can now be used to decision making and as project guide into different locations. See Figure 4.

Table 1 describes theoretical aspects in an LCA along with OCL features, as well as assumptions made. OCL is an online LCA application that require reports, such as a BIM model inventory file from either MS Excel or gbXML. The elaboration of the LCAs that use MS Excel reports from Solibri Model Checker were based on quantity take-offs from BIM and attached automatically to EPDs in OCL. These LCAs represents three calculations, namely LOD 200, LOD 300 and LOD 350. The LCA obtained from NCC, called *final LCA*, used empirical input data because the Industry Foundation Class (IFC) convey objects to the information take-off reports that causes errors. The structural systems are better to analyze on empirical values in OCL, as they will save time compared to checking all objects from the IFC [10].

2.2 Proposed LCA framework

The proposed framework consist of three main steps [11].

- (i) The definition of an evolution of LOD: The definition of element categories is the Norwegian Standard NS 3451 shown in Table 3. The definition of early design phases which appear as project delivery phases is shown in Figure 6 with respect to LOD evolution.
- (ii) Consistent combination of LCA databases: EPDs are the determined LCA database. Where no EPDs are available, average values should be employed as Table 5 shows.
- (iii) The link between LOD levels and LCA databases: At LOD 400, the exact quantities of each materials should be known as product specific data can be utilized.

3 Case

"Valle Wood is going to be Norway's largest commercial building in cross laminated timber. The building will be certified in accordance with BREEAM, the world's most demanding environmental certification system, which takes a holistic view of the building's entire ecocycle" [16].

Valle Wood covers the first phase of the project. This phase is 6700 m^2 , and the total site is going to be 60000 m^2 including all five phases [16].

Table 1: LCA methodology in One Click LCA

LCA methodology and assumptions made in One Click LCA	
Goal and scope definition	Evaluate the Global Warming Potential (GWP) caused by Valle Wood using OCL.
Functional Unit (FU)	FU of this LCA is Kg $CO_2 - eq$ emission per material. The reference unit is m^3 . Other units like kg, kW, kWh, l m and m^2 could have been applied, but OCL do not possess a unit conversion factor.
Temporal- and geographical scope	OCL execute a static LCA model. It is possible to setup the service of the materials that would be preferable to include. This will have an impact on B4-B5 (Replacements) during the building life cycle and impacts associated with B6-B7 are introduced on an annual basis. At the moment OCL do not allow changes to the energy mix as this is not allowed in the standards OCL follow. Operating variables do not affect the inventory of the system. Nevertheless - this is out of the scope of the study, and mitigate the potential downsides in terms of only gather Life Cycle Inventory (LCI) data to unit processes, which is the smallest element considered in the LCI for which input and output are quantified [12]. The time period covered in this LCA is updates in the BIM model as per December 2018 [13]. Geographical scope is Oslo, Norway.
Technology coverage	The tool utilized is LCA for BREEAM NOR. The template used to export and structure information from Solibri is "One Click LCA (metric).ITO".
Change-oriented LCA	This is a change-oriented LCA that comparing three BIM models (three LOD levels), up against a modified and reliable LCA at a correct LOD 350.
Intended application	This is a LCA that can be applied to different situations; BIM-model improvement, strategic planning and public decision making.
System boundary	Consider embodied emission, cradle to gate, A1-A3 as this contribute the most to GWP.
LCI analysis and data collection	MS Excel file that imported materials from the BIM (.smc file) and grouped them based on 5 criteria: CLASS: values have to be one of the listed ones in exactly the same format (sorted in .ITO template used in information takeoff in Solibri). IFC-MATERIAL: Use the distinguishable material name to map the material to the label in the tool. Mapping is based on CLASS and IFC-MATERIAL combination. For material label, the database is EPD-Norway. When importing it for the first time, one can teach it to the tool and it will be automatically recognized in the future. QUANTITY: Number, comma as decimal separator. QTY-TYPE: Units. TRANSPORT-KM: Transport distance in km from manufacturer site to the building site (optional, can also be added later in the query).
Data quality	Cut-off criteria to this LCA is materials < 1% of the volume. Also, OCL's category 6, Building Technology, is out of the scope. The cut-off lead to the fallacy of disaggregation by splitting up processes which lower the data quality and putting flows explicitly to zero [14]. The cut-offs are related to undefined objects from the BIM model. Data information included are obtained from EPDs witch follows the same sets of standards.
Life Cycle Impact assessment (LCIA)	The impact category is global warming, characterized as per CML-IA 2012 methodology, required by EN 15978 and EN 15804 [15].
Interpretation	OCL is an transparent analysis as the tool is online and can be easily modified. As this features, this assessment is also a comparative analysis in the way the assessments comparing four alternatives to which performance at different LOD.



Figure 1: Valle Wood

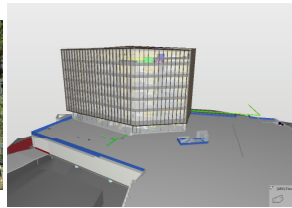


Figure 2: LOD200

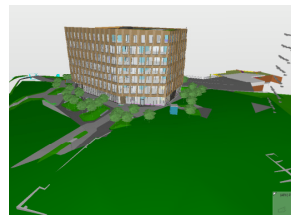


Figure 3: LOD 300

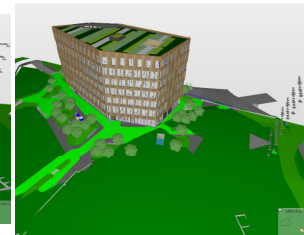


Figure 4: LOD 350

4 Results and Discussion

There are three main approaches ranging from the use of several software, the inclusion of LCA information in BIM, and quantity take-offs generated by BIM, to conduct BIM based LCAs. All approaches are seeking on reduce costs, lower the GHG emissions and increase the efficiency during early design stages of buildings [17]. Moreover, the interaction of BIM-LCA is utilized in several ways. Studies in [11, 18–27] have used several programs and LCIA databases to conduct LCAs at different stages. Some of the studies also take advantage of LOD implementation. In spite of several attempts, there is clearly a missing linkage of different databases, automatized design and impact calculation. However, the integration of LCA within the BIM is not available.

4.1 LCA of Valle Wood

The quantity takeoff information for building materials provided by Solibri Model Checker is obtained in units of volume. The mismatch between the properties in the smc files, quantity takeoff information, and OCL screening method, provides errors regarding the actual amount of materials and due to dissimilar products and EPDs. The MS Excel upload purely contains the information from the .smc file, but it is structured in a way so that the MS Excel can be read by OCL. When this occurs, a unit conversion factor is needed to evaluate the embodied environmental impacts. OCL does not possess this feature, which leads to heavier workload on the LCA performance in early design. An example can be incomplete design by architects that ignore specific requirements, regarding fire or lighting in the BIM.

4.2 LCAs Using Quantity Take-Off Generated by BIM With EPD-Norway as the LCA Database to Obtain Environmental Impact in OCL

LOD 200, LOD 300 and LOD 350 in Table 2 shows LCA results from OCL when the quantity take-off in Solibri Model Checker was used to generate the LCI report that was attached to EPDs in OCL.

The main contributors to GWP in all these designs are *horizontal structures* and *other structures*. Metals and concrete are the materials with the highest impact on the environment. Despite the fact that steel and concrete are the materials responsible for the high GHG emission, a reduction of 75% between LOD 200 and LOD 350 is present. The absence of data information through the transitional process into OCL, initiated unreliable results.

The LCA on LOD 200 indicates a low level of information in the BIM object, as the GHG emission is calculated to be more than 32000 tons of $CO_2 - eq$. Valle Wood, presented in Section 3, is going to be built in cross-laminated timber, which is not the case illustrated in February 2017 (LOD 200). Only 1% of the materials are timber. In low LOD levels, there is not a requirement to specify the type of materials, and because of the low level of information inside the BIM object, the design has not distinguished the environmental and material properties. Default settings were probably set to materials during the early design process in BIM.

At LOD 300, the materials are not yet in accordance with the project description. Steel and concrete are still dominating the design, and no timber is contributing to the design, which contradicts to the information in the BIM model (Figure 3).

At LOD 350, [28] state that the BIM model should contain all relevant information to be environmentally assessed, but as one can see from Table 2, essential data elements are missing. This leads to errors that do not correspond to the reality of materials that should have been in the LCA. Despite the great improvement in GHG emission, the LCA is not reliable as the material distribution differs from the project description. In addition, the number of materials in OCL are incorrect compared to the BIM model in Solibri Model Checker.

4.3 Final LCA Conducted With Empirical Values

Instead of improving the quantity take-off generated by Solibri Model Checker and the transitional format (.ITO template), empirical values were added in OCL to calculate a correct value for the GHG emissions, with the right quantity for the right type of materials. This is shown in Table 2. Here, 42% of the material contribution is timber, which is in accordance with the project description.

The great reduction in GHG emission was calculated with the right type of materials, linked to the right EPD, which resulted in 2700 Tons of $CO_2 - eq$. The measurements and units were obtained from the BIM model without utilizing the quantity take-off generated by Solibri Model Checker at LOD 350 (Figure 4).

Table 2: Results from OCL related to different LODs

LOD	Building Element	%	Material Type	%	Material Sub-types	%	Tons of $CO_2 - eq$
LOD 200	Horizontal Structures (HS)	82	Steel and Metals (SM)	88	Aluminum	87	32523
	Other Structures (OS)	12	Concrete	8	Prefab. concrete walls	4	
	Vertical Structures (VS)	6	Glass	2	Concrete foundation	3	
			Timber	1	Cross Laminated Timber (CLT)	1	
			Gypsum	0	Glass	2	
LOD 300	OS	51	SM	74	Aluminum	67	9553
	HS	25	Concrete	21	Prefab. concrete	13	
	VS	24	Floor (undefined)	2	Concrete	5	
	Ground and Foundation (GF)	0	Glass	1	Steel	4	
			Insulation	1	Steel and Iron	3	
LOD 350	OS	56	SM	75	Aluminum	67	8066
	HS	27	Concrete	19	Prefab. Concrete	13	
	VS	17	Timber	3	CLT	12	
	GF	0	Floor (undefined)	2	Steel	5	
			Insulation	1	Concrete	3	
LOD 350 (Final LCA)	VS	54	Timber	42	CLT	56	2713
	HS	31	Windows and doors	14	Mortar	13	
	GF	11	Gypsum	14	Interior walls	12	
	Building technology	3	Insulation	11	Rockwool	11	
	OS	1	Floor (undefined)	8	Carpets	8	

4.4 Suggested Use of LOD in a BIM Environment With Respect to LCA Application

To support an efficient and user-friendly LCA application in early design, strategies for simplification in BIM based LCAs have been proposed by several parties. The common knowledge gap in the proposals is the need for an envelope that deprives BIM to carry out an LCA single-handedly.

To minimize the carbon footprint, the writers of this report believes that early design delivery phases can help the efficiency and the automated work regarding LCAs. By using LOD as the direction-setting process in

LCA, the more environmental attention is given to the design and, the GHG emission will be considered as a determining factor through decisions. This approach and proposal desires to connect Architecture, Engineering and Construction (AEC) professionals and designers to deal with the issues through BIM based LCA in the early design stages (low LOD). The influence to alter the functionality of the building is high and the costs are low in early design stages [29, 30].

The capability of IFC's layered data structure, which has different objects with different level of details for the representation of information, should be specific regards to Model View Definitions (MVD) standard before heading to a higher LOD level. There is two distinct advantages of a standardized LOD related to the embodiment of an LCA. These are that the IFC can be imported into LCA analysis tools from any BIM authoring tools, without performing further data manipulation for mapping imported data to the used LCI database [21]. In addition, more realistic and concise results can be achieved by choosing a proper LCI database and a LCA calculation method, with respect to LOD of the elements contained in a BIM model [21].

A BIM model is a comprehensive collection of objects that are rich in information, and an LCA is a set of unit processes that are linked with each other using flows [31, 32]. It is by this required to link object in the BIM to LCI database using flows. Therefore, it can be hard for designers to handle several unit processes at a time. Henceforth, this proposal allow to break down this information into manageable and logical groups according to NS 3451 building table of building elements and OCL main distribution of building elements shown in Table 4. In addition, milestones to which LOD levels construction categories have to be developed in the BIM are expressed in the same table.

Table 3: NS 3451 - Table of building elements

NS 3451 - Table of Building Elements	
1 digit building element	2 digits building element
2 - Building	20 - Building in general
	21 - Ground and foundation
	22 - Structural system
	23 - External walls
	24 - Interior walls
	25 - Slab
	26 - Roof
	27 - Building inventory
	28 - Stairs and balcony
29 - Other building related parts	
3 - Plumbing installations	30-39: out of scope of this study
4 - Electrical Power	40-49: out of scope of this study
5 - Telecom and automation	50-59: out of scope of this study
6 - Other installations	60-69: out of scope of this study
7 - Outdoor area	70-79: out of scope of this study

Table 4: Construction categories divided with respect to LOD and its milestones

Construction categories divided with respect to LOD		
OCL main distributions	NS 3451	LOD
1) Ground and foundation	20	100
	21	150
2) Vertical structures and facade	22	175
	23	175
	24	175
3) Horizontal structures	25	175
	26	200
4) Other structures and materials	27	300
	27	300
	29	350
6) Building technology	3	350
	4	350
	5	350
	6	400
5) Outdoor area and elements on site	7	400

To systematize to which early design phase (or project delivery phase) that represents the different LOD levels is suggested in Figure 6.

A comprehensive LCA is to be done at LOD 350, building permit stage [11, 18, 21, 24, 25, 28, 33–35]. By this stage, the major elements are stated, and 80% of the 3, 4, 5, 6 and 7 categories (see Table 3) are agreed upon. The building can be stated complete in the BIM, apart from the uncertainty in the empirical, min/max or most likely values in the 80% of LOD 400 posts. Generic LCA databases can be used to obtain LCIA data when the BIM is incomplete and not considered as LOD 400. Another source to most likely values is considering conservative EPDs. An example of conservative EPD can be concrete instead of CLT.

At technical elaboration, the BIM represents LOD 400 (Figure 6), and the environmental impacts should be assessed on equal terms as the structural design issues. EPDs are the dominated LCIA database at LOD 400. Environmental impacts on different products are various, and therefore should EPDs represent the specific brand of the selected material. This will lower the uncertainty in the complete LCA. By using endpoint indicators instead of midpoint indicators in the low LOD LCAs, it would simplify the results and turn the interpretation phase into a more understandable phase for AEC professionals.

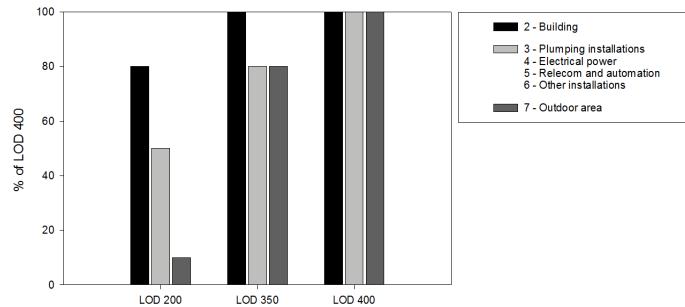


Figure 5: Degree of completeness in different stages of LOD

Table 5: Level of completeness and LCIA databases

LOD	NS 345 (1 digit)	% of LOD 400	LCIA database for building elements
LOD 200	2	80	Average values, mean values, min/max values, most likely value
	3, 4, 5, 6	50	
	7	10	
LOD 350	2	100	EPD-Norway Average values, mean values, min/max values, most likely value
	3, 4, 5, 6	80	
	7	80	
LOD 400	2	100	EPD-Norway
	3, 4, 5, 6	100	
	7	100	

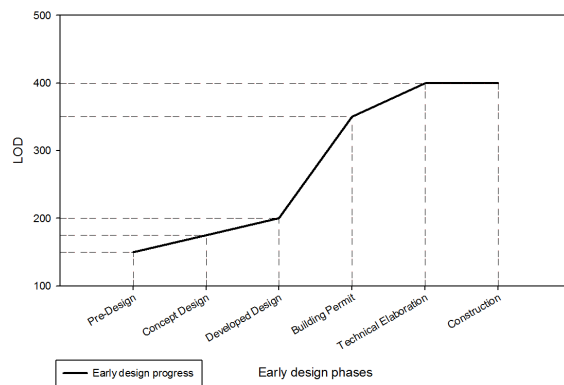


Figure 6: Design phase evolution according to LOD

Components regarding building manner should be given important effort in LOD 200, while plumbing, electrical, telecom and automation and other installations are usually depending on the architectural design as Figure 5 and Table 5 shows. The building components are 80% completed at LOD 200. This is due to unpredictable issues regarding clash detection and if building elements within 3, 4, 5 or 6 categories are determinate. At LOD 350, building components is fixed as these components are the major contributors to GWP and determine the structural design of buildings. In addition, the building components determines the structural design of buildings. By clearly state these materials in LOD 350, than the majority of building materials can be assessed with high accuracy.

5 Conclusion

Main aims of a BIM based LCA is to establish a convenient decision-making method with an environmental perspective, and an ongoing environmental assessment during the early design stages. Investing more time in the design stages and utilize LOD and its requirements consistently, would enhance the level of information and detail in BIM objects. This amplifies the information within the IFC files and leads to fewer errors in BIM-LCA tools.

Therefore, we suggest the designers and design tools to be acquainted with the requirements to each LOD levels, and consequently use average, mean (\pm) values and best practice where the LOD level is low. The proposed LCA framework is corresponding to LOD levels, as the design delivery phases are determined by milestones of completeness in the BIM model. Designing the building project in BIM in accordance with this framework will improve the GWP, as interaction with BIM and LCA tools enables substitution of materials that contribute to the highest release of CO_2 . Such automation in LCAs, and the ability for ongoing assessments will assist the decision-making processes to emphasize the environmental issues during design.

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