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Early Design Stage Building LCA using The LCAbyg Tool: New Strategies For Bridging The Data Gap

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Abstract. There is an increasing demand for Life Cycle Assessment (LCA) as a method for environmental impact and resource assessments of buildings. At early design stages, where major design decisions are made, the potential for improving the environmental performance using LCA is greatest. However, detailed building information is usually not available at this time. This paper presents the recent extension of LCAbyg, the official Danish building LCA-tool, integrating an LCA approach for situations, where building design and material choices are not yet fully determined. The tool assists the user in establishing a complete building inventory by providing a default component library including building services and a guide for estimating quantities. Default components in the library are based on the integrated product database Ökobaudat. A convenient generation and comparison of variants improves usability, while a new LCA design guide shall increase the uptake of LCA in larger parts of the building industry. The methodological choices of the approach are laid out and discussed. The presented approach is not limited for use in early stages, but may improve feasibility in building LCA in general as default and estimated values may be refined towards more detail in later stages of the project.

1. Introduction

Life cycle assessment (LCA) has become a widely accepted approach for assessing the environmental performance of buildings. Comprehensive LCA, however, require expert competencies, a considerable data processing and advanced calculation tools and databases. In order to increase feasibility and making it a routine building parameter, LCA is often conducted based on simplifications, such as in green building certification schemes, which have been a driver for the uptake of LCA in the built environment [1][2][3][4].

In Denmark, LCA requirements for integration into the Building Code are currently under development. As a precondition, the requirements shall be voluntary to follow and feasible for broader parts of the building sector. This paper proposes a simplified approach to LCA, allowing a feasible and low-cost adoption at the current state of the industry. Based on LCAbyg, a free building LCA tool recognized by DGNB in Denmark [5], the approach is implemented in the new version LCAbyg 4.0 beta [6].

Existing LCA simplification often includes reducing the number of parameters in the building life cycle or the functional unit, which may be called a horizontal approach. Simplification by reducing data quality and allowing generic data address information depth and may belong to a vertical approach.

Integrating LCA feedback in early design stages, where major decisions can be made, is essential for meeting a given benchmark at a later stage of the project [7]. Here, feasibility is dependent on the level of integration into existing workflows, since clients cannot be expected to accept the cost for advancing detailed design e.g. regarding building services or structural analysis solely for achieving a complete LCA inventory. However, there are different strategies for filling data gaps.

Some research contributions attempt at identifying critical parameters with greatest relevance or sensitivity to variation regarding the overall result in order to omit other parameters for workload [2][8][9][7]. Selective approaches are dependent on knowledge on the relevance and sensitivity of included building parts for all the cases to which an LCA is applied, however studies are limited to a narrow range of building types and properties [9][8]. The same problem of generalization applies to the level of detail in a given building element, where often neglected products show varying relative influence depending on the construction principle, building type or other variables[10]. Common to a selective approach is an uncertainty related to the omitted parameters.

Another approach is pursuing a complete and detailed inventory from the start. As a full building model is usually not available, this approach is dependent on a reliable methods for bridging missing input data related to building design, material choice and environmental impact.

A possible, emerging solution is linking LCA with existing BIM/CAD models [11][12]. Here, feasibility is dependent on the question, if digital models with suited data structure are already used in early design stages and if eventually more parameters such as energy and indoor environment are assigned to a shared model.

Yet, complete and detailed inventories may be achieved by manual input as well. Similar to the BIM approach, this solution shares the dependency on data bridging methods. Manual inputs are independent from the adoption of certain design tools and potential data compatibility issues in early design. Crucial for feasibility is the availability of default values and an easy transfer of quantities, which are based on already available information in concept design.

The manual input approach is chosen, because it is expected to meet the requirements of an LCA tool adoptable for most of the building practitioners and different projects type and scale. The new functions are implemented in the existing LCAbyg tool enabling building generalists to integrate LCA into early stages of design, eventually pursuing a DGNB screening, however, and providing a seamless adaptability for further refinement e.g. later full DGNB reportings. LCAbyg already uses a simplified system boundary including the product stage, replacements, operational energy and End-of-Life stages [13], see the feature list in the appendix.

2. Method

The three main features presented are a component library, guided quantification and comparison of variants (figure 1). A case study-based test of deviation compared to LCA with specific inventory is presented in a separate paper [14]. The project was carried out in collaboration with architects, civil engineers, surveyors and other representatives from the Danish building sector in series of open workshops in 2017/18.

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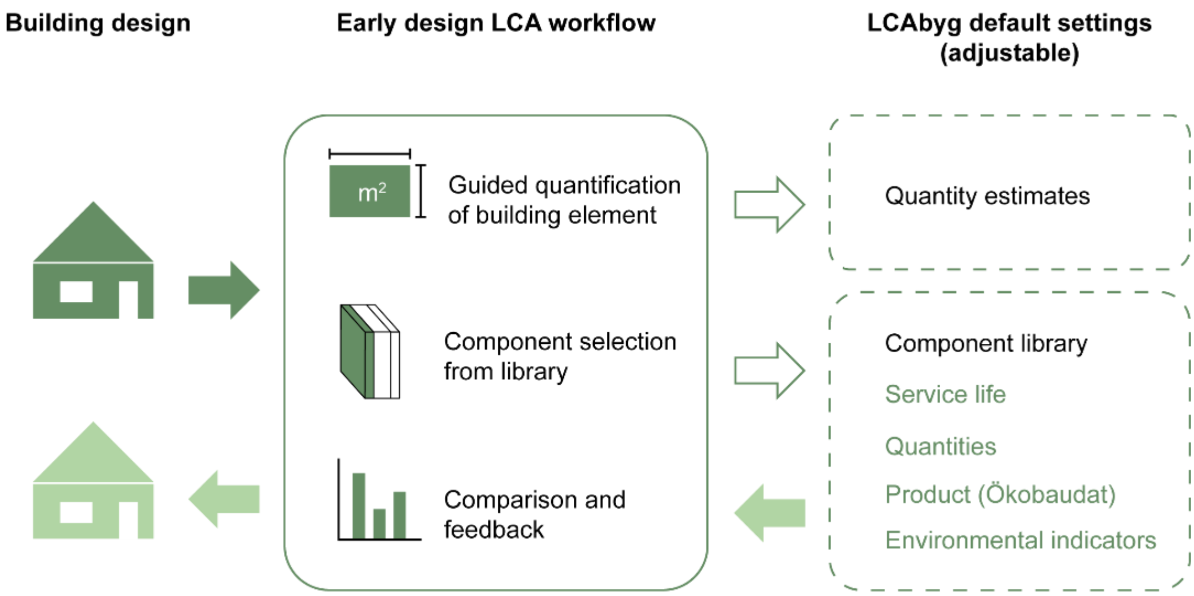

Figure 1. Early design LCA approach: Key elements include guided quantification, component library and comparison & feedback

3. Proposed early design approach

3.1. Default component library

A default library is proposed for bridging incomplete information on the detailing of the building model – or just for quicker and more convenient data input in general. Components are based on the data structure level between building elements and building products (table 1).

Table 1. Building model structure

Level	Function	Example
Element category	Main building parts	*External wall*
Element subcategory	Quantity estimation rules for specific kinds of building elements	*External basement wall*
Element	A member of the actual building design	*Specific wall in project*
Component	Functional layer of an element	*Brick wall with EPS insulation*
Product (Ökobaudat)	Includes quantities and service life	*Brick*
Stage	Environmental life cycle data	*Brick production (A1-3)*

Components consist of aggregated products and are functionally independent layers (figure 2). Making use of the already integrated database Ökobaudat, products are further aggregated to components (table 1). The layering method has been innovated by the previous LCA-profiles approach[15], however with different rules for layer division. The present approach is based on a load-bearing and insulating core layer (figure 2). Including both functions in one layer allows for specifying their mutual quantities, as in framed constructions and for better compatibility among all layers in general. This approach, though, requires a larger number of core samples in each element category in order to provide a palette of different dimensions and insulation types.

The two remaining layers cover the core from each side. These layers do not need to be scaled within each solution as much as the core allowing for a greater variety of solutions for covering layers. Scaling may include fire protection or acoustic insulation functions.

A given exterior wall might for instance include plaster rendering as interior layer (1), a brick wall with EPS-insulation as the core layer (2) and a facing brick façade layer (3).

Non-planar building elements use the layer structure conceptually for functionally independent system parts such as production (layer 1), distribution (2) and terminal units (3) in building services (table 2).

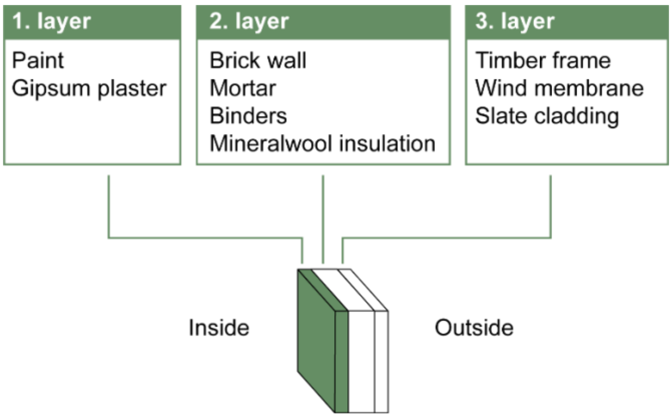

Figure 2. Layering of building elements. Example of an exterior wall divided into three functional layers. The individual layers can be replaced by compatible items from the component library.

The library offers sufficient components for modelling inventories of all supported building types. A complete level of detail including membranes and fastening is pursued, however joints between elements, corners or overlaps are not considered in most of components.

Both detailing and assignment of environmental product data follow conservative assumptions, such as low-energy insulation, ample dimensioning and tight grids. The approach tries to avoid rewarding the use of default values by accepting slightly higher mass and environmental impact compared with LCA based on complete specific inventory data.

Table 2. The function of levels and number of variants

Element category	#	Layer 1	#	Layer 2	#	Layer 3	# 1-3
Foundations	13	Foundations		-		-	13
Ground floor slabs	15	Flooring	3	Load-bearing system	2	Insulation and underlay	15
External walls	17	Inside finishing	31	Load-bearing and insulating system	19	Façade system	67
Internal walls	15	Finishing	25	Load-bearing and insulating system	16	Finishing	56
Floor decks	15	Flooring	11	Load-bearing and insulating system	12	Ceiling	38

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Element category	#	Layer 1	#	Layer 2	#	Layer 3	# 1-3
Stairs and ramps[2]	0	Structure	0	Flooring	0	Balustrades and handrails	0
Columns and beams	84	Columns and beams		-		-	84
Balconies	5	Platform	8	-	3	-	16
Roofs	7	Roof cladding	20	Load-bearing and insulating system	12	Ceiling	39
Windows, doors, glazing systems	18	Profiles[1]	2	Panes	0	Solar shading[2]	20
Building services[3]	18	Production unit	6	Distribution	3	Terminal unit	27

3.2. Guided quantification

LCAbyg provides help for estimating quantities within a couple of element subcategories requiring no more than the information given in concept design (table 4). Some guidelines are mere intermediate calculations integrated in the tool, while others are based on actual default values based on estimates. The latter includes building services, balconies and foundations.

Guided quantification is presented as a proposal in a permanent wizard section of the programme window. As a principle, the user has to actively select the transfer from the wizard to the model every time, an adjustment is performed in order to prevent unintended change of quantities. User help text explains the assumptions and procedures related to every estimate. The calculation of relevant quantity suggestions requires the placement of building elements under correct subcategories and a minimum building information (table 3).

Table 3. Required basic building information input

Building type
Gross area
Gross area, heated
Gross area over terrain
Floor-to-floor height
Number of basement floors

Table 4. Required input for element quantification

Element category	Element subcategory	Required quantity input[4]
Foundations	Strip footings, deep	Length
	Pad foundations, shallow	Number
	Pad foundations	Number
	Pile foundations	-

[1] Including full product datasets, which are not divided into components, e.g. doors
[2] Not implemented yet
[3] Includes the categories drainage, electrical systems, water systems, ventilation/cooling and heating
[4] Minimum input refers to assigning area-based quantities to the components. Not included is the specification og layer thickness and basis building data (table 3)

Element category	Element subcategory	Required quantity input[4]
Ground floor deck	Ground floor deck	-
External walls	Basement external walls	Length
	External walls	Length
Partition walls	Non-load-bearing basement walls	Length
	Load-bearing basement walls	Length
	Non-load-bearing walls	Length
	Load-bearing walls	Length
Floor deck	Ground floor deck	-
	Floor deck	-
Stairs and ramps	Stairs and ramps	Number
Columns and beams	Columns	Number
	Beams	Length
	Fire protection	-
Balconies	Platform	Length, width
	Balustrades and handrails	Length, width
	Mounting	Number of balconies
Roofs	Roofs	Inclination
Windows, doors, glazing systems	Windows	Window number and area or Window-facade ratio and facade area
	Doors	Number, area
	Glazing systems	Area
Drainage	Plumbing	-
	Down comer	-
Drinking water	Production unit	Number of shafts
	Plumbing	Number of shafts
Space heating	Production unit	-
	Plumbing	Number of shafts
	Radiators	-
	Underfloor heating	-
Ventilation and cooling	Production unit	-
	Ductwork	Number of shafts

3.3. *Comparison & feedback*

The tool offers data comparison in different ways. First, Items on any level may be compared by checking a box. Up to five items can be displayed in a graph showing results within three indicators. Alternatively, comparison may be performed already in the dialogue window for selecting new items from the library. Finally, the currently opened project can be compared with a number of other projects, results are aggregated on building level.

Separate projects files can be opened in multiple windows, eventually for generating variants or for review reasons. Input changes are immediately shown in the results, although these changes are not traced or marked for immediate review.

4. Conclusions and discussion

An early design approach has been developed and implemented based on existing simplifications and integrated product database in LCAbyg. New functions include a default component library and a guide for estimating material quantities in order to fill incomplete data with default values. Focus has been on guiding practitioners to achieve a complete and detailed inventory and allowing for variant-based design.

Since the system boundary given in LCAbyg 3.2 is already simplified and all stages for embodied impacts are being calculated by default, a further simplification by reducing stages would not increase feasibility.

The functional unit is based on a whole building approach and a detailed and complete inventory already in early design. The effort and robustness of achieving a full detail and complete model has been evaluated more manageable than managing uncertainty in a reduced inventory approach. Here, simplification refers to making full detail inventories as simple to generate and manage as possible.

Functional layers make the detailing of building elements manageable, since the user selects solution packages without having to specify every single product, its dimension and quantity.

Further, the user is guided through specifying a number of element quantities including those, which often remain undefined in concept design such as foundations and building services. Inventory input is based on information on quantities, which usually will be available during concept design such as wall length, storey height and number of cores. Insulation thickness is given by default, however dimensions of load-bearing walls, columns or beams have to be selected from a handful of choices, since this information is evaluated difficult to generalize.

The full and complete inventory approach is expected to reduce the risk of incomplete Bill of Masses, however, the risk is being transferred to the reliability of default quantities and components. This uncertainty is sought to be addressed by making conservative assumptions and choices in specifying dimensions, included products, membranes, densities, lambda-values or selection of environmental dataset. Ideally, this in-built uncertainty margin shall lead to slightly higher mass and impact results in the early stages. However, guided input and default values are optional to use and may be edited or replaced as the project evolves and specific data becomes available.

Since the project result may serve as a prototype for potential LCA regulation in the building code, the solution had to be accessible to a large variety of actors and projects under the given digitalization level in the Danish building sector. A stand-alone LCA tool is proposed in order to achieve robustness in light of a diversity of workflows.

5. Perspective

Component library and quantity estimates will need further testing and feedback from practical use in order to better meet real life building inventories. Future improvements in usability may be achieved by integrating a visual representation of components or results, a sensitivity analysis module and the integration with building design tools.

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Appendix: LCAbyg 3.2 and new features in LCAbyg 4.0 beta[5]

Topic	Feature	Definition	New
Input	Building model structure	Default building model structure (table 1)	x
	Data exchange	Import/export on all levels of detail, manual EPD input, project export to Microsoft Excel format	
	Default database (product)	Building product library, adopted from Ökobaudat 2016	
	Default database (component)	Component library covering solutions for all supported building types, 3-layer structure, conservative assumptions	x
	Reference study period	Guidance in national report [16]	
	Service life	Guidance in national report [16]	
	Environmental indicators	GWP, ODP, POCP, AP, EP, ADPe, ADPf, PEtot, Sek	
	System boundary	A1-3, B4, B6, C3-4	
Output	Quantification	Bill of Quantities including assigned service life	
	Score	Aggregated score on all levels between building and product life cycle module (all supported environmental indicators)	
	Functional unit	Buildings in total, gross area or gross area / year	
Usability	User support	Built-in user guide (revised version), no user forum	
	Learning resources	Publication[6] introducing early design LCA	x
	Flexibility & adaptability	Default building model structure and component library are optional	
	Incomplete inventory support	Guided quantity estimation, building model structure as a checklist for completeness	x
	Building types	Residential (detached / terraced, multi-storey), school / day-care, office	
	Data review/change	Component dimensioning indirectly available by a variation in the library. Responsive quantity estimation based on a few available variables (table 3)	x
	Loss of data	No auto save or undo/redo functions	
	Variant-based design	Create, replace and duplicate functions on all instances. Variants are stored in the project file. Persistent user data can alternatively be stored by using export/import (external user database)	x
	Comparison & feedback loops	Variant comparison on the level of elements, components, products and stages both in the model or dialogue for selecting new items. Project comparison on building level. Multi-window work possible	x
	Visual editor	No visual representation of the building	
	Proposal generator	No automatic solution generation	
	Integration with other tools	No direct link. Developer solution for indirect BIM-integration	
	Results informing design decisions	Exportable results in table and graph format, mass and indicators aggregated on all instances and indicators. They include operational/embodied impacts comparison, accumulated life cycle impact, hot-spot analysis, and DGNB reference values. Export to Microsoft Excel format for further data analysis.	
	Normalization	CML 2001	
	Documentation	Report generator including a selection of results.	
	Uncertainty	No integrated sensitivity analysis	
	Calculation time	Real-time calculation and results	

[5] The feature list is based on the requirements for early design LCA tools by [17]
[6] Publication with guidance on early design LCA [18]

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