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## A case-based study on the use of life cycle assessment and life cycle costing in the building industry

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# A case-based study on the use of life cycle assessment and life cycle costing in the building industry

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**Abstract.** The environmental impact of human activities has been a concern for engineers and architects for centuries, from limitation of energy and raw materials to predicting future energy and resource demands. This review demonstrates how life cycle assessment (LCA) and life cycle costing (LCC) tools can be used to support design decisions in the building industry throughout the design process. The study is primarily based on DGNB certification projects in Denmark conducted by the engineering consultancy company Ramboll and focuses on how LCA and LCC tools can be used in the early design stages to quantify decision making and how tools are used in the final stages of a certification process to verify the building geometry with regard to life cycle costs and environmental impacts.

## 1. Introduction

In accordance with the Danish Construction Association only 4% of all building projects in 2018 were considered sustainable in Denmark, counting buildings with sustainability certifications, meet the voluntary Danish low energy class or additional sustainability measures exceeding the Danish building regulations [1]. In Ramboll Denmark approximately 6.5 % of the projects within the building industry are described as sustainable in the project database, half of these are certification projects like DGNB, LEED and BREEAM<sup>1</sup>. Looking at all Ramboll's projects within the building industry globally there has been an exponential growth in projects described as sustainable over the last 10 years.

The Danish building regulation has tightened the requirements to energy consumption of buildings over the last decades, but has yet to finalize the currently developing voluntary sustainability class, which will contain a requirement for LCA and LCC estimates for major building components. In the long term, specific requirements for a building's total energy and resource consumption over its life time may be implemented [2]. With lack of interest and demand for sustainable buildings and a lack in regulations it is crucial that engineers, architects, developers and contractors have entrepreneurial spirits when it comes to sustainable building design and informing the clients and developers of the possibilities and value propositions herein.

The aim of this paper is to increase awareness of design driven by life cycle methods through case studies in the engineering and design company Ramboll [3]. The case studies focus on different

<sup>1</sup> Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM)



methodologies utilising life cycle engineering<sup>2</sup> as a driver for design decisions and the paper will present the potentials and boundaries in both early design stages as well as detailed design stages.

## 2. Life Cycle Engineering Screening Approach

A common design constraint is limited time and budget for a project. To enhance informed decision making and promote sustainable solutions it is important to have tools which provide quick feedback to the designers and client. This section will explain the Ramboll sustainability screening methodology through theory and examples. This approach can be used both in early design stages as well as very late design stages and even during construction. The methodology has been developed to qualify the answer to one of the most common questions posed by clients; *what is the most sustainable material/product for a given function?*

### 2.1. Sustainability Screening of Building Materials and Products

To enhance informed decision making and promote sustainable solutions a screening tool as seen in figure 1 can be used. The screening tool can be used to compare functional equivalent products or materials which means the primary functions and services must be equivalent. They are compared on a variety of parameters which includes the life cycle and both social, economic and environmental qualities.

Functional equivalent product group		Sustainability Parameters		
		Social	Economic	Environmental
Life Cycle Stages	Production			
	Construction			
	Use			
	End of Life			

*Figure 1. Scheme for sustainability screening of building materials or products*

The use of this scheme will enable the designer to compare products over the entire life cycle of a building and on all three sustainability parameters; social, economic and environmental. This method can be adapted to all project phases. In the early design stages, it is possible to compare different materials, products or systems based on experience and generic data. Environmental data is accessible through the free online database *oekobau* [5], whereas costs can be found in the Danish cost tool *molio price data* [6]. Social data can be both descriptive and specific. A descriptive parameter could be aesthetic and cultural quality and a specific material property could be light reflectance which will influence the daylight in a room and thereby also the users, thus some parameters are easy to quantify whereas other are subjective.









The scheme can also be used to specify material qualities in a tender through requirements for e.g. enclosure of environmental data and building sustainability certifications. In a later design stage, the scheme can be used to compare specific building components or products against each other on a chosen set of parameters. The data will primarily be derived from the manufacturer's websites combined with generic data when needed e.g. for life span, maintenance and cleaning cost.

<sup>2</sup> Life cycle engineering enables informed decision making by evaluating environmental, economic and social impacts of products, buildings or cities in a life cycle perspective. The Life Cycle Engineering methodology presents results clearly and enhance transparency to create a solid basis for decision makers [4].

Table 1 gives an example of what parameters can be chosen when comparing different ceiling products on their sustainability in the early design stage. The method helps the practitioner identify comparable measures and can be used to ensure equal focus on both social, economic and environmental aspects in a life cycle perspective. In figure 2 the final visual presented to the client is seen. The purpose of the visual is to quickly enable the client to make a decision based on both social, economic and environmental data in a life cycle perspective.

*Table 1. Example of a sustainability screening for comparing different ceiling products*

Comparison of ceiling products		Sustainability Parameters		
		Social	Economic	Environmental
Life Cycle Stages	Production (A1-A3)	FSC Certification & Cradle2Cradle	Building Component Cost [EUR/m <sup>2</sup> ]	Global Warming Potential (kg CO <sub>2</sub> e/kg) & Recycled content
	Use (B1-B7)	Aesthetic, Light reflectance & Off-gassing	Maintenance [EUR/m <sup>2</sup> /year] Life Span (years)	Maintenance and cleaning Life Span (years)
	End of Life (C1-C4)	-	-	Global Warming Potential (kg CO <sub>2</sub> e/kg) Cradle2Cradle

Acoustic ceiling panels								
	Environmental Impact [kg CO <sub>2</sub> eq]	Lifetime [years]	Price [kr/m <sup>2</sup> ]	Maintenance friendly	Recycled Material Content [%]	Toxicity and degassing [mg/m <sup>3</sup> ]	Product Certification	Aesthetics
Ceiling Panel 1	0,43 kg CO <sub>2</sub> eq	50 years	130 kr/m <sup>2</sup>	<b>Yes</b> Possible de- and remounting for easy accessibility	0%	0,02mg/m <sup>3</sup>	FSC/PEFC	The solution does <b>not</b> meet the requirement for a "uniform ceiling surface"
Ceiling Panel 2	1,87 kg CO <sub>2</sub> eq	30 years	296 kr/m <sup>2</sup>	<b>Yes</b> Possible de- and remounting for easy accessibility	71%	<0,5mg/m <sup>3</sup>	C2C	The solution meets the requirement for a "uniform ceiling surface"
Ceiling Panel 3	1,20 kg CO <sub>2</sub> eq	50 years	225 kr/m <sup>2</sup>	<b>Yes</b> Possible de- and remounting for easy accessibility	52%	0,01mg/m <sup>3</sup>	?	The solution meets the requirement for a "uniform ceiling surface"

*Figure 2 Example of a sustainability screening of different ceiling products as it is visualised to the client*

## 2.2. Potentials and barriers related to the simplified life cycle approach; Sustainability screening

The simplified life cycle approach has shown the potential to enhance designers and clients to make more informed and thereby more sustainable design decisions. The method can be tailored to the specific client needs and context, but is also vulnerable as it depends on the consultant's competences and experience. This method requires the practitioner to have a basic understanding of the functional unit of environmental impact data to ensure data comparability and knowledge of product certifications.

Even though this simplified method is faster than conducting environmental and economic life cycle assessments it has shown to be time consuming in data gathering. The data needed can be found in various databases and from manufacturers directly, but currently no common database that can create this overview exists. A database requires continuous maintenance in securing accurate and updated data, hence the manufacturers should see the benefit of reporting and updating their data.

A potential flaw to this method is the risk of making comparisons based on too few parameters and thereby neglecting important issues which might lead to taking wrong decisions. As both qualitative and quantitative data can be used to describe materials or products it can result in a subjective weighting of the variants. A common understanding in the industry of the minimum requirements for a comparison is important in order to not neglect important issues or parameters.

A common barrier for the specific product comparison is the lack of data on the manufacturers' websites and the lack of specific environmental product declarations in Denmark. The lack of data limits

the design space and may result in the same few products being used repeatedly. Some manufacturers do not disclose their product content online which could make the designer choose another brand where the data is easy to access. This might leave new and innovative products out of the comparison, as they often have not declared their product through environmental declarations (EPD) or have certifications and labels like *Cradle to Cradle* or the Danish indoor climate label etc. This approach could then make it even harder for new and potentially more sustainable products to penetrate the market.

### 3. LCA and LCC comparison studies of building elements

This section describes the process of conducting LCA and LCC comparison studies during a design phase. What building components or design solutions should be compared will depend on the specific context and should thus always be evaluated to ensure that design solutions with substantial impact are chosen.

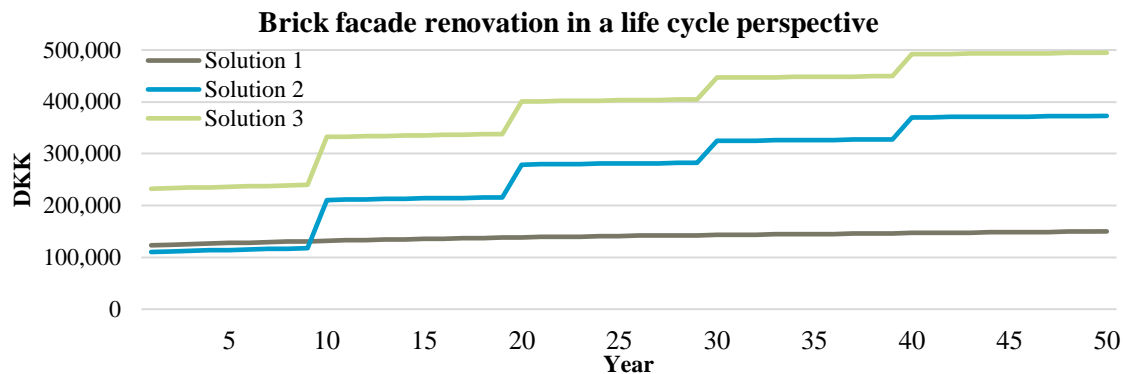
#### 3.1. LCA and LCC comparison studies of building elements

Often various solutions are explored and discussed and poses questions like; *which solution is more sustainable, solution A or solution B?* In this case it is possible for the sustainability consultant to utilize the Danish LCA and LCC tools; LCAByg [7] and LCCByg [8] developed by the Danish Building Research Institute to visualize the environmental and economic impacts over the life span of the given building to enhance transparency of environmental and economical sustainability impact. Comparison studies requires a stringent methodology and a common understanding on how to define prerequisites and set up assumptions. To conduct LCAs and LCCs the right data needs to be at hand, an overview of the different data needed can be seen in **Table 2**.

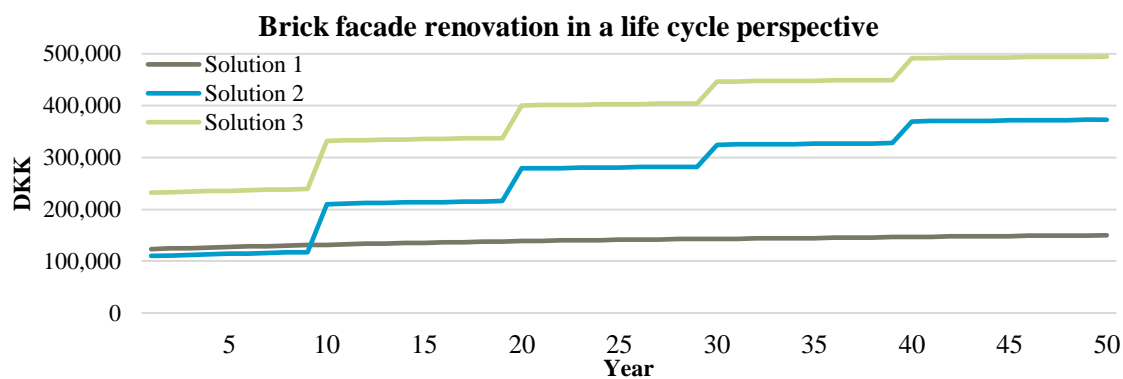
*Table 2. Data Requirements for calculation LCA and LCC*

	<b>Data Requirements</b>	<b>Where do we get the data from?</b>
<b>Life cycle stages</b>	Quantities	Estimates, 2D or 3D design models e.g. Sketch Up, Revit
<b>Production (A1-A3)</b>	Cost	Estimates, Molio cost database, Contractor's <i>list of products</i>
	Environmental impact	Oekobau, EPDs or Proxy data
<b>Use phase (B1-B7)</b>	Energy consumption	Be18 calculation
	Maintenance & Cleaning	Molio cost database, Danish Facility Management (office), The Danish social housing sector (social housing), Manufacturers maintenance & cleaning guidelines
<b>End-of-life (C1-C4)</b>	Life Span	Oekobau, EPDs or Proxy data
	Environmental impact	SBI 2013:30 Industry Guidance on life span, Levetider.dk (A Danish database of building component life span)

Financing data like inflation and discount rate is already implemented in the Danish *LCCByg* tool and national standards for CO<sub>2</sub> emissions related to energy production is already implemented in the Danish *LCAByg*. Figure 3 shows an example a comparison of the life cycle cost of three different possible solutions to a façade renovation. The different alternatives were discussed with the building owner, the project team and the facility manager and then modeled and compared via the Danish *LCCByg* tool. The price data for the different processes in the renovation solutions were found in the *Molio cost database*, where it is possible to find the related cost per area for pressure washing of the existing façade, repair and re-painting, etc. The three different renovation solutions over a 50 year life span are depicted in



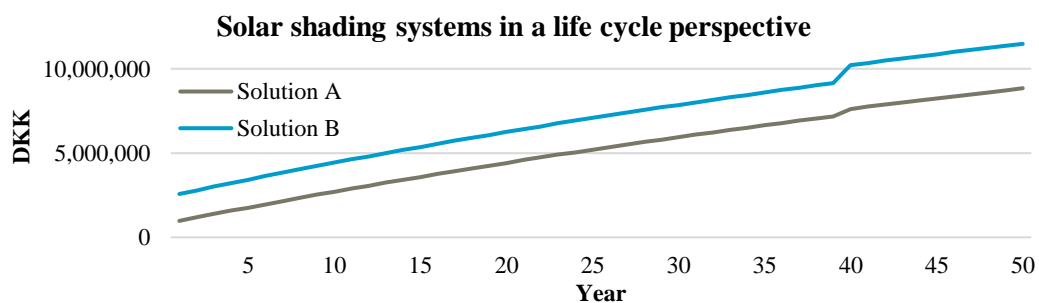
**Figure 3.**



**Figure 3.** Life cycle cost of 3 brick wall renovation solutions. Solution 1: Revert to raw brick wall by cleansing the façade. Solution 2: Clean the façade, re-plaster and repaint. Solution 3: Repair the cracked façade with new plaster and repaint.

### 3.2. LCA and LCC comparison studies including whole building simulations

LCA and LCC comparison studies can be integrated into engineers' and architects' design explorations. As an example, a client wanted to explore different solar shading systems and the related energy and daylight performance. The life cycle cost comparison of a fixed and a dynamic solar shading system can be seen in figure 4. Here the yearly energy consumption, daylight levels and heating and cooling demands are accounted for as well as the construction and maintenance cost. This life cycle cost assessment not only compares the performance of the two systems 1:1, but also sees the systems in the relation they are in, within the building. The energy and daylight simulation data were retrieved from a whole building simulation model by the indoor climate engineer and the cost data were provided by the contractor on the project as well as the specific product manufacturers. Maintenance and cleaning data were derived from the DGNB manual.



**Figure 4.** Life Cycle Cost of a fixed (solution A) and a dynamic (solution B) solar shading system

### 3.3. Potentials and barriers related to the LCA and LCC comparison studies

The LCA and LCC comparison studies provide a quantified overview of consequences and is a useful tool in a decision-making process. Even stronger arguments and more holistic decision making would be obtainable by conducting LCAs and LCCs simultaneously. An integration possibility between the two tools would ensure consistency in data and enhance the use of both assessments.

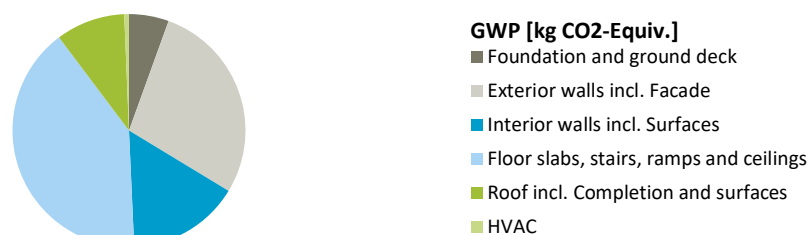
Numerous barriers prevent the utilization of LCA and LCC as decision making tools e.g. limited time which is often related to limited knowledge and experience of the consultants or project managers. The building industry is rather conservative and tends to go on with a “business as usual” approach, thus not allowing time for comparative studies like the examples above. Other barriers can be the data gathering, and discussion on how simplified a comparison can be without leading to wrong decision making. This dilemma of LCA and LCC is related to the nature of the design process. Early design choices are responsible for a significant amount of the total environmental impacts and costs, but conducting LCAs and LCCs during this stage is based on assumptions and incomplete data [9].

Another limitation during the design process is the many different stakeholders that need to be involved to give input to the calculation. Often different companies need to be involved as well as facility managers and contractors, which often are not included in the early design stages. It is crucial to find the right balance between involving the needed stakeholders and not spending too much time.

As the data and information needed to perform the LCA and LCCs come from many different sources it is important to have standardized methods of e.g. modelling, to allow for easy quantity take offs and calculations.

#### 4. Whole building LCA and LCC

Most of the whole building LCA and LCCs conducted in Ramboll has up until now been conducted at the end of the design process, during construction or even by the time of handover. This approach has mainly been due to the lack of experience within these early stage analyses in the market and the complexity and large amount of information required as well as due to time constraints. The reasoning has been to conduct the LCA as late as possible where the exact data is at hand and time can be saved as no design changes will occur. This approach will only be useful for benchmarking and help the client get a sustainability certification (DGNB) and does not utilize the potential of LCA and LCC as a design tool in the early stages to improve economic and environmental sustainability. The importance of life cycle calculations of both environmental and economic aspects is the ability to visualize the impact over the entire building life cycle for the client and not only the construction cost and impact. In current DGNB projects LCA and LCC studies are initiated during conceptual or schematic design on the largest building components and will be finalized during the construction stage with exact data from the contractor. **Figure 5** visualises the distribution of global warming potential (GWP) or carbon emissions between building components in a large office building in Denmark.



**Figure 5.** Life Cycle Assessment result visualising the global warming potential (GWP) related to the building components for a large office building in Denmark.

##### 4.1. Potentials and barriers related to the whole building LCA and LCC

Even though the use of LCA and LCCs as design decision tools are not currently an integrated part of the design phase, the potential of it is being recognized. This has initiated an internal global development in the company. As seen in **Figure 5** the LCA can help the designer understand where the largest optimization possibilities are. Conducting a related LCC assessment will help visualize the business perspective and cost optimization possibilities.



LCA and LCC is currently not implemented in the early design, which may be due to the lack of BIM integrated tools [10]. The lack of integration between BIM and LCA/LCC tools means that design changes must be imported manually, re-calculated and exported back into the models. The manual work is time consuming and prone to human error. However, during the testing of several BIM integrated LCA tools in Ramboll the problem occurred to be the lack of standardization of the models, which can be difficult to change when collaborating with external stakeholders. Another lack within the BIM-integrated LCA and LCC tools were the fact that the 3D models may only be available at schematic or detailed design, when design changes become increasingly difficult to make. Utilizing LCA and LCC as drivers for the entire building design in the early design phases is currently difficult due to the vast design space of interrelated data and parameters to consider. On the other hand, LCA and LCC can no longer successfully be used as a decision-making tool in late design stages because proposed design changes likely will require large costs [9]. For certification purposes an as-built model with adequate detailing is necessary for the BIM integrated design tools to give the exact quantities. These models are, however often the responsibility of the contractor and are thus not as detailed as is needed for the certification purpose. An example is that the rebar in the reinforced concrete is not modelled in 3D and the actual amount will have to be retrieved from delivery notes from the building site. Another reason to why LCA and LCCs are not integrated design tools may be due to the lack of professionals and training courses within life cycle assessments and life cycle costing [11].

## 5. Conclusion

Life cycle calculations for buildings are receiving increased attention from national building regulations like the environmental ministry of Finland announcing that building LCA will become mandatory by law in 2025 at the latest [11]. Similarly, the number of DGNB certified buildings in Denmark is increasing and thus pushing the market. The increased experience with LCA and LCCs will impact the industry to develop methodologies adapted to the different design stages, but to see an even faster transition in the industry, legislation is needed. Since 2006 it has been mandatory to calculate the overall demand for primary energy in all new buildings in Denmark, with a continuously increasing threshold. This regulation has resulted in early design simulations as an integrated part of the design process today, whereas in the beginning the calculations were made at the end of the design or during construction only. Through regulation on LCA and LCC similar changes in the industry may occur. The industry needs access to comprehensive national databases with both product specific EPDs and generic country specific data as well as regulation pushing for LCA and LCC for new buildings.

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