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Overview of Whole Building Life-Cycle Assessment for Green Building Certification and Ecodesign through Industry Surveys and Interviews

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Abstract

Whole Building Life-Cycle Assessment is a methodology whose importance has been steadily growing in the construction industry, as a reliable way to assess the environmental impacts of a building through its whole life-cycle. Life-Cycle Assessment is used by designers, architects, manufacturers, and consultants for various purposes: eco-design, the achievement of Green Building certifications, including DGNB DK, and Environmental Product Declarations (EPD). This paper will examine the current advantages and challenges of performing Life-Cycle Assessment (LCA) and Life-Cycle Costing (LCC) calculations in the building sector based on the results of 41 survey responses and 110 interviews conducted between 2016 and 2017. The survey indicated that 86.5% of respondents believe that the integration of Building Information Modelling (BIM) in the automation of Life-Cycle Assessment calculations will allow LCA to be used effectively during the building design process. Also, according to our interviewees, the integration of LCA and LCC is a considered valuable approach for building sustainability but it is mainly driven by green building certifications.

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Keywords: life-cycle assessment; life-cycle costing; ecodesign; green-building certification; EPD; BIM;

1. Introduction

While the construction industry accounts for 13% of global GDP [1], the sector is also the largest consumer of resources and waste producer [2]. Moreover, buildings are the largest consumers of energy and drivers of global warming [3]. Therefore, the construction industry faces important challenges when it comes to resource efficiency and environmental impact reduction. This has led to an increase of both official regulations [4] and voluntary certification systems [5] to control the environmental impact of the construction sector.

1.1. Life-Cycle Thinking

To understand all the impacts associated with a building, it is necessary to look at its life-cycle performance [6].

Life-cycle assessment and life-cycle costing allow to break down the environmental impacts and the cost associated with its life stages.

Life-cycle assessment (LCA) provides a reliable picture of material and building environmental impacts using science-based standardized metrics. The most known of these metrics is the Global Warming Potential, or the (life-cycle) carbon footprint [7]. In Europe, the use of environmental product declarations (EPD) standards provides a common methodological framework to calculate these metrics [8]. This is useful for regulators and certification schemes. Also, projects desiring to achieve better environmental performance can benefit from using LCA [9,10]. CEN/TC 350 provides the standards and common rules for whole-building LCA.

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Life-cycle costing (LCC) helps to understand the financial implications of material selection, construction methods, operational performance, and decommissioning. It is a tool for the comparison and optimization of building solutions [11].

This paper will start by describing the main drivers behind these methodologies and their use in the construction industry. Then, it will look into the advantages of implementing these methods to reduce environmental impacts through eco-design and the main obstacles for implementation. In conclusion, it will summarize which strategies can be used to leverage the benefits of LCA and LCC for a more sustainable built environment.

1.2. Main drivers for LCA and LCC

The implementation of LCA and LCC is driven by many factors. First of all, the fact that buildings are responsible for 35% of global carbon emissions [12] has been an increasing cause of concern and has led to increased public interest in reducing emissions [13]. Publicly listed companies have often chosen to report their emissions, for example by adopting the GHG Protocol. When it comes to the construction sector, there are two main drivers for LCC: the possibility for designers to find the most cost-efficient solutions by adopting the LCC methodology, and for building owners to reduce costs over the whole life-time of their buildings, which makes them more attractive for tenants [14]. The drivers for the adoption of LCA are related to use of Life-cycle methodology in Green Building certification schemes, and the need to assess the environmental performance of buildings in a more objective manner that will cover the total lifespan of the buildings, and not only its construction.

1.3. Why is the life-cycle approach needed?

Historically the building sector in the EU has focused on reducing operational energy consumption [15]. However, many studies show that embodied emissions in building materials can have a significant impact, as shown in Figure 1., and are actually caused by building material embodied impacts [16] and other life-cycle stages of building [17]. Figure 1 compares these case studies.

Also, improvement in energy efficiency increases the relative weight of emissions from other building life-cycle stages in comparison to operational energy consumption alone. Figure 2 shows how, after achieving significant reductions in operational emissions, construction and maintenance/repair emissions increase in proportion to operational emissions.

Therefore, the next natural step is to look at the building over its whole life-cycle [19]. LCA is the methodology that measures these impacts and allows to make design decisions for an optimal solution.

1.4. How LCA and LCC are used in construction sector

LCA measures and compares the environmental impacts of different stages during the whole life-cycle of a building. LCC measures the financial costs of different building solutions by including the present values of capital investment and maintenance/replacement costs [11]. Both LCA and LCC can be used for construction project design improvement, product development, the selection of products and product/building certification [21], strategic planning, land use and zoning regulations, public policy making, procurement, and marketing purposes. The scientific base of LCA and LCC has made them valuable tools for decision-makers.

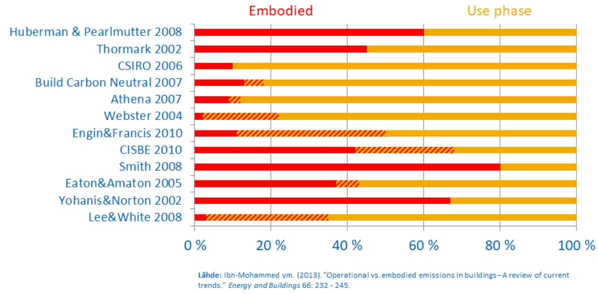

Figure 1. Building life-cycle emissions: embodied and use phase impacts [18]

At the moment there is no EU level requirement for the use of LCA. However, the Construction Products Regulation (EC/305/2011) [22] aims at harmonizing the technical specifications of construction products performance. This requires the use of standardized Environmental Product Declarations (EPDs) to estimate material emissions based on LCA.

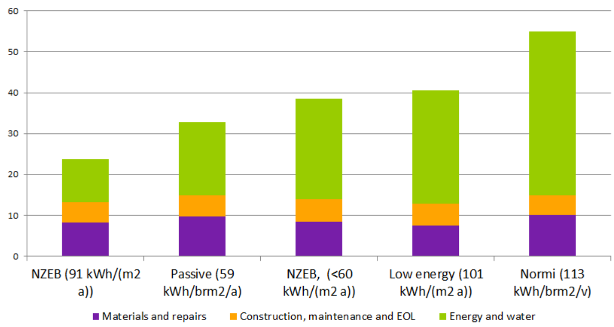

Figure 2. Carbon footprint of five apartment buildings (kgCO2e/m2/a) [20]

The basic requirements for LCA in all sectors are built upon ISO 14040 [23] and ISO 14044 standards [24]. In the construction sector, the specific requirements are found in the CEN standard family TC/350 Sustainability of Construction Works and the building LCA standard EN 15978 Sustainability of construction works [25]. The calculation method described in EN 15978 is de facto building LCA methodology.

In fall 2017, the European Commission published a framework for building sustainability performance. Level(s) is a voluntary reporting framework to improve the sustainability of buildings providing a uniform set of key indicators. It is based on European EN standards and leverages LCA methodology. Key indicators include building life-cycle carbon footprint [26].

The EN standards are the basis for any EU country level regulations. Also, the EN 15978 standard is used in almost all of the Green Building certification systems in Europe and outside Europe, including LEED (US), Green Star (Australia), and Konut (Turkey). In addition to this, the ISO 21930

Sustainability in buildings and civil engineering works is at the moment being aligned with the EN standards.

Table 1 lists some the existing Green Building certification schemes that include LCA and/or LCC as part of the overall assessment process.

The uniform LCA methodology, as defined by the standards, helps users to fulfill many different purposes. Green Building professionals can achieve points in the certification of their choice, share their environmental efforts with the public, and fulfill legislative requirements, all with the same method, which helps them understand carbon emissions and other environmental impacts

Table 1. Green Building certifications in Europe.

Certification	LCA	LCC
BREEAM (UK, NL, NOR, SE, ES, Intl)	X	X
LEEDv4	X	-
DGNB (DE, DK, Intl.)	X	X
HQE (FR)	X	
BBAC (FR)	X	
Miljöbyggnad (SE)	X	
Minergie (CH)	X	

1.4.1. Life-cycle perspective

The traditional way of improving building environmental performance has been to reduce energy consumption and to set targets for certain defined measures like waste production during construction operations. In other words, the focus has been on elements that are somehow tangible for the designers and, thus, easier to manage.

This approach does not allow a complete understanding of what actually causes the building emissions over the whole life-time, therefore making it difficult for building designers to make optimal, knowledge-based decisions. With LCA there will not be sub optimization of emissions as the whole life-time is taken into account. For instance, material emissions can be estimated analyzing the entire upstream process, and not just emissions from the manufacturer's last production process. LCA also enables comparisons between different stages to find the optimal solution that takes into account emissions over the whole life-time (e.g. choosing a higher quality and heavier flooring material might mean increased emissions and cost in the original investment but lower emissions over the whole life-time due to longer service life).

1.4.2. Holistic view of environmental impacts

By adopting the LCA methodology, there is no need to focus just on waste or certain emission category. For instance, EN standards include 24 different environmental information, including carbon footprint, acidification, and eutrophication when it comes to emission categories, but also energy, waste, water, and recycled content.

It is expected that LCA and LCC enable building investors and policy-makers to set numeric targets for building emissions instead of requiring some specific technology or material that has been proven environmentally-friendly in the past or making decisions based on marketing materials. This way the designers will have room for innovation and be able to find optimal solution to every specific building.

2. Methodology and Results

2.1. Survey and interview methodology

This paper presents information collected from a survey conducted between 2016-2017 among Green Building professionals. Moreover, it includes information from interviews and the authors' experience while working with over 150 building and building product LCA studies in Europe during the study period.

The survey was responded by 41 Green Building professionals conducting whole-building LCAs. It includes responses from project teams located in Europe, the Middle East and South-East Asia. The building types included hotels, logistic parks, office and retail buildings.

The personal interviews were conducted with building LCA practitioners and BIM experts (17 respondents) and backed up with additional interviews with 93 professionals that participated in LCA trainings conducted by Bionova Ltd. in 21 countries, mainly in Europe.

The survey and interviews sought to establish what was the purpose of carrying out an LCA. The results are summarized in Table 2.

Table 2. Purpose of LCA by interviewed professionals

Objective of LCA	% in sample
Green building certification	84%
EPD calculations	2%
CSR reporting	5%
Infrastructure project	3%
Other	6%

In addition, 50% of respondents claimed to integrate LCA and LCC in their studies due to the requirements in BREEAM and DGNB certifications. Yet, approximately 80% of participants viewed the integration of both methods as positive and necessary to deliver sustainable building improvements.

Those interviewees that mentioned carrying out both LCA and LCC described the following advantages and challenges.

2.2. Advantages of LCA and LCC

2.2.1. Support multi-stage decision-making process

LCA can be used in all different stages of construction decision-making from city planning to architectural design, structural design and commissioning.

It can be used to set targets and to verify the results after the process, which enables learning from past cases. After the construction process the same calculation method can also be used to follow up the building emissions through its use phase.

2.2.2. Combining LCA with LCC enables finding the cost optimal solutions

Finding cost optimal solutions to reduce both emissions and costs over the whole life-time helps to release the emission reduction potential. Moreover, reducing emissions in a cost-optimal way will be attractive for building owners

Finding optimal solutions ensures that we invest the available resources in the best possible way to achieve the highest potential emission reduction. This will increase the sector's capacity to reduce emissions as a whole.

2.2.3. LCA creates an incentive for manufacturers to innovate products with less emissions

A uniform, reliable method to measure products emissions and calculate them on building level enables building material manufacturers to discover their own emissions and discover ways to improve their products.

If emissions do not get measured in the building design process there will be no demand for less emitting products and, therefore, no incentive for manufacturers to reduce emissions. Using LCA in the design phase enables better design choices and improved environmental performance in the whole sector.

2.3. Challenges of performing LCA and LCC

The obstacles for whole-building LCA include:

2.3.1. Information is not timely for the design process

According to a study by Bionova Ltd., conducted in 2016 on European Green Building experts, over 40% of respondents needed 1-4 weeks to complete a LCA and 13% over a month. If several different design options were to be studied or the study was repeated in several different stages of the design process, the time would be longer.

If the time of completion for a LCA study is this long, it is unlikely to provide timely information for the decision-making process. Also, the work hours will directly increase the cost of implementation, making the new method less attractive for the cost-conscious building sector.

In addition to this, owners are reluctant to invest the time in creating alternative LCA studies when the design team has made important material specifications for the building and the LCA takes so long to produce. As a consequence, teams are not inclined to revise building specification data. In addition, the accuracy in the quantification of emissions increases through the design process. For instance, exact information on the planned building structures will be available in the structural design phase and the manufacturers of purchased materials might only be available in the commissioning stage. However, at these stages most of the important decisions for geometry, architectural choices etc. have already been made.

2.3.2. Being difficult to understand

As a numeric method, LCA does not tell if something is good or bad. To use LCA for decision-making, more than 90% of respondents believed that an understanding of the typical emissions (i.e. benchmarking) and being able to compare the impacts to a baseline are needed. This corroborated some of the findings related to the complexity of LCA, as mentioned in a 2011/2012 survey in the North American building sector [29].

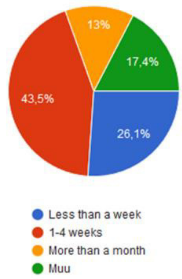

Figure 3. Actual time spent on whole-building LCA [27]

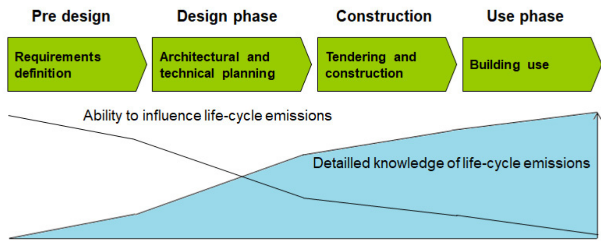

Figure 4. Ability to influence the emissions in different stages of decision making process [28]

2.3.3. Enabling non LCA experts to do the calculations reliably

In our sample cases LCA was the responsibility of dedicated Green Building consultants. However, it is normally design professionals such as architects, structural and/or mechanical engineers who have access to the information needed for LCA and enough understanding of the available design choices to find the optimal solutions to reduce life-cycle impacts. At the moment these design professionals have normally only a limited or no knowledge of LCA.

2.3.4. Availability of building LCA background data

96% of respondents considered the availability of product specific data in the form of locally relevant EPDs as a key issue in achieving high quality LCA results. This data needs to be EN 15804 based and verified.

In January 2017, there were over 3600 verified EPDs to EN 15804 for construction products registered globally [30] and the amount of this data is increasing rapidly. Out of these declarations 1500 have been published in Germany and 320 in Norway. The remaining EPDs are divided between areas, with sharp differences between countries in availability of product EPDs.

In addition to the EN EPDs users might still find old ISO standard based EPDs but their methodologies do not often fulfill the EN standard requirements, and, thus, they lack comparability. Additionally, there are some construction specific LCA data sources such as IMPACT and Oekobau.dat.

As the availability of the relevant and standards based LCA data varies highly between different building locations it might set requirements for the use of LCA data. An additional obstacle might come from estimating the LCA data reliability, which requires high level of methodological understanding that very few Green Building experts have. This is in line with the results of the 2006 survey of LCA practitioners by Cooper and

Fava, who found out that 68% of respondents found data collection the most time-consuming aspect of performing a LCA [31].

2.3.5. Ability to use existing building data efficiently

Another key issue for all respondents is obtaining building material quantity information. This kind of information is available from various sources depending on the stage of design process. Potential sources could be design or construction drawings, design specification documents, building information models (BIM), energy models, and bill of materials or quantity takeoffs but this information might be in a form that is not easily accessible or difficult to use. For example, specifications that include aggregate materials.

2.3.6. Heterogeneous requirements of various certifications

The heterogeneous requirements in various certifications schemes and regulations, like different life-cycle stages in the scope, different building area definitions, and/or different service life proved challenging for the development of cost effective tools for LCA calculations.

2.4. How to integrate LCA and LCC solutions

An important finding in our research is related to the growing use of building information models (BIM). As we will show in the next section, BIM can improve access to material quantity information linked to the design process. This allows the evaluation of multiple design scenarios from an environmental and financial points of view.

2.4.1. Automated / BIM integrated LCA enabling using various design data sources to ensure timely results

According to a study by Bionova Ltd. in 2016 for European Green Building experts 86,5 % answered that they would use LCA if it was BIM integrated. The study highlights the importance and potential of BIM and design data automation as an enabler for LCA. Integration with BIM can drop the time of LCA to minutes instead of weeks making it more attractive for building owners and designers. With automation, design experts can compare their choices in real time, design for lower emissions, and find optimal solutions in each design stage.

Different design sources provide different potential for LCA automation. This is discussed in more details in section 2.5.

2.1. Opportunities of using BIM to automate LCA

BIM are digital three-dimensional representations of buildings. The necessity for interoperability of different software tools has promoted the development of platform neutral data structures to represent building information. These include the Industry Foundation Classes (IFC), used in parametric models, and gbXML, used in energy models. Other commercial solutions include proprietary structures such as those found in Revit models.

The importance of BIM in the industry lies in its ability to improve stakeholder collaboration, save time and resources in managing building information, and facilitate energy

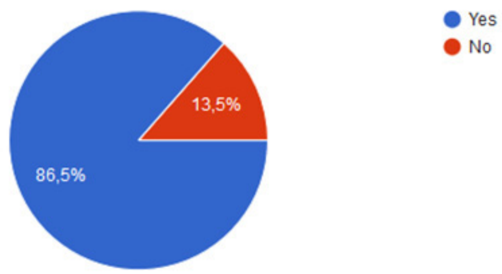

Figure 5. Respondents that would perform a LCA if integrated with BIM [32]

modelling and integration with environmental assessment tools, including LCA [33].

In the case of LCA, BIM provides the physical material data defined in the building to be matched with the corresponding environmental product data needed to calculate the environmental impacts [34].

2.1.1. BIM and quantity takeoffs for LCA

A complete architectural model will include the material data related to a building structure, its envelope or facade, and its interior partitions and finishes. Other information can also be found, such as furniture and special equipment. However, the material requirements for a LCA will depend on the certification scheme or objective of the study. For instance, a LEED version 4 compliant LCA only requires structure and envelope data. At the early design stages, any material data represents a good opportunity to start evaluating material choices.

2.1.2. Availability of building LCA background data

Design data currently available in BIM is suitable for LCA automation. The data comes in formats that provide material description and quantities that can be mapped to environmental data. Although the design data may be lacking or too extensive for LCA, the scope can be easily adjusted to provide valuable results.

Moreover, in many cases, the people doing LCA are not the designers. Yet, BIM allows for easy visualisation of design alternatives and collaboration. The LCA provides feedback by showing the materials with the highest environmental impacts. The design team can choose between material efficiency or design alternatives to reduce the overall impact.

2.1.3. Timely material data for LCA and LCC integration

In our sample, we found the integration of LCA and LCC to be mainly driven by Green Building certification requirements.

The timely availability material quantity and specification data from BIM models allows to perform cost analysis in parallel to LCA. For example, when looking at material options, the replacement costs incurred during the life-cycle of the building can be brought to their net present value (NPV). The NPV and LCA results of alternative options can be compared in order to choose the most financially and environmentally feasible option. For example, the accumulated environmental impacts of replacing materials could be higher than those more durable options that are not replaced at all. The integration of LCA and LCC will make the financial and environmental information available to decision-makers.

2.1.4. Including LCA and LCC to building sector education

Finally, all respondents agreed that this is growing field and believe that adding LCA training to the educational requirements for building professionals would help increase the knowledge on the sector and the capability to design for lower emissions.

3. Conclusions

According to the interviews, 84% of respondents considered the pursue of a Green Building certification scheme the major incentive to carry out a whole-building LCA. Moreover, certain certification schemes have promoted the adoption of integrated LCA and LCC. Yet, the level of integration is not widespread with only 50% of total certified buildings within this sample.

The integration of BIM with LCA has delivered a fast and reliable way to produce material quantity takeoffs of building design and has enabled the automated mapping of materials with environmental impact factors. This is helping realize the potential of Life-Cycle thinking for sustainable building design and construction. LCA and LCC provide effective tools for environmental and financial analysis of design options. There is still work to be done in making it easy to communicate and visualize these results for decision-making. Yet, the widespread inclusion of LCA in certifications schemes and regulations is proving an effective incentive in the development of this market.

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