Life Cycle Assessment as a tool to improve sustainability of the Flemish residential construction sector: methodology for simplified designs

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Abstract: - Improving the sustainability of our society is a growing issue of concern, as well in research, policy and industry. Also in the construction sector is a growing awareness to reduce environmental burdens. This paper starts with a description of tools to examine sustainability on a scientific basis considering the entire life cycle of buildings, like Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). Despite some inherent limitations, these instruments are useful to indicate hotspots of the environmental burdens and indicate potentials for improvements.
This knowledge will provide a basis for a new project to evaluate sustainability of the Flemish residential construction sector. First, an evaluation will be made of the current practice by cooperating with project developers, since they work with more standardized designs. The main topic will be modeling simplified standard designs, which are representative for the Flemish context. Then, the results will be used to formulate possible improvements, both for the individual companies as for the current and future policy and subsidies.

Key-Words: -Life Cycle Assessment, Residential Construction Industry, Flemish Project

1 Introduction

Enhancing sustainability of our society and securing the future of next generations are growing issues of concern, as well in research, policy as in industry. To achieve this, the current situation should be improved from an ecologic, economic and social point of view. Since the publication of the report 'Our Common Future' by the World Commission on Environment and Development (WCED), also known as the Brundtland Report, sustainable development has gained much attention in all nations [1]. In the report, sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This general increasing awareness led to the Kyoto-protocol, an international agreement on reducing the emission of greenhouse gasses and global warming [2]. In the construction sector, this resulted in, for instance, regulations to decrease energy consumption of dwellings and consequently their ecological burdens, i.e. the Energy Performance of Buildings

Directive 2002/91/EC (EPBD, 2003) and the revised EPBD 2010/31/EU (EPBD, 2010) issued by the European Union [3], [4]. These regulations stimulate the reduction of energy consumption, but before any conclusions can be drawn on sustainability, the entire life cycle has to be taken into account. By executing a Life Cycle Assessment (LCA), the environmental burdens of a product or a process can be evaluated considering the whole life cycle, from cradle to grave [5]. All aspects considering natural environment, human health and resources are taken into account and together with the life cycle perspective, this avoids problem-shifting between different life cycle stages, regions and environmental problems. A similar tool exists to examine financial aspects, namely Life Cycle Costing (LCC).

This paper starts with a discussion on LCA methodology and its limitations and the current situation of research on sustainability in the construction sector. The next step will be implementing this knowledge by starting up a project to evaluate sustainability of the Flemish residential construction sector by modeling a set of simplified standard designs, which are representative for the Flemish context, and analyze possible future developments arising from the implementation of new European standards.

2 LCA Methodology

In current practice LCAs are executed within the framework of the ISO 14040 series [5]. To analyze the environmental burdens of processes and products during their entire life cycle, four steps have to be run through, making it possible to compare different studies: goal and scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and an interpretation [6], [7].

Goal and scope define purpose, objectives, functional unit and system boundaries. The second step (LCI) consists of collecting all data regarding inputs, processes, emissions, etc. of the whole life cycle. Third (LCIA), environmental impacts and used resources are quantified, based on the inventory analysis. This step contains three mandatory parts: selection of impact categories depending on the parameters of goal and scope, assignment of LCI results to the selected impact categories (classification) and calculation of category indicators (characterization). Nowadays there is a large set of impact categories commonly used, i.e. global warming potential (GWP), but ISO 14044 states that when the existing categories are not sufficient, new ones can be defined. LCIA also contains two optional parts: normalization and weighting. Normalization is the calculation of the magnitude of category indicator results relative to some reference information, for example the average environmental impact of a European citizen in one year. Weighting is the process of converting indicator results of different impact categories into more global issues of concern or into a single score, by using numerical factors based on value-choices, e.g. based on policy targets, monetarisation or panel weighting. The fourth and final step is the interpretation of the results [5], [7].

Although ISO-standards describe the global framework of a LCA, the exact method to be used is not defined. The latter depends on goal and scope of a research. When analyzing results of a LCA this can be confusing as different methods applied to an identical case can generate different results, e.g. a narrow scope carbon footprint study versus studies with a set of more differentiated impact indicators [8], [9]. Various methods can assign a different importance to properties or impacts, which can result in other suggestions of action to reduce the ecological impact [10]. Results of a Life Cycle Assessment are no absolute values and therefore can not serve as a certification on itself. They do not guarantee the sustainability of a product or service, but are valuable for the comparison of different products and processes. Comparing results of a LCA is only meaningful when the subjects fulfill exactly the same function, i.e. the functional unit.

The methods described in the previous paragraph can be subdivided into two types, attributional and consequential LCA. Attributional LCA is defined by its focus on describing the environmentally relevant flows within the chosen temporal window, while consequential LCA aims to describe how environmentally relevant flows will change in response to possible decisions [11], [12]. Generally, most authors state that consequential LCAs are more appropriate for decision-making, unless their uncertainties in the modeling outweigh the insights gained from it [13], [14]. When LCA is used to indicate hotspots of the environmental burdens as base for improvements, the consequences of these implementations should not be neglected. Such actions will influence the production of upstream products, other life cycles and more in general, other economic activities. Both positive and negative mechanisms can occur. If efficiency measures are profitable, economic activities may increase and diminish the environmental benefits. This negative mechanism is also called a rebound effect [15]. A positive mechanism is that investments in emerging technologies are likely to reduce manufacturing costs, which can trigger similar investments of other manufacturers [12]. If such a new technology has a lower impact, this can entail huge savings for the entire society and in that case a consequential approach is more appropriate.

In addition, two extra steps can be included besides the mandatory steps of a LCA, namely a sensitivity check and an uncertainty analysis. The first one is to verify the robustness of results by varying parameters, choice of data, assumptions or impact assessment methods to check if the results are still valid. If not, this has to be documented. The uncertainty analysis investigates the reliability and completeness of the model, also referred to as parameter uncertainty. Since a LCA is always a simplification of reality, the calculated uncertainty range and distribution gives insight in the reliability of results. However data quality indicators are sufficiently available, e.g. in the Ecoinvent database, this step is often excluded in LCAs in the construction sector [16]. Parameter uncertainty is also often enhanced by data gaps, resulting in less accurate data to be used. These elements limit the reliability of results, but with the degree of uncertainty known, still useful conclusions can be drawn. In addition to parameter uncertainties, LCA has some other limitations as well. Despite its scientific basis, when quantifying and interpreting environmental impacts, some value choices have to be made. Even if they are formulated by experts, such choices will always be subjective. Next, a LCA is always a simplification of reality, which entails other types of uncertainties too, namely model and scenario uncertainties. Since they are difficult to process statistically, they are often excluded. Finally, executing a detailed LCA is very time consuming, so it is important to find a balance between the simplifications and the required level of accuracy, especially at complex systems with a long lifetime, i.e. buildings.

3 LCA in the construction sector

In industrial processes, LCA is widely spread and used frequently to evaluate the environmental impact of products and processes. In the construction industry however, such a study is much more complex because of the long lifespan of buildings (50 – 100 years [17], [18]), a shorter lifespan of some elements, the use of many different materials and processes, the unique character of each building, the distance to different factories, etc. [18]. Since the building process is less standardized than industrial processes, such a Life Cycle Assessment is a challenging task.

The growing importance of LCA as an analytic environmental tool in the construction sector is illustrated by the number of recent case studies of entire buildings [17–19]. Most studies are simplified LCAs which only consider energy consumption during the different phases of the life cycle: embodied (production and construction), operational, demolition and recycling energy. They are also known as Life Cycle Energy Assessments (LCEA). Less frequent are regular LCAs, full or partial, which are executed employing a wide variety of methods, which are sometimes linked to policy targets. A discussion on these methods is beyond the scope of this review.

The parameters of these case studies vary substantially, but nevertheless some general trends can be indicated. A conclusion of almost every study is the dominance of the use phase, especially due to energy consumption for heating and cooling. The share of the use phase of standard houses is in the range of 60 - 90% of the total environmental burdens, mainly with a contribution to global warming potential [20], [21]. A common recommendation of these studies is therefore the necessity of reducing the need for heating and/or cooling by improving insulation, air-tightness and controlling ventilation. All these aspects are put into practice in low-energy houses. Several studies analyzed the impact of measures in this kind of buildings, however only on dwellings so far. Blengini and Di Carlo investigated a low energy dwelling in Italy. Although the energy consumption was 10 times lower than the reference standard house, the total environmental impact was only reduced by a factor 2.1 [16]. So when the energy use is pushed back, the other phases of the life cycle grow in importance, i.e. construction concepts, choice of materials and end-of-life scenarios. Citherlet and Defaux mention that it is only relevant to pay much attention to the indirect impacts, like construction and demolition, when the yearly energy consumption is below 150 MJ/m² [22].

As new buildings are designed more energy-efficient, a next step in research is to pay more attention to the growing relevance of the other phases. Thormark focused on the recycling potential and the concept 'Design for disassembly', while Blengini examined the demolition of a flat to verify and/or complete the LCA literature data [8], [23–25]. Both studies show the benefits of reuse in the first place, which is slightly superior to recycling, yet they do have reservations about the feasibility of reuse on a large scale.

Another frequent conclusion is the minor importance of the transportation of materials during the construction stage. Almost all studies included this aspect, but as building materials are often locally produced, the travel distances and associated impacts are limited, 1 % or less according to Adalberth and Ortiz et al. [20], [26]. Even when some parts are transported over a long distance, this impact does not play a major role [16]. Only when almost all materials are transported over a great distance, transportation becomes an issue of concern, which can be seen in the research of Chen and Burnett. Materials of two analyzed office buildings in Hong Kong are mostly imported, often overseas, as can be seen in the contribution of transportation, which represents 7 % of the total environmental burdens [27].

4 Research opportunities in the Flemish residential sector

A drawback of current LCA practice in the construction sector is the isolated approach of environmental issues. Often the focus is limited to the search for environmental optima, without linking it to other aspects. For example, LCA does not take into account any quality, energetic, structural nor esthetic requirements. Also economic feasibility is rarely taken into account. A second remark on the current practice is the predominant attention for single case studies. Although this kind of studies give insight in the distribution of environmental burdens over the different phases of a life cycle, they do not evaluate the situation on a larger or regional scale. In this field, more research is needed to evaluate current situation and develop future scenarios. The next part of this paper contains a proposal for such a new project, evaluating the sustainability of the Flemish residential construction sector, both on environmental and economic aspects, also including energetic and structural requirements. The main goals will be to get a clear picture of the sustainability of current practice and indicate hotspots for improvement.

In Belgium dwellings are the most dominant kind of constructions: 82% of all buildings were residential buildings at the start of 2008 and also a great part of new buildings are residential, with an average of 84% of the building permits over the last 13 years [28], [29]. So focusing on residential buildings seems to be an obvious starting point.

Since each design is unique, it is impossible to examine all dwellings, so modeling more general types of houses is the only realistic option. Therefore is decided to collaborate with Flemish project developers. On one hand they work with more standardized designs and construction techniques, on the other hand they can provide the most accurate data on these standard dwellings, like expected quantities of materials, cutting losses, layout, structural properties, etc. It is not the intention to focus on one special aspect, but to cooperate with a wide range of developers and contractors, to cover all commonly used building concepts, designs and techniques. This way an overview can be created of the current situation and hotspots for improvements can be identified. Modeling the simplified standard designs will be done based on the expertise of the project developers. For each company, two models will be made according to their most used construction methods. The first one has the average net floor area of a Flemish dwelling, the second one a net floor area of the average dwelling built by the company. This way it will be easier to compare results.

When evaluating the results, different viewpoints are possible. First and most common is only evaluating different building concepts, i.e. standard versus low-energy houses, masonry versus timber frame,… Second, this kind of research can be carried out on a regional scale. The advantage of the latter is to take such studies to a next level by comparing different companies who are active in the same field, i.e. which company has the most efficient and environmental friendly way of building standard houses and how come? Which techniques and concepts turn out to be the most efficient? The latter can also be examined with the design as starting point. As stated by Allacker in a recent Flemish study, the design has often more influence in an optimization (economic and ecologic) than material choice, level of insulation or construction techniques [29]. So the third point of view could be focusing on the design, i.e. are energy efficiency measures - like compactness, air tightness and optimizing solar gains - commonly taken into account, besides aesthetic, insulation and structural requirements? Which design choices can play a major role in reducing ecologic burdens and does this entail also economic advantages?

To investigate the sustainability of the dwellings, two criteria will be taken into account: the ecological and economic aspects. Integrating the third aspect of sustainability, namely social issues, is beyond the scope of this project. As mentioned before, research will be carried out by combining existing tools and methods of LCA and LCC. A deeper analysis of LCC is beyond the scope of this research, as the main goal of this project is to reduce the environmental impact with the economic feasibility as a reality check. However on both fields tools are sufficiently available, they are barely combined despite the multiple advantages. This way, it will be possible to calculate the economic impact of actions for improvement. Even though some proposals may look excellent from an environmental point of view, if the additional costs are too high, one can be sure they will never be implemented on a large scale. Such a combined approach can also work the other way round, to convince clients of the advantages of environmental improvements, especially when they reduce costs over the entire life cycle. For example, even it is commonly known insulation reduces the cost of heating, still this tool can be useful to demonstrate, on a scientific basis, the benefits of insulating. And maybe insulating more than imposed by regulations is more interesting from an ecological and economic point of view. Further, such an approach can also serve as a basis for policy on subsidies.

Obtaining an overview of the current situation will not be the endpoint of the project. The results can provide a basis for improvements on the level of companies and at the same time they can be used to evaluate Flemish policy in the construction sector and to suggest improvements, both on current regulations, subsidies and future policy goals. The first depends on the goodwill of the companies and are more likely to be based on the economic savings of actions, even though marketing issues may play a role too. As the topic of sustainability is gaining importance in the public opinion, some project developers may want to present themselves as 'green contractors' if they score well. The second possibility is to evaluate current and future policy and associated regulations. Is the current EPBD 2010/31/EU the economic-ecological optimum or does this depend on the building practice of the project developers? Are project developers today already trying to achieve zero-energy buildings as the standard will be in 2020? And are regional regulations relevant, like the requirement to install green roofs in Antwerp for new buildings and renovations [30]?

Another potential for optimization is broadening the scope beyond reducing energy consumption. As Allacker states, when buildings become more and more energy efficient, the contribution of water consumption gains relatively in importance [29]. The impact of water consumption equals 18 % for a non-insulated dwelling and up to 88 % for a low-energy dwelling of the burdens of heating. Until now, the impact of water use has barely been investigated from a life cycle point of view.

As this project tries to give insight in possible evolutions on a larger scale, it might be useful to analyze actions for optimization with a consequential approach in the LCA part. To evaluate regulations, it might be useful to see their impact on other sectors.

5 Conclusion

In the construction sector sustainability is gaining importance as can be seen in the implementation of new regulations and the growing output of academic research. To evaluate this issue on a scientific basis, analytic tools as LCA and LCC have become indispensable, despite some inherent limitations. So far, multiple studies on buildings have been carried out over the past few years, mainly focusing on energetic optimization of residential buildings. Notwithstanding the differences of these studies, some general conclusions can be drawn: the dominance of the use phase, the growing importance of other phases of the life cycle as energy efficiency increases and the negligibility of transportation.

Although these studies and their conclusions are valuable to identify hotspots and suggest measures of improvement, they often focus only on environmental issues. To get a more coherent picture, other aspects like economic feasibility play an important role too. This paper is a starting point for a Flemish project trying to connect all these elements by modeling simplified standard designs. The main goal is to evaluate current situation in the residential construction sector and the current policy. The next step will be to formulate possible improvements, both on the level of policy as individual companies. The usability of the final output has to be verified on a macro scale, according to the consequential approach, before reaching final conclusions.

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