Evaluating the sustainability of the Flemish residential construction sector: methodology for simplified designs

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***Abstract*—**Last decades there is a growing awareness for enhancing the sustainability of our society, either in research, policy and industry. This evolution has also affected the construction sector with 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 environmental burdens and indicate potential improvements. From current academic case studies some overall trends can be derived: the dominance of the use phase, the growing importance of other life cycle phases, as energy efficiency of buildings increases, and the negligibility of transportation.

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 collaborating 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. In this model, there will be worked with distributions instead of deterministic values, to improve the reliability of the results. Then, the results will be used to formulate possible improvements, both for the individual companies as for the current and future policy and subsidies.

***Keywords*—** Life Cycle Assessment, Residential Construction Industry, Flemish Project.

I. INTRODUCTION

ENHANCING the 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 actions to reduce 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.

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II. 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. One of the strengths of LCA is defining the investigated products and processes based on their function instead on their specific physical characteristics. This way, products can be compared which are inherent different, but fulfill a similar function i.e., paper towels versus reusable cotton towels for drying hands. The second step (LCI) consists of collecting all data regarding inputs, processes, emissions, etc. of the whole life cycle. Thirdly (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. Depending on the nature of research, different methods can be chosen, defined by their environmental mechanisms [7]. Such a mechanism is the process for any given impact category, linking the LCI results to category indicators i.e., a sequence of effects that can cause certain level of damage to the environment. These category indicators can be combined to more comprehensible and general indicators. The valuation factors used in environmental mechanisms are the difference between LCA methods, as they may assign other importance to the same physical values.

To quantify environmental impacts two approaches can be identified, namely the problem-oriented (midpoints) and damage-oriented (endpoints) ones [8]. The first group of methods uses values at the beginning or middle of the environmental mechanism. Impacts are classified on environmental impact categories such as global warming potential, acidification potential, ozone depletion potential, etc. This type of method generates a more complete picture of the ecological impacts, but requires good knowledge of LCA to interpret the results. The second group is at the end of the mechanism, where the midpoints are grouped into general issues of concern such as human health, natural environment and resources, which eventually can be calculated into a single score. The results of the latter are easier to understand, but tend to be less transparent [9], [10]. Another drawback of the endpoint approach is the use of more subjective factors in the conversion to general categories. This will entail greater uncertainties and affect the reliability of the results.

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 approaches to calculate environmental impacts 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 examined in more detail and 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 i.e., in the Ecoinvent database, this step is often excluded in LCAs in the construction sector [9]. 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.

III. LCA IN THE CONSTRUCTION SECTOR

In industrial processes, LCA is widely spread and used frequently to evaluate the environmental impact of products and processes [16]. 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 [17–21]. 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. Even in very different climates this conclusion appears to be valid, as studies in Nordic and Mediterranean countries come to similar results [22–24]. 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 [25], [26]. 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 ten times lower than the reference standard house, the total environmental impact was only reduced by a factor 2.1 [9]. 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 [27].

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 [28–31]. Both studies show the greater 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. In line with this kind of research are the studies on potential benefits of renovating and retrofitting existing buildings. This construction concept is gaining importance as can be seen in Belgian statistics: the share of renovations increased by more than 30% over the last 15 years. Also in absolute terms there was an increase in number of renovations, whereas the number new constructions declined [32]. With older buildings it is more likely thermal, comfort and aesthetic requirements are not met, so major adaptations are often required. However many parts of such buildings can still be in good condition i.e., the main structural parts. The studies point out that retrofitting is in general more eco-friendly, but urban regulations sometimes limit optimal interventions, especially if they are applied on the outside of the building i.e., additional insulation [33].

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. [22], [23]. Even when some parts are transported over a long distance, this impact does not play a major role [9]. 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 [34].

The previous sections demonstrate that in current academic practice, only general trends can be derived from the examined studies, because buildings are not directly comparable. All these studies are executed according to the framework described in the ISO 14040 series applicable on all types of LCA studies. As life-cycle thinking becomes more integrated in policy and marketing, there will be a need for a more delineated framework, specifically for buildings. Beside academic research, there is an evolution at the regulatory level in order to improve the comparability of studies on sustainability and provide a basis for certification. In the last decade, there are developments specifically for the construction sector, in addition to the ISO 14040 standards. In 2003, SETAC published a state-of-the-art report on Life-Cycle Assessment in Building and Construction, an outcome of the Life Cycle Initiative [35]. This study highlights the differences between the general approach of LCA and LCAs of buildings. Standardization continued, with two leading organizations: the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN). The first, more specifically the ISO Technical committee (TC) 59 '*Building Construction*' and its subcommittee (SC) 17 '*Sustainability in Building construction*', published four standards describing a framework for investigating sustainability of buildings and the implementation of EPD's [36]. The CEN Technical Committee (TC) 350 '*Sustainability of construction works*' is developing standards for assessing all three aspects of sustainability (economic, ecological, social) both of new and existing construction works and for the environmental product declaration of construction products [37]. A main goal of these standards is documenting environmental performance of a building for use in, for example, certification, declaring environmental performance, labeling and marketing. As stated by CEN TC 350 in EN 15978:2011, '*the purpose of this European Standard is to provide calculation rules for the assessment of the environmental performance of new and existing buildings*' [38]. These rules consist of the description of system boundaries, procedures to be used for the inventory analysis, a list of environmental indicators and procedures for the calculation of the impact categories, rules for reporting and communicating results, etc.

When talking about sustainability, also other aspects have to be taken into account: beside the ecological component there are also two other cornerstones, namely economic and social items. To date such a holistic approach has barely been implemented. Some studies combine ecological (LCA) and economic (LCC) features, but the incorporation of the social side (SLCA) is still in its infancy [39–41]. The previous mentioned regulation EN 15978:2011 is part of an umbrella

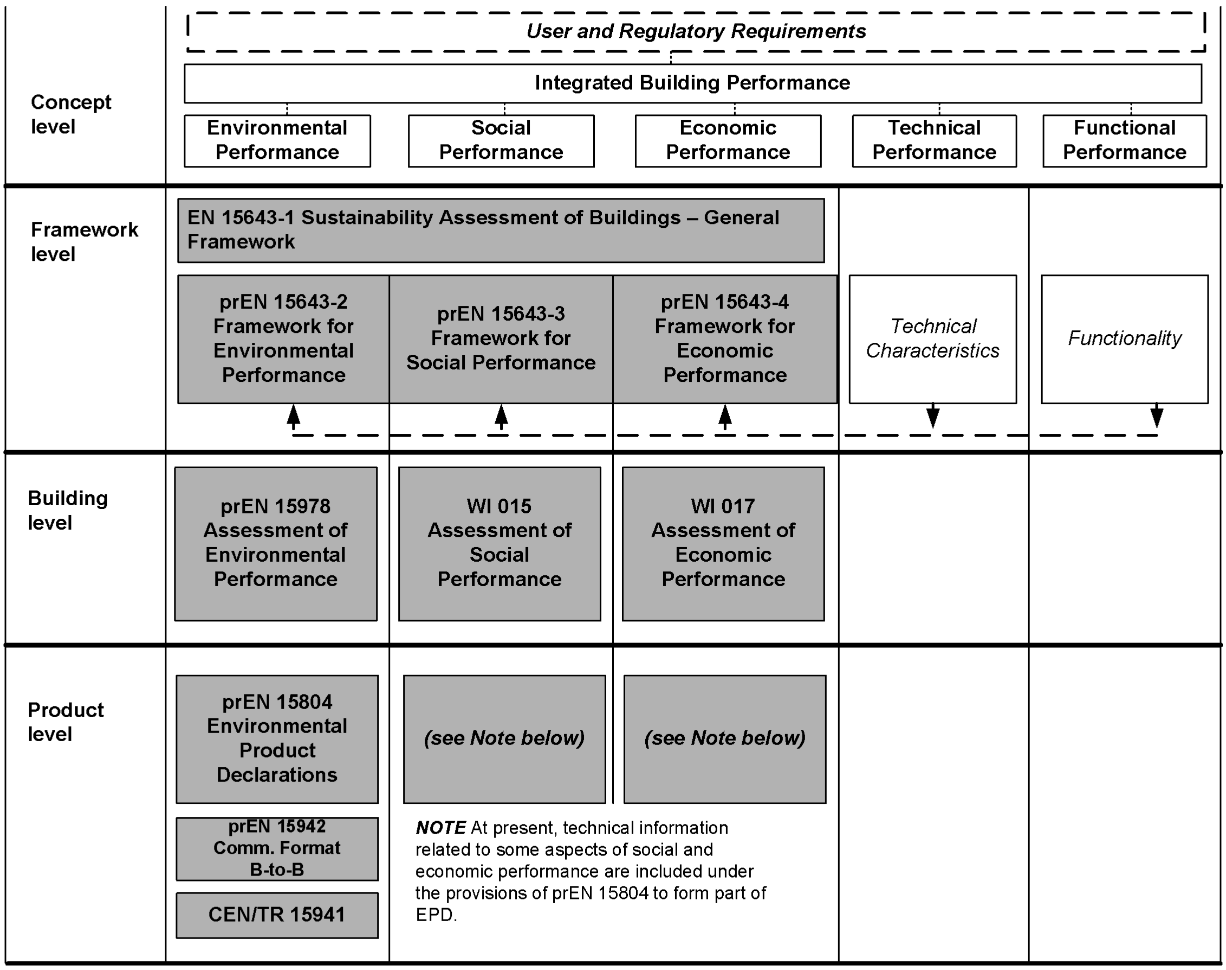

Fig. 1 framework of CEN TC 350

framework, developed by CEN TC 350, to improve and facilitate the integration of all aspects of sustainability, see in figure 1.

A second advantage of this umbrella framework, is the alignment of studies at different levels. For example, the methods for analyzing buildings, products and components are very similar (impact categories, system boundaries, etc.), which encourages and facilitates the incorporation of results of external studies at product level (EPDs) in studies at building level.

IV. Research opportunities in the Flemish residential sector

A. Project description

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, but with the newly developed framework by CEN TC 350 this will change hopefully. 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 to 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 [39], [42]. In Flanders households have a share 36 – 40 % of the total energy consumption, and the residential sector in Belgium produces about 40 % of the emitted CO2 [43], [44]. So focusing on residential buildings seems to be an obvious starting point, carried out according to the CEN TC 350 framework.

Since each design is unique, it is impossible to examine all Flemish dwellings, so modeling more general types of houses is the only realistic option. In order to still obtain representative results, a balance is needed between simplifications of the model and hard data from the building sector. 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 of current practice, but to collaborate 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. The advantage of the first type of models is the comparability between companies, with the net habitable surface as functional unit. The results can serve as an indication of environmental awareness of the project developers in relation to others in Flanders. On the other hand, the second type of models is very useful to formulate improvements at company level.

A second aspect of this project will be the type of used data that are mostly deterministic values in current practice. Although such values often come from averages and national statistics, more research is needed to evaluate if they are representative for any specific case study. A study of Aktas and Bilec investigates the influence of the assumptions on the functional lifetime: they considered the expected lifetime as a distribution based on data published by the US Census Bureau, used extensively for building related statistics, and compared the results with deterministic data derived from average values [45]. They state that the use of distributions instead of deterministic values for the lifetime of products and buildings improves accuracy of the study and make results more objective. A second conclusion of this research is the observation that a product's actual lifetime is usually different than the one the product was designed for and that this is basically determined by consumer behavior. So this approach can partly overcome the uncertainties caused by user behavior. It is obvious this entails a huge potential for improving the reliability of LCA results.

The most important conclusion of section III is the dominance of the use phase, but the values of the energy consumption are assumptions strongly dependent on user behavior. A major challenge of this project is to incorporate the use of distributions by collecting on actual energy consumption, supplemented by additional information on the profile of inhabitants, occupancy rate of the dwellings, household composition, etc. Other aspects e.g., water use, transport loads and distances, cutting waste, etc. should also be evaluated by using parameter distributions. However a major problem can be the lack of data.

When working with more abstract models, it will be easier to vary different parameters, like design features, orientation, compactness, used materials, etc. At the one hand this can serve as a kind of sensitivity check, on the other hand such an approach of optimizing can generate significantly different results than simply improving existing case studies. This results can provide a better understanding of sustainable building, but a reality check is needed before any conclusions can be drawn.

The methodology of working with a framework based on simplified models, distributions instead of deterministic values and flexible optimizations linked to reality offers a great tool to get a complete picture of the sustainability of the Flemish construction sector. Yet one must keep in mind the results can not serve as an calibrated statement or certificate, they facilitate the comparison of studies executed according to EN 15978:2011.

B. Possible outcome

When evaluating the results, different viewpoints are possible. First and most common is evaluating different building concepts i.e., standard versus low-energy houses, masonry versus timber frame,… This approach is very similar to the current academic approach, although the conclusions can be different due to the local construction traditions. In Flanders for example, there is a strong focus on the use of masonry cavity walls. Due to the proximity of usable materials and producers, the environmental profile of this sector can diverge from the information of international accepted databases (cfr. Eco-invent).

Second, this kind of research can be expanded to a bigger scale. The advantage of the latter is to take individual 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 environmentally friendly way of building standard houses and why? Which techniques and concepts turn out to be the most efficient? Which techniques entail also financial benefits, for the companies itself or for potential clients? The outcome of the latter must also be investigated on a regional scale, as positive results can trigger an evolution that goes beyond modifications of a company.

Evaluating the models can also be carried out with the design as starting point. As stated by Allacker in a recent Flemish study, the design has often more influence in an optimization (economical and ecologic) than material choice, level of insulation or construction techniques [39]. This research includes 16 case studies (four typologies, four historical time periods) and an overall conclusion points to a greater influence of the design on the sustainability to building period and technical improvements. So the third point of view could be focusing on the design, which is perfectly possible with the flexible model. This way it is possible to investigate the design related influences of different aspects. We could address this by finding an answer to the next questions: 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? Is the potential for improvement only based on the reduction of the energy consumption and using passive solar techniques or play other aspects a role too? Design decisions may require a specific use of materials, will some esthetic choices best be avoided from an environmental point of view?

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 (1) to reduce the environmental impact (2) with the economic feasibility as a reality check and (3) to stimulate the commitment of companies to participate at this project. 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. Different scenarios for a payback time can be calculated of investments, depending on the expected evolutions of prices for materials, energy, etc. For example, even it is commonly known insulation reduces the cost of heating, still this tool can be useful to demonstrate the science-based benefits of insulating, and even maybe more insulating than imposed by regulations is more interesting from an ecological and economic point of view. By analyzing possible benefits with science-based tools, it may be possible to increase social support for environmental issues. Further, such an approach can also serve as a basis for policy-makers when defining legislation and subsidies.

Obtaining an overview of the current situation will not be the final goal of the project. The results can provide a basis for improvements at 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, either on current regulations, subsidies and future policy goals.

The first depends partly on the goodwill of the companies and are more likely to be based on the economic savings of actions (immediate profits and/or subsidies), 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, or building concept? Is there a significant difference between European regulations and the Flemish implementation? Are project developers today already trying to achieve zero-energy buildings as the standard will be in 2020 and is it relevant to focus on zero-energy buildings? Maybe this way other important eco-impacts will be neglected? And are regional regulations relevant, like the requirement to install green roofs in Antwerp for new buildings and renovations [46]?

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 [39]. 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. The current available data are averages per household, but it is logical to apply a similar method as for the energy consumption, using distributions.

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.

V. Conclusion

In the construction sector sustainability is gaining importance as can be seen in the implementation of new regulations, internationally recognized frameworks 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 and material choices of residential buildings. Notwithstanding the differences of these studies, some general conclusions can be drawn: the dominance of the use phase especially at standard houses, 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. To achieve this, there will be worked with simplified and standardized designs, developed in association with project developers. To guarantee and improve the reliability of the results, dominant aspects like lifetime, energy and water consumption will be evaluated on the basis of the distributions. This way one gets a better insight into the reliability of the results.

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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