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Use of life cycle assessments in the construction sector: critical review

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Abstract

A life cycle assessment (LCA) is an internationally accepted and useful tool to assess the environmental impact of products. In this paper, the use of LCA in the construction sector has been critically analyzed. The analysis is based on specific literature cases and different standards and frameworks. As an example, a detailed comparison of four LCA studies for structural concrete is presented. LCA is one of the most promising techniques for an ecological design of products. However, in order to appeal to the benefits of LCA, it is important to know how to use LCA properly. From the review in this article it becomes clear that the LCA research is still in a fragmented state, due to the existence of various unspecific guidelines and different interpretations of those guidelines. Since for example the international standards on LCA, ISO 14040/44, only provide a global framework, and no exact technique to calculate environmental impacts, it is possible to create an LCA with different boundary conditions. Hence, a valuable comparison between distinct LCAs is difficult. Comparisons should thus thoughtfully be performed, taking into account all information about the LCAs under study. When this background information is communicated transparently, LCAs can be interpreted correctly.

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Keywords: Construction sector; life cycle assessment; ecology; sustainability; EPD; review.

1. Introduction

According to the United Nations Environment Programme (UNEP) three planets will be necessary by 2050 to bear the world consumption and our way of life. This will be the case if the current consumption and production is

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continued, taking into consideration the growing population [1]. Hence, in several fields, there is an increasing focus on sustainability in general and on the environmental impact of different processes in various sectors. In the European Union, approximately three billion tonnes of waste are generated each year. About one-third of this waste (i.e. one billion tonnes) has its origin in construction and demolition activities [2]. Moreover, the building industry is responsible for the consumption of more than 40 percent of the world energy and for approximately one-third of the emitted greenhouse gasses worldwide [3]. This "sector" consumes about 25 percent of the global wood harvest and approximately 40 percent of the materials entering the global economy. Every year, the construction sector uses three billion raw materials [4]. These facts reveal that the building industry has a large, negative impact on the environment. It is necessary to identify how this consumption, pollution and waste processing is caused, in order to address the causality of these issues.

To thoroughly analyze these causalities, a frequently used and generally accepted method is the life cycle assessment (LCA). This system is used to evaluate the possible environmental impacts and used resources throughout the whole life cycle of a product: starting from the extraction of resources, to the production and use phases up to the waste processing [5]. The introduction of LCAs in the construction industry is highly important since this system can systematically and objectively evaluate and quantify each ecological impact [6]. As such, LCA is one of the most promising techniques for an ecological design of a product.

Since the beginning of the 21st century, the interest in LCAs has increased strongly. This is reflected in the wider application of this methodology. Moreover, the use of LCA is further encouraged by incorporation in recommendations of authorities and the increased use of LCA on policy level [7,8]. For example, the Integrated Product Policy (IPP) has in this context been developed by the European Commission [9]. In 2002, the United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) launched an International Life Cycle Partnership, known as the Life Cycle Initiative (LCI). This partnership enables users from all over the world to put life cycle thinking into effective practice [10].

Despite the different advantages of LCA causing this increased interest in the topic, various drawbacks still exist. To be able to clarify the use of LCA in the building industry, an extensive literature review has been carried out for this paper. Based on this review, a general background of LCA in the building industry is presented in this paper, together with a focus on advantages, recurrent drawbacks and possibilities to solve problems.

2. General regulatory context

The general standards in the context of LCA, ISO 14040:2006 and ISO 14044:2006, describe and specify respectively the principles and framework, and the requirements and guidelines for LCA [5,11]. These standards describe the four main phases (Fig. 1) of an LCA, of which the first is the definition of the goal and scope. In this first phase the purpose of the study, the system boundaries and the definition of the functional unit (FU) have to be determined. The FU should be defined very accurately, since all of the inputs and outputs are calculated per functional unit. To enable fair and equivalent comparison of two products, each system should thus be composed according to the exact same functional unit. In this context of comparability, attention should also be paid to other requirements, such as a closer look at the system boundaries and allocation principles. [12].

The second phase of an LCA is the life cycle inventory (LCI). This is the data collection process of all relevant inputs and outputs of a product life cycle. In this phase, it is important to work with very accurate data, since the accuracy of the final results of the life cycle assessment strongly depends on the life cycle inventory data [13].

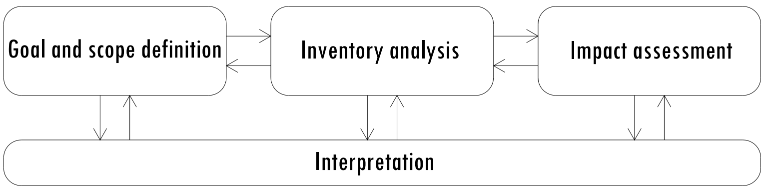

Fig. 1: Stages of an LCA according to NBN EN ISO 14040.[

Thirdly, the life cycle impact assessment (LCIA) will evaluate potential environmental impacts and used resources, based on the data of the LCI phase and depending on which impact assessment method is used. Basically, there are two types of methods in conducting an impact assessment: the problem-oriented (or midpoint) methods and the damage-oriented (or endpoint) methods. Midpoints are considered as a point in the cause-effect chain (environmental mechanism) of a particular impact category, prior to the endpoint. To nuance the midpoint results, characterization factors can be calculated to reflect the relative importance of various specific emissions or extractions in the LCI. However, LCA studies that require a combination of impact categories will often acquire endpoint methods [14].

The fourth and final step in an LCA is the interpretation which identifies significant issues, evaluates results in order to draw conclusions and provides recommendations [6]. The three last phases all refer to the goal and scope definition. This complete procedure should be applied as an iterative technique, in which collected data and information may imply a modification of the scope in order to meet the original goal of the study [5].

This abstract summary of these four stages in LCA reveals that the international LCA standards are precise in some points, but leave room for interpretation in others. In this context, it is important to know that ISO never aimed at defining the exact methods for creating an LCA, by stating in ISO 14040 as one of the key features of an LCA that 'there is no single method for conducting LCA' [5,15].

3. Drawbacks in LCA

Being one of the most functional assessment tools, LCA is used regularly in the architectural and construction industries to assess sustainability. However, presently there are still some shortcomings of LCA in general and for building-specific LCAs. Some of these overall complications with LCA are discussed in the following section of the paper, after which a closer look will be taken to issues with the use of EPDs and building rating systems.

3.1. Obstacles and problems

A first obstacle is the existence of several different databases with which LCAs can be performed. These databases contain inventory data for complete supply chains, i.e. specific information about the inputs and outputs related to the processes in the LCA [16]. The databases are owned by different companies which maintain their own data. Hence, the absence of a reference database results in gaps and overlaps between the databases. These gaps and overlaps create issues of quality and comparability of the LCA results [17].

Recently, a study has been published in this context, which reviews LCA databases that focus on construction materials [16]. The authors analyzed the methodology, documentation, data quality and comprehensiveness of the databases. According to this study, only a few of the existing LCA databases contain information about construction materials. Further results of the study [16] show clearly that Ecoinvent [18] and Gabi Database [19] surpass other databases through their integrity, usability and dedicated resources. However, when comparing Ecoinvent and Gabi, based on a case study performed in 2014, it becomes clear that the mutually numerical results can still differ significantly between these two generic databases [20].

A second obstacle occurs in the LCIA, the third stage of life cycle assessment. In the LCIA, the results of the LCA can be defined using an endpoint method, as mentioned above. To calculate the results using the endpoint method, "weighting" must be applied to combine separate impact categories. This weighting is a value-based process that represents the scientific interpretation of the importance of each separate impact category. The structure of this scientific interpretation goes along with ideological, political and ethical principles. As a matter of fact, the weighting makes the results of an LCA subjective, since the weights are often defined by a group of professionals who only rely on their general knowledge.

Despite the subjectivity, weighting provides also a great benefit, since it is helpful in decision making. By means of the weighting, endpoint methods show a single-value result which helps decision makers to better understand the differences between the environmental impact of various options [21]. A similar consensus was reached at an international workshop in Brighton in 2000: "Both endpoint and midpoint methodologies have complimentary merits and limitations, they both provide useful information to the decision maker. Midpoint indicators are more certain but can have a lower relevance for decision support in some cases. Endpoint indicators were argued to often have a higher relevance but lower certainty" [14]. In any case, researchers should take into account the fact that the weighting factors vary depending on economic, cultural and social conditions [22], and when choosing the weighting factors, some criteria should be taken into account, as described by Johnsen and Løkke [23]. Because of these restrictions, some researchers still prefer to work with alternatives for weighting factors, such as indicators based on laws of physics [24].

The third and fourth obstacles concern respectively the end of life phase, and the lack of benchmarks in the construction sector. During the life cycle of a building product many types of waste are produced, depending on the product under review and the life cycle stage in which the waste is produced. Taking into account the recycling of this waste in the LCA may result in negative values for impacts, which can reduce the overall impact of a building. However, the methods to account for recycling activities are not yet well integrated in LCA tools [21]. This is important, since the way in which the recycling activities are accounted for, can greatly affect the LCA results. The other, fourth, issue is the absence of well-defined benchmarks in the LCA analysis of buildings in many parts of the world. This is unfortunate, since benchmarks can be very useful in providing a basis for comparison of existing products, and in evaluating the performance of new ecological alternatives [21].

3.2. The use of EPDs

In Journal of Industrial Ecology, Bo Weidema raises the question whether ISO 14040/44 has failed its role as a standard for LCA [25]. This questioning is based on the fact that there exist different guidelines that aim to define more explicit rules to perform an LCA of specific product groups. These types of guidelines are called Product Category Rules (PCRs). Unfortunately, different PCRs sometimes cover the same product categories, but include different interpretations of ISO 14040/44. In this way, the standard does not fulfill its role to minimize or eliminate unnecessary variation, and failed in this respect according to Weidema.

PCRs are used to compose Environmental Product Declarations (EPDs). These declarations are, according to ISO 14025, Type III environmental declarations [26] and are widely used by product manufacturers in the construction sector to report the environmental impact of their products. In this context, EN 15804 has been developed by the European Committee for Standardization (CEN/TC350) to define more specific rules for EPDs of construction products [27,28]. These specific rules are necessary, since the number of "Type III environmental programs" —"the bodies supervising and administrating the development of PCRs and verifying EPDs under a Type III Environmental Declaration Programme (also known as EPD schemes or EPD operators)" [29] — has grown steadily in recent years. While until 2002 only seven operators were active, a fivefold increase by the end of 2013 has been observed in a study by Minkov et al. [29]. The PCRs associated with these programs cause an increasing overlap and duplication among each other. This does not only confirm what Weidema points out, but this causes also a risk to the legitimacy of environmental claims.

According to the previous paragraph, it can be seen that EPDs are being used frequently. Minkov et al. analyzed 39 EPD schemes and show that 56% of these have a European origin (followed by North America (28%) and Asia (8%)). Of the analyzed EPD schemes, 44% is generic, and next to this, the "building and construction" related programs hold a large share of the total amount (36%). EPDs are not only a useful instrument in this sector, but this large share originates also in newly introduced requirements for green building certification. For instance, LEED, the rating system of the US Green Building Council, awards additional points to projects that use products verified with EPDs that meet predefined criteria [30].

Moreover, Subramanian et al. developed a comparison template to compare PCRs from different global program operators, and a broad selection of product categories [31]. Based on this comparison, Subramanian et al. conclude that there is indeed a lack of consistency, as mentioned before in this current paper. The disparity between PCRs of the same product category range from broad differences in system definition (scope, system boundaries, impact assessment) to specific variation of technical elements. These differences can be due to contrasting purposes of the PCR, the application of different standards, the use of other product categorization systems, or simply methods being developed independently. From this angle, it is interesting to perform a comparison of two versions of an EPD considering the same product. Such a study was published in 2012 by Modahl et al. This study highlights the importance of precise definitions regarding data quality in EPDs. The paper shows that there are substantial variations arising from using two datasets with different degrees of specificity: generic and specific data [32]. Furthermore, when comparing the Ecoinvent generic database with an EPD database developed in France for construction materials, Lasvaux et al. indicate deviations of different magnitudes at the database level, depending on the LCIA indicators and the building materials [33]. The results of these studies illuminate the fact that it is necessary to avoid comparisons of products based on different assumptions.

3.3. LCA building rating systems

Since the early 1990s the construction sector has seen an emergence of tools that aim to develop environmental certifications of whole buildings. This induced an acceleration of changes in construction practices [34,35]. Fowler and Rauch give the following definition of these rating systems: "tools that examine the performance or expected performance of a 'whole building' and translate that examination into an overall assessment that allows for comparison against other buildings" [36]. These rating methods have become a popular research field, but an international tool which allows the assessment of buildings in different regions of the world, taking into account differences in climates, topographies and cultures has not yet been developed [35]. Banani et al. indicate that the most popular and globally used schemes are BREEAM (Building Research Establishment's Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design), Green Star, CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) and Estidama [37]. Each system defines its own categories that have to be analyzed and evaluates these categories according to different assessment methods (and thus weighting factors). In this way the results of an evaluated building by one rating system is not comparable to the evaluation based on another rating system [38].

4. Evaluation and comparison of four case studies

4.1. Background information

Life cycle assessments in the construction sector are a complicated issue. Evaluating the drawbacks listed earlier in this paper, it becomes clear that these problems are the result of the complexity of LCA. When trying to compare distinct LCAs performed by different researchers, it is important to consider the background information of each study carefully. To illustrate this, the following section presents a comparison of four different LCA studies [39−42] which all concern the material concrete. Summarizing elements of these studies are shown in Table 1.

The first study [39] regards cradle-to-gate LCAs by Tait and Cheung of three concrete mix designs containing different cementitious blends. A part of the article is subdivided into the four phases of LCA as prescribed by ISO 14040/44. Furthermore, the system boundaries are clearly defined in a separate section. The goal of the mentioned study is to make a comparison between the three concrete mixtures and thus to help industry make key decisions in mix designs. In this way, a further objective is to achieve lower CO_2 emissions.

In the second study [40], Knoeri et al. analyze a cradle-to-gate LCA of 12 recycled concrete mixtures with two different cement types, and compare this with corresponding conventional concretes for three structural applications. Here, the sequence of the four different LCA phases is also respected. This study's objective is to perform a comparative LCA of conventional concrete (CC) and recycled concrete (RC) to analyze the effect of cement content and transport distances. In this way the researchers can provide policy recommendations for construction waste management and support construction stakeholders' decisions.

The third study [41] consists of an LCA by Sjunnesson which concerns two types of concrete: an ordinary mixture and a frost-resistant mixture. An extra focus has been put on the effect of superplasticizers. The LCA is a cradle-to-grave LCA in which the use phase has been neglected. Since this study has been executed in 2005, the study is based on the older version of the standards, ISO 14040-14043. Moreover, no databases or software have been used: a literature study was the source for LCI data and conversion indicators.

For the fourth study [42], previous research of the authors of the current paper has been taken into account. The LCI for this analysis is based on specific information of a Belgian producer of prefabricated, prestressed concrete elements, and on the Ecoinvent database. The study has been performed according to the four LCA stages, and aims to analyze an ecological alternative for the traditional production of prefabricated, prestressed concrete elements.

4.2. Attempt at comparison

Although all four studies consider LCAs of concrete and are all based on the ISO standards, different issues appear when trying to compare the studies. A first occurring problem is the composition of the concrete mixtures. Of course, the mixtures in the different articles are not equal, since these mixtures are composed according to the specific goals of the respective studies. However, all four studies use at least one concrete mixture that can be assumed conventional, and which will be used for further comparison. These mixture compositions are shown in Table 2.

Table 1: Summary of comparative elements of four studies concerning LCAs of concrete [39−42]

	Tait and Cheung [39]	Knoeri et al. [40]	Sjunnesson [41]	Dossche et al. [42]
Year published	2016	2013	2005	2015
Software + database	SimaPro 8 Ecoinvent 3.01	Ecoinvent 2.2 Unknown	LCI and LCIA data based on literature	SimaPro 7 Ecoinvent 2.0
Functional Unit (FU)	1 m³ of concrete	1 m³ concrete of a specific strength class at the construction site	1 m³ of concrete	1 m³ of concrete with a service life of 50 years
System boundaries	Cradle-to-gate	Cradle-to-gate	Cradle-to-grave, without use phase	Cradle-to-gate with options
Allocation mentioned?	GGBS and FA: only processing and transportation emissions	Allocation is avoided by system expansion and substitution (cfr. ISO 14044)	Allocation for macadam production. Other allocation: included in LCI data	Mass and economic allocation
Transport	- All transportation by road - Estimation of transport distances of the materials to the concrete plant: assumed as typical for the UK	- Average transport distances to the concrete plant: typical Swiss information - Additional transport distances for the RC options - Transport sensitivity analyses for some components	- Typical transport distances for Sweden - All transport by (medium) heavy trucks, except 'cement to depot': by ship	- Transport by road, by river and by sea - Typical transport for Belgium
Impact assessment	- Eco-indicator 99 - EPD 2008 - Ecopoints 97	- Eco-indicator 99 - Ecological Scarcity 2006 - GWP and ADP	- Indicators included: GWP, EP, AP, POCP, toxicity of superplasticizers	- Eco-indicator 99 - EPD 2008

GGBS = Ground granulated blast furnace slag	C&D waste = Construction and Demolition waste	EP = Eutrophication potential
FA = Fly ash	ADP = Abiotic depletion potential	AP = Acidification potential
RC = Recycled concrete	POCP = Photochemical oxidant creation potential	GWP = Global warming potential

A second issue appears in the LCIA phase: the studies use different impact assessment methods and -categories to present the impact of their mixtures on the environment. To be able to compare the studies adequately, only the overlapping categories can be incorporated in the comparison. The values for these overlapping categories are summarized in Table 3. For this, the values of Sjunnesson [41] had to be calculated by hand, with the help of the LCI data and characterization indicators provided by Sjunnesson.

To obtain comparable results in Table 3, a third issue had to be overcome. The different studies initially analyze a different proportion of the life cycle of concrete, as summarized in Table 1 under 'system boundaries'. Since the studies by Knoeri et al. and Tait and Cheung consider only a cradle-to-gate study, the results of the other two studies were adapted in order to also reflect a cradle-to-gate study. In this way, Table 3 shows the results for Sjunnesson with abstraction of the LCI data for demolition. In addition, in the study by Dossche et al., only the results for a cradle-to-gate were accounted for in Table 3.

When evaluating and comparing the values in Table 3, it becomes clear that all values of the same impact category are more or less of the same order of magnitude. As a matter of fact, these results are now comparable as a result of, firstly, comparing LCAs with the same functional unit, and secondly, taking into account the above mentioned issues. Still, the LCIA results remain more or less different, which can be explained by different use of data, contrasting transport distances and various means of transport, slightly different system boundaries, other impact assessment methods (especially in the case of Sjunnesson), older or newer information, and other influencing factors. The larger values for global warming potential (GWP) of Tait and Cheung's study and of the research by Dossche et al. most likely arise from a larger use of Portland cement.

Table 2: Conventional concrete mixtures of four compared references [39−42]

Tait and Cheung	"Mix 1: CEM I" kg/m³	**Knoeri et al.**	"Outdoor CC" kg/m³	**Sjunnesson**	"Ordinary concrete" kg/m³	**Dossche et al.**	"Mixture 4" kg/m³
Portland Cement	380	**Portland Cement**	300	**Cement**	295	**Cement**	335
Limestone aggregate							
10/20-mm	615	**Natural aggregates**	1890	**Natural gravel**	1093	**Coarse aggregates**	1194
4/10-mm	413						
0/4-mm fine aggregate	806			**Macadam**	749	**Fine aggregates**	832
Plasticizer	2	**Additive (superplasticizer)**	3.3	**Super-plasticizer**	1.51	**Additives**	0.8
		Filler (fly ash) *(avoided disposal)*	-20				
Water	190	**Water**	105	**Water**	202	**Water**	127

CC = Conventional concrete

Table 3: LCIA per FU (i.e. 1 m³ of concrete) of four compared references [39−42]

	Tait and Cheung	Knoeri et al.	Sjunnesson	Dossche et al.
Eco-indicator 99 [Pt]	13.9	9.76	-	14.8
GWP [kg CO_2 eq]	339 (EPD 2008)	278	273.5	330 (EPD 2008)
EP [kg PO_4--- eq]	0.14 (EPD 2008)	-	0.09	0.10 (EPD 2008)
AP [kg SO_2 eq]	0.54 (EPD 2008)	-	0.62	0.57 (EPD 2008)

4.3. Conclusion of the evaluation

Out of the evaluation of the four different studies, it becomes clear that no study can be accounted as equal to another, since there will always be a very specific goal attached to each study. According to this goal, different assumptions and decisions are made. However, when taking into account the broad background information listed in the papers about the composition of the LCAs, an attempt can be made to compare the results. Here, it is important to always consider every single issue mentioned to make a fair comparison.

When performing such a comparison of LCAs, the comparative elements should be fair and equal. Tait and Cheung for example compare in their own study [39] three different concrete mix designs, and make sure that all three mix designs are capable of producing equivalent mechanical performance and durability. For example, all three concrete mix designs have the same water/cement ratio and the same overall binder content. Moreover, the LCAs are in that specific study performed according to the same system definition. Taking into account all these similar boundary conditions, the comparison made by Tait and Cheung can be assumed fair.

This fairness is not always strived for. For instance, a study in 2009 about an environmental analysis based on LCA of bridges in the Netherlands [43] had to be renewed in 2013 [44], since the results of the first study created a large discussion about the correctness of the comparative elements. This implies that producers who try to make their products more sustainable than others, have to strive for sustainability in a correct manner. In this way, the producers do not lose their credibility, and, moreover, an attempt to achieve true and fair sustainability can be made. In order to attain correctness, it is important to incorporate all the information which is necessary to fully understand the life cycle assessment. The functional unit, boundary conditions and impact assessment method cannot be omitted. Next to this, it is important to mention information about the composition of the LCA, such as details about allocation, transport, software and databases. Only when this background information is communicated transparently, an LCA can be understood completely and can induce correct reporting. In addition, sensitivity and uncertainty analyses can be a useful tool to cope with assumptions and uncertainties, and to inform others better.

5. Assets and solutions in LCA

Life cycle assessments provide a holistic approach of product environmental impacts, since the methodology accounts for the whole life cycle of a product or service. It is interesting to obtain such an overall view of the life cycle to identify the major sources of environmental impact. Furthermore, the implementation of LCA can support designers, engineers and decision makers in their work, by providing an analytical environmental evaluation [6]. Moreover, LCA is capable of analyzing products and processes based on their function instead of on their specific physical characteristics. Consequently, products that are inherently different, can still be compared when they fulfill a similar function [8].

Because of these benefits, the LCA methodology remains a very valuable system and is it worthy to solve the earlier mentioned drawbacks worldwide. In Europe, for example, several standards are being developed to stimulate horizontal standardized methods for the assessment of the sustainability aspects of construction works. The two leading organizations for this are the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN). The ISO/TC 59/SC 17, or Technical Committee (TC) 59 with subcommittee (SC) 17 'Sustainability in buildings and civil engineering works', has published several standards defining a framework for analyzing sustainability of buildings and the implementation of EPDs [45]. Next to this, the CEN/TC 350 'Sustainability of construction works' has developed standards for the sustainability assessment of buildings (EN 15978), as well as for relevant product information (EN 15804) [28]. These standards, and other standards written by CEN/TC 350, provide a system for the environmental, social and economic performance of buildings. The purpose of this series of European standards is to enable comparability of the results of an LCA. The construction sector is for example the only sector for which the impact indicator selection process in the LCIA phase has been harmonized [17].

In addition to this positive evolution, researchers around the world try to provide answers to the drawbacks of LCA. Concerning the earlier mentioned first problem, i.e. the various databases on which an LCA can be based, Takano et al. opine that it is more realistic to develop reporting and communication systems for LCA results, rather than trying to unify the methodologies among the databases. According to these authors, the development of open databases on a national level would be helpful. Moreover, two important goals for the further development of databases are first to enrich the number of data, and second to attach to this data transparent background information [20].

In its turn, the benchmark problem is mostly being addressed on a national basis, since the practices in the construction sector can vary widely from region to region. Moschetti et al. present for example a methodology to define reference values based on the analysis of four exemplary Italian residential categories. In Belgium, the Public Waste Agency of Flanders, OVAM, in collaboration with many other institutes, seeks to communicate transparent information about the Environmental Performance of Materials used in Building Elements. In this way, decision makers in the field of constructions obtain knowledge that is required for objective and transparent creation, selection or support of eco-friendly material solutions. As a result, information which is specifically related to the Flemish-Belgian building methods and scenarios can be shared [46].

Concerning the problem with EPDs, Passer et al. tries to illuminate the differences in EPDs and the different programs. These authors present an overview of the EPD programs in five European countries. According to this comparison, it can be seen that more similarities than differences exist. All EPD programs are based on EN 15804, and some countries are working on an (additional) national appendix of this standard because of national legislations or particularities.

Next to this, the existence of many environmental claims results in the necessity for clarification and harmonization, at least on a regional level. The ECO Platform is the first step to obtain such harmonization on the EPD level [47]. In its turn, the Product Category Rule Guidance Development Initiative tries to develop a PCR guidance document to enhance and harmonize the development of PCRs [48].

As earlier mentioned, comparisons between different buildings in different countries cannot yet be performed by a rating system due to local and regional differences. This is also recognized by the European Commission since it funds the project 'Open House'. This project is about creating a methodology for LCA that enables comparisons and ratings of various buildings in different local contexts [49].

6. Conclusions

Despite the existence of a global framework about life cycle assessment, the standards ISO 14040 and ISO 14044, there are some elements which are not defined precisely enough. The standards only provide a global framework, and no exact technique to calculate environmental impacts. Due to these elements, it is possible to conduct an LCA in various ways. As a result, the LCA research is in a fragmented state. However, life cycle assessments are still internationally accepted and are a useful tool to assess the environmental impact of a product, based on its life cycle. The importance of LCA in the construction sector is still increasing, inducing a more frequent use of this tool. In this respect, the occurring problems are internationally addressed in various ways. In the meantime, it is important to communicate about life cycle assessment research in a transparent way, with as much information as possible. In this way life cycle assessments can be interpreted correctly.

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