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LCA DATABASE OF STEEL BUILDING TECHNOLOGIES

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Abstract: This paper aims at presenting one solution for the main constrain that is hindering the use of LCA in the building sector. The main constrain is the lack of environmental data for most building materials, products and technologies, including steel products and steel-based building systems. Based in the work of CEN TC 350 and in the work of iiSBE Portugal in the development of the Portuguese rating system SBTool^{PT}®, this paper will present and discuss the development of a method to simplify LCA for effective use during the design phase. The presented method is based in the development of an LCA database that covers most of the building technologies used in buildings in Portugal, including steel assemblies.

1. Introduction

The use of improved materials and building technologies can contribute considerably to better environmental life cycle and then to the sustainability of the constructions.

An environmental product declaration (EPD) is a communication tool that provides quantified information of the potential environmental impacts of a product or process, through a life cycle assessment (LCA). The information can regard aspects such as raw material acquisition, energy use and efficiency, content of materials and chemical substances, emissions to air, soil and water and waste generation. EPDs do not provide an evaluation of the environmental performance but are a comprehensive and transparent set of environmental information covering a predefined set of life cycle stages. An important advantage of using EPDs is the possibility to add LCA-based information in the supply chain. This feature makes EPDs particularly valuable for the building sector where the final building is based on a large number of materials, construction products, semi-manufactured products and processes.

According to ISO 14025, Environmental Product Declarations act as a basis of information for life cycle assessment. Therefore this is a fundamental source of information for building sustainability assessment and certification.

LCA is as a usable approach to evaluate the environmental impacts of products or processes during their whole life-cycle. It is basically quantitative, and it considers the material and energy flows. The methodology has been developed and used for tens of years, but it was only standardized in the mid-to-late 1990s', by the International Organization for Standardization (ISO14040). The LCA fits at best to the level of single product or material, but it is generally accepted to be applied for construction products and whole building, too. Environmental performance is generally measured in terms of a wide range of potential effects, such as: global warming potential; stratospheric ozone depletion; formation of ground level ozone (smog); acidification of land and water resources; eutrophication of water bodies; fossil fuel depletion; water use; and toxic releases to air, water and land.

It is widely recognised in the field of Building Sustainability Assessment that LCA is a much more preferable method for evaluating the environmental pressure caused by materials, building assemblies and the whole life-cycle of a building. Although there are several recognized LCA tools, these tools are not extensively used in building design and most of building sustainability assessment and rating systems are not comprehensive or consistently LCA-based. Reasons for this failure are above all related to the complexity of the stages of a LCA. Besides of being complex, this approach is very time consuming and therefore normally used by experts at academic level. For these reasons most of the building sustainability assessment methods are relied on singular material proprieties or attributes, such as recycled content, recycling potential or distances travelled after the point of manufacture [1].

The adoption of environmental LCA in buildings and other construction works is a complex and tedious task as a construction incorporates hundreds and thousands of individual products and in a construction project there might be tens of companies involved. Further, the expected life cycle of a building is exceptionally long, tens or hundreds of years. For that reason LCA tools that are currently available are not widely used by most stakeholders, including those designing, constructing, purchasing or occupying buildings. Due to its complexity most of them are used and developed only by experts, most times only at academic level.

In order to overcome this situation, most popular rating systems simplified LCA for practical use. The simplified LCA methods currently integrated in rating systems are not comprehensive or consistently LCA-based but they are playing an important role in turning the buildings more sustainable. Nevertheless, the LCA approach is not the same in the different sustainability assessment methods and therefore the results of the environmental performance assessment are not the same nor comparable. It is necessary to integrate more accurate environmental assessment methods in order to verify if the required performance has really been achieved, to accurate compare solutions and to compare the results from different rating systems [2].

In order to standardize, facilitate the interpretation of results and comparison between different building sustainability assessment methods developed within the European Countries, European Centre of Normalization (CEN) started on the Technical Committee 350 (CEN/TC 350 – Sustainability of construction works). The document EN 15643-2:2011 (Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance) is a part of the a suite of European standards, technical specifications and reports written by CEN TC 350 that will assist in evaluating the contribution of buildings to sustainable development through the assessment of the environmental performance of the building. In these standards the assessment methodology is based on a life cycle approach for the quantitative evaluation of the environmental performance of the building. For now these standards are specific for buildings but, with the necessary adaptation, their approach could be adopted to any type of constructions.

The two most important barriers for the quantification of the environmental indicators and therefore to the incorporation of LCA in rating systems are: a lack of LCI data for all building products and the inherent subjectivity of LCA. Environmental Product Declarations (EPDs) are a good source of quantified information of LCI environmental impact data. In order to potentiate their use, rating systems should be based in the same LCA categories, as stated in the CEN standard. Nevertheless, at the moment, there are important limitations on this approach, since there is only a small number of companies either having or making publicly the EPD of their products.

This paper proposes a solution to overcome the abovementioned problems that is based in the development and use of databases with the LCA data of the most used building materials and components. Therefore, based in the work of CEN TC 350 and in the work of iiSBE Portugal (in the development of the Portuguese rating system SBTool$^{PT®}$), this paper will present and discuss the development of an LCA database with the environmental data for conventional and non-conventional Portuguese building solutions, including steel construction elements (macro-components). A macro-component is, according to our definition, a component of a building for which a technical specification can be given in relation to a set of essential structural characteristics and that is actually a combination of various materials.

The developed database is continuously updated and covers common building technologies for each building macro-component (floors, external walls, partition walls, roofs, windows and doors), the most used building materials and the impacts of the transportation processes, according to the used type of transportation.

2. The framework of the LCA database

2.1 Environmental impact categories

The number and type of environmental impact category indicators are different in the several sustainable assessment methods. There is a wide range of impact category indicators, normally categorized according to the endpoints or the midpoints. Endpoints are also known as damage categories and express the effect of the product in the Human Health, Ecosystems Quality, Climate Change and Resources. LCA methods that use this type of impact categories are damage oriented and they try to model the cause-effect chain up to the endpoint, or damage, sometimes with high uncertainty. The midpoints, also referred as indicators, express the environmental effects between the emissions and resource extraction parameters, from life-cycle inventory (LCI), and the damage categories. These impact categories are used in the classic impact assessment methods to quantify the results in the early stage of the cause-effect chain to limit the uncertainties. Midpoints group LCI results in the so-called midpoint categories according to themes as “destruction of the stratospheric ozone layer”, “acidification of land and water resources” or “global warming”.

LCA can be incorporated into rating systems for buildings to quantify environmental burdens associated with the manufacture of building products. Such burdens include the consumption of primary resources and the output of gaseous, liquid, and solid wastes. Most of the rating systems use midpoint impact categories but do not assess the Building and Construction’s environmental performance in a LCA consistent way, because they do not include LCA-based indicators.

Three examples of rating tools that integrates LCA-based Environmental Performance Criteria are: SBTool, Green Globes and Code for Sustainable Homes. Nevertheless, they use a simplified LCA approach to promote its practical use.

SBTool incorporates LCA into its criteria as referred in Table 1. The environmental performance is based on the embodied energy of building products and assemblies, quantified per unit floor area [3]. User can both select the LCI data or an external LCA tool to calculate the embodied energy [4].

Green Globes incorporates LCA into several of the used criteria, as outlined in Table 1. LCI data for building materials are developed by the ASMI [5]. However, documentation describing the methodology in which points are awarded based on LCI data is not publicly available.

Table 1: SBTool, Green Globes and Code for Sustainable Homes LCA-based Environmental Performance Criteria [9]

Rating system	Category	Aim	Criteria
SBTool	Non-renewable primary energy embodied in construction materials	To minimize the embodied primary energy used in the building	Meet threshold for embodied energy of structure, envelope and major interior assemblies, as determined by LCA
Green Globes	Low Impact System and Materials	To select materials with the lowest life cycle environmental burdens and embodied	Select materials for structural, roof and envelope assemblies that reflect the results of a 'best run' LCA
	Minimal Consumption of Resources	To conserve resources and minimize the energy and environmental burdens of extracting and processing non-renewable materials	Specify materials from renewable sources that have been selected based on a LCA Specify locally manufactured materials that have been selected based on a LCA
Code for Sustainable Homes	Environmental impact of materials	To encourage the use of materials with lower environmental impacts over their lifecycle	Credits are awarded depending on the LCA performance profiles of the building materials and components used in the building

Code for Sustainable Homes encourages the use, in housing construction, of materials that have less impact on the environment, taking account of the full life cycle [6]. The credits are obtained for choosing a specified proportion of major building elements that have a high environmental performance. To assist the user, the system integrates a handbook that provides a "green" guide to specification of construction materials for housing which is both easy to use and soundly based on LCA studies of the environmental impacts of different materials [7].

Unlike the three presented rating systems, an example of a popular rating tool that does not incorporate LCA criteria is LEED. Rather, the criteria for building products are based on percentage requirements established through pilot projects conducted in the late 1990s [8].

The differences between the environmental impact assessment approach in the several rating methods – because some of them are not LCA-based, not based in a reliable LCA method (because do not integrate the most common impact categories) or do not share the same impact categories – turns difficult the comparison of results from different rating systems.

The goal of the work undertaken by CEN/TC 350 standardization mandate is to overcome this problem at the European level, through the development of an approach to voluntary providing environmental information for supporting the sustainable works on construction. This technical committee set the environmental indicators that should be used in the European building sustainability assessment methods. The aim of the list of the impact categories is to represent a quantified image of the environmental impacts and aspects caused by the object of assessment during its whole life cycle. The assessment approach of the CEN standards is applicable to new and existing buildings. It provides a calculation method that covers all stages of the building life cycle (assembly, operation and disassembly phases) and the list of environmental indicators is developed in such way that potentiates the use of the LCI data issued from Environmental Product Declarations (EPDs).

According to EN 15942:2011 (Sustainability of construction works - Environmental product declarations - Communication format business-to-business), the environmental parameters to be declared in a EPD are organized in three types: i) parameters describing environmental impacts; ii) parameters describing resource input; iii) additional environmental information describing different waste categories and output flows. Table 2 presents the environmental parameters to be declared according to this standard.

Table 2: Environmental parameters according to EN 15942:2011

Parameters describing environmental impacts
– Global warming potential (GWP)
– Depletion potential of the stratospheric ozone layer (ODP)
– Acidification potential of soil and water sources (AP)
– Eutrophication potential (EP)
– Formation potential of tropospheric ozone (POCP)
– Abiotic depletion potential (ADPelements) for non fossil resources
– Abiotic depletion potential (ADP-fossil fuels) for fossil resources
Parameters describing resource input
– Use of renewable primary energy excluding renewable primary energy resources used as raw materials
– Use of renewable primary energy resources used as raw materials
– Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)
– Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials
– Use of non renewable primary energy resources used as raw materials
– Total use of non renewable primary energy resources (primary energy and primary energy resources used as raw materials)
Parameters describing resource use, secondary materials and fuels, and use of water
– Use of secondary material
– Use of renewable secondary fuels
– Use of non renewable secondary fuels
– Use of net fresh water
Other environmental information describing waste categories
– Hazardous waste disposed
– Non hazardous waste disposed
– Radioactive waste disposed
– Use of net fresh water
Other environmental information describing output flows
– Components for re-use
– Materials for recycling
– Materials for energy recovery
– Exported energy

In future, all standardized European sustainability assessments should consider the same list of indicators, the new sustainability rating systems should be consistent with it and it is expected that the existing ones will be adapted to this new approach. The Portuguese building sustainability assessment method (SBTool$^{PT®}$) it is already updated according to the requirements of this standard. Therefore the developed LCA database covers the six parameters that describes environmental impacts: i) Global warming potential (GWP); ii) Depletion potential of the stratospheric ozone layer (ODP); iii) Acidification potential of soil and water sources (AP); iv) Eutrophication potential (EP); v) Formation potential of tropospheric ozone (POCP); vi) Abiotic depletion potential (ADP).

2.2 Time boundary of the LCA analysis

As presented in Figure 1, a typical life cycle of a building can be separated into three distinct phases, each consisting of one or several life cycle stages. The assembly phase refers to the collection of raw materials through resource extraction or recycling, the manufacture of these raw materials into products, the assembly of products into a building, the replacement of building products and assemblies, and intermediate transportation. The operation phase refers to heating and electricity requirements, water services and other services excluding material replacement. The disassembly phase refers to the decommissioning and demolition of the building, the disposal/recycling/reuse of building products and assemblies, and intermediate transportation steps. Each life cycle stage can consist of many unit processes.

The LCA database for building technologies covers the "cradle-to-gate" impacts, i.e. the environmental impacts from the raw material extraction to the manufacturing of building products and assemblies and the disassembly phase. Additionally, the database covers the environmental impacts derived from the transport of the demolition waste to the treatment units and with its treatment. The considered processes are highlighted in Figure 2.

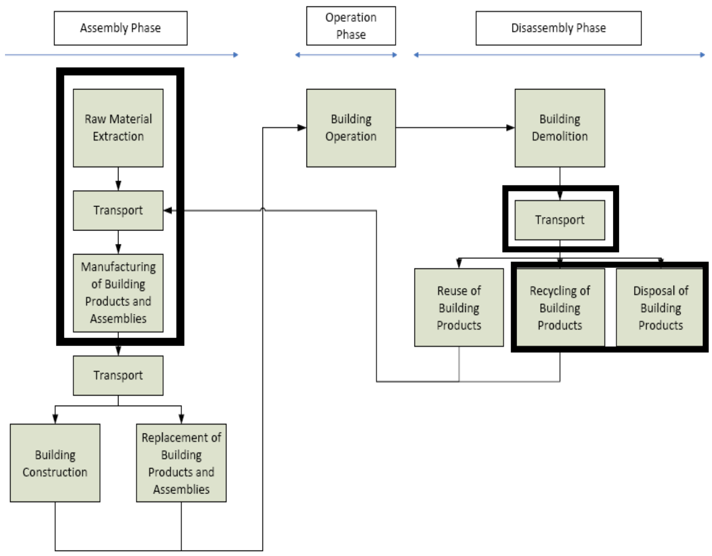


Fig. 1: Life cycle of a building [9]

2.3 Life-cycle inventory and waste scenario

The inventory analysis entails the quantification of the flows for and from a product system. In traditional life cycle environmental analysis, the inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. Taking into consideration the aims of this approach, the production and final destination of waste should also be included in the inventory. Therefore the database presents the quantified potential environmental impact categories for the embodied flows (cradle-to-gate) and the flows of the end-of-life scenarios, based in data from the companies that manufacture the materials and components.

Table 3 presents the considered end-of-life scenario, which is based in the Portuguese average context. In this context, the building materials that are normally recovered after demolition are the steel-based ones. The LCA database also covers the potential environmental impacts of the transportation processes, according to the used type of transportation.

Whenever was not possible to found specific inventory data related to a process, average European databases (generic data) was used (e.g. EcoInvent and IDEMAT). Nevertheless the database is prepared to be updated whenever specific LCI data for a product is communicated from a manufacture.

Table 3: Considered waste scenarios

Material/waste	Waste scenario	Percentage
Reinforcing steel	Recycling	80%
Steel in profile	Recycling	95%
Other	Construction waste (inert) to landfill	100%

2.4 Life-cycle Environmental Impact Assessment (LCIA)

According to EN ISO 14044, Life Cycle Environmental Impact Assessment (LCIA) is a phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. Impact assessment should address ecological and human health effects together with resource depletion. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts. Therefore, this tasks aims to convert the LCI data collected into potential environmental impacts using one or more normalized LCIA methods.

As above mentioned, this database covers six environmental impact categories. The environmental impact categories and the used LCA methods for their quantification are presented in Table 4.

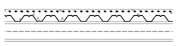
Table 4. Environmental impact categories declared in the built-in LCA database for building technologies and the used LCA methods

Environmental impact categories	Unit/declared unit	LCA methods
Depletion of abiotic resources	[kg Sb eq.]	CML 2 baseline 2000
Global warming potential (GWP)	[kg CO_2 eq.]	IPCC 2001 GWP 100a
Destruction of atmospheric ozone(ODP)	[kgCFC-11 eq.]	CML 2 baseline 2000
Acidification potential (AP)	[kg SO_2 eq.]	CML 2 baseline 2000
Eutrophication potential (NP)	[kg PO_4 eq.]	CML 2 baseline 2000
Photochemical Ozone Creation (POCP)	[kg C_2H_4 eq.]	CML 2 baseline 2000
Non-renewable primary energy	[MJ eq.]	Cumulative Energy Demand
Renewable primary energy	[MJ eq.]	Cumulative Energy Demand

In order to facilitated the quantification process, a life-cycle analysis software (SimaPro) was be used to modulate the macro-components' life-cycles and to assess the mentioned life-cycle impact categories.

2.5 Communication format

Figure 2 presents how the information is organized in the LCA database for a building macro-component and the list of environmental indicators and LCA methods used. In the database of the building components the quantification is presented per each component's unit of area (m^2) and in the materials database, figures present the environmental impacts per each unit of mass (kg). Quantification is presented for two life-cycle stages: "cradle to gate" and "demolition/disposal". Using this database it is possible to estimate the overall impact of a building using a bottom-up up approach. The quantification begins at the level of the embodied environmental impacts in building materials and ends at the whole building scale.

Building technology	Collaborating slab (with steel structure and lost steel formwork) for floors								Ref: Floor 10
	Life-cycle stages	Environmental impact categories						Embodied energy	
		ADP[1]	GWP[2]	ODP[3]	AP[4]	POCP[5]	EP[6]	ENR[7]	ER[8]
	Cradle-to-gate	3,84E-01	5,79E+01	2,10E-06	1,69E-01	2,32E-02	3,31E-02	7,08E+02	1,55E+01
	End-of-life	1,02E-01	1,48E+01	2,39E-06	7,00E-02	2,70E-03	1,46E-02	2,35E+02	1,37E+00
	Total	4,86E-01	7,27E+01	4,49E-06	2,39E-01	2,59E-02	4,77E-02	9,42E+02	1,69E+01
	Comments:	Considered materials: Concrete and steel (including steel panels, profiles and reinforcing steel bars) LCA methods: CML 2 baseline 2000 version 2.04 (to assess the environmental impact categories) and Cumulative Energy Demand version 1.04 (to assess the embodied energy) LCI libraries: Ecoinvent system process and ETH-ESU 96 system process							

Notes:
1Abiotic depletion potential in kg Sb equivalents;
2Global warming potential in kg CO_2 equivalents;
3Ozone depletion potential in kg CFC-11 equivalents;
4Acidification potential in kg SO_2 equivalents;
5Photochemical ozone creation potential kg C_2H_4 equivalents;
6Eutrophication potential in kg PO_4 equivalents;
7Non-renewable embodied energy in MJ equivalents;
8Renewable embodied energy in MJ equivalents.

Fig. 2: Part of the SBTool$^{PT®}$ LCA database

To evaluate the transportation impacts, the designer must know (for each building material or product) the distance from the factory to the construction site and the distance from the construction site to the recycling/management centre. By multiplying the distance (km) by the weight (ton) and by the unitary impacts associated to the used type of transportation it is possible to estimate the transportation impacts of the building technology. Adding the transportation impacts to the figures presented in Figure 2 it is possible to estimate the overall life-cycle impacts of a building technology. Table 5 illustrates the calculation principle of the total environmental of the building life cycle using the SBTool$^{PT®}$ LCA database.

At this stage, the developed database covers more than 100 building's macro-components (16 floors, 28 external walls, 22 partition walls, 23 roofs and 18 types of windows), 47 construction materials and the potential environmental impacts associated to the use of 12 acclimatization and hot water production equipments.

Table 5. Method quantification of the whole building's life cycle environmental impacts

Building Component (C_i)	Area (m^2)		LCA indicators							
C_1	A_1	x	ADP_1/m^2	GWP_1/m^2	ODP_1/m^2	AP_1/m^2	$POCP_1/m^2$	EP_1/m^2	ENR_1/m^2	ER_1/m^2
			+	+	+	+	+	+	+	+
(...)	(...)	x	(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)
			+	+	+	+	+	+	+	+
C_n	A_n	x	ADP_n/m^2	GWP_n/m^2	ODP_n/m^2	AP_n/m^2	$POCP_n/m^2$	EP_n/m^2	ENR_n/m^2	ER_n/m^2
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts			ADP'_e	GWP'_e	ODP'_e	AP'_e	$POCP'_e$	EP'_e	ENR'_e	ER'_e
			÷	÷	÷	÷	÷	÷	÷	÷
			Time boundary of the LCA assessment							
			÷	÷	÷	÷	÷	÷	÷	÷
			Net floor area of the building							
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts $/m^2$.year			ADP_e	GWP_e	ODP_e	AP_e	$POCP_e$	EP_e	ENR_e	ER_e
			+	+	+	+	+	+	+	+
Environmental impacts of the maintenance scenario $/m^2$.year			ADP_m	GWP_m	ODP_m	AP_m	$POCP_m$	EP_m	ENR_m	ER_m
			+	+	+	+	+	+	+	+
Environmental impacts of the operational energy use for heating and cooling $/m^2$.year			ADP_o	GWP_o	ODP_o	AP_o	$POCP_o$	EP_o	ENR_o	ER_o
			=	=	=	=	=	=	=	=
Total life cycle impacts of the whole building $/m^2$.year			**ADP**	**GWP**	**ODP**	**AP**	**POCP**	**EP**	**ENR**	**ER**

3. Discussion and conclusions

Although LCA is considered the best method available to assess the environmental performance of a product, its application in construction is very complex. This is because the huge number of different materials, actors, processes and also the wide life cycle span of a construction product.

Based in the work of CEN TC 350 and in the development of the Portuguese sustainability rating system (SBTool$^{PT®}$), this paper presented some solutions to overcome the difficulties in the integration of more accurate LCA-based approaches is the assessment of the environmental performance in rating systems. The development by experts of databases with the LCA data of the most used building technologies and materials is a good solution to integrate more accurate and LCA-based approaches, without turning the rating systems too complex for practical use.

Compared to other existing databases, the one presented in this paper has two main differences that could promote the practical implementation of the LCA approach during the design of a new construction or refurbishing operation. Consequently, it will promote the practical implementation of the sustainable construction concept.

The first difference is that this database covers a larger number of environmental parameters (those that are included in the EN 15942:2011). Therefore it could be directly used to support the environmental performance assessment of a building according to recent standardization work (EN 15643-2:2011).

The other advantage is that this database presents the environmental data for construction macro-elements normally used in steel construction (e. g. slabs, walls, panels, etc.) and not for single materials and products (i.e. steel profile) as in other databases. A macro-component is, according to our definition, an entity of a building for which a technical specification can be given in relation to a set of essential structural characteristics and that is actually a combination of various materials. As an example, a roof construction may comprise load-bearing structures, thermal insulation, layers of moisture barrier and water-barrier and internal finishes. The purpose of defining a set of macro-component typical for steel-framed building and steel-intensive renovation solutions is to establish a data bank that informs about the essential characteristics, especially in relation to sustainability issues.

This situation will decrease the time and cost for conducting an environmental life-cycle analysis of a steel construction. Additionally, this advantage could indirectly promote the use of steel construction systems in design operations aimed at developing more sustainable construction.

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