Environmental LCA database for conventional Portuguese building technologies

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ABSTRACT: Nowadays there is an increasing concern with the high emissions of polluting gases, the high use of natural resources and energy related to construction sector. There are several environmental impacts in this sector that can be moderated. This paper presents a study that allows the designers to quickly and easily apply the Life-Cycle Assessment (LCA) method to projects and therefore to understand which solutions are the "best" in what regards to sustainable construction. To fulfill the abovementioned goals this work studies the environmental performance of building technologies covered by the ITE50 manual – "coefficients of heat transfer of the building envelope elements". This manual covers the majority of building technologies used in Portugal.

1 INTRODUCTION

1.1 *State – of- art and goals*

The Human being, as other living creatures, grows and depends on the conditions of the surrounding environment. Therefore, preserving the environment is a matter of survival. However, this is not the case in most times. The industrial revolution of the 18th century started the "boom" of the air and soil pollution. Humanity was moved by rampant greed and begun a process of unprecedented exploration (Maio, 2006).

The intensification of climate changes and natural disasters are everyday on the news and they are consequences of the way of living acquired by Humans. The fact is that Human activities are developed in a built environment which brings severe consequences.

The construction sector is responsible for resource depletion and environmental damage (Grigoletti, 2001). It's recognized for its high-energy consumption, global greenhouse gas emissions, solid waste generation and pollution at all levels. The records shows that building activities are responsible for exploring and consuming about 40% of the natural resources such as stone, sand, wood and water.

Due to a poorly designed or managed built environment, the waste of resources throughout the life-cycle of buildings has a significant impact on global environment.

The selection of adequate materials and building solutions to the specific uses should be the base criteria of a designer. For instance, the preference for lower embodied energy and "easy-disassembled" structures that facilitate the separation of materials at the end of building's life-cycle, are ways of reducing environmental impacts. At the moment, the designer has to demonstrate, some sensitivity in the choice of materials and building technologies which allow putting in practice the current need to minimize these impacts in the construction sector.

Nowadays there are several methods and software tools that could be used by designers in order to identify which design approach best fits the sustainable construction aims. Nevertheless, the complexity of the process and the high quantity of needed life-cycle inventory data are factors that limit their application by experts.

Life-cycle assessment is a methodology for evaluating the environmental load of processes and products (goods and services) during their life cycle. Although the LCA method was at first oriented to materials and products, its application in construction is generally accepted (Bragança & Mateus, 2011).

The aim of the study presented in this paper is the development of a database that presents the potential environmental impacts of the building elements commonly used in Portugal. These results will allow the designer, or designer team, to identify the potential environmental impacts which result from the use of a building technology. Therefore, making comparisons, the designer can easily understand which construction solution or which material is the most adequate for the project, in terms of environmental performance.

Other advantage is that this database presents the environmental data for construction macro-elements normally used in buildings (e. g. slabs, walls, etc.) and not for single materials and products (i.e. brick) as in other databases. This situation will decrease the time and cost for conducting an environmental life-cycle analysis of a building.

Through the combination of the environmental performance of the four types of processes (support, coating, insulation and transport) that constitute the systems in analysis- building solutions, the designer can estimate the environmental impacts of any chosen building solution.

In order to cover the most commonly used building solutions in Portugal, the database includes all technologies presented in the manual ITE50 "Coefficients of heat transfer of the building envelope elements" (LNEC, 2006).

1.2 *The LCA methodology*

Life cycle assessment (LCA) is a systematic approach to measuring the potential environmental impacts of a product or service during its lifecycle. LCA considers the potential environmental impacts throughout a product's life cycle.

LCA is very important to compare several possible alternative solutions, which can bring about the same required performance but differs in terms of environmental consequences. For constructions, such as bridges, the embodied environmental performance of the building materials as well as the construction impacts on landscape and biodiversity will often dominate the construction's life-cycle environmental impacts. For buildings, such as dwellings and offices, life-cycle environmental impacts are often dominated by energy consumption, in space heating or cooling, during the operation phase: it is estimated that the operation phase in conventional buildings represents approximately 80% to 94% of the life-cycle energy use, while 6% to 20% is consumed in materials extraction, transportation and production and less than 1% is consumed through 1% end-of-life treatments (Berge, 1999). In buildings, design teams should seek for more energy-efficient alternatives, while in other constructions, like for instance dikes and bridges, priority should be given to eco-efficient materials. Nevertheless, with the development of energy-efficient buildings and the use of less-polluting energy sources, the contribution of the material production and end-of-life phases is expected to increase in the future.

There are two combined standards developed specifically to set the framework and requirements of a LCA that replaced the former four LCA standards (ISO 14040, ISO 14041, ISO 14042, ISO 14043) on 1st July 2006: ISO/FDIS 14040 2006-07-01 Environmental management – Life cycle assessment – Principles and framework; and ISO/FDIS 14044 2006-07-01 Environmental management – Life cycle assessment – Requirements and guidelines.

According to ISO 14040, the framework for LCA includes:

- Goal and scope definition of LCA;
- Inventory analysis (LCI);
- Impact assessment (LCIA);
- Interpretation;
- Reporting and critical review;
- Limitations;
- Relationships between the LCA phases, and

- Conditions for use.

As presented in Figure 1, LCA is essentially an iterative process.

In the first step, Goal and Scope, the purpose of the work is defined, the audiences and the system boundaries (temporal, geographical and technological) and mainly the environmental impact categories to be used are identified. As mentioned above, this work aims at accessing the environmental performance of most common building elements used in Portugal. According to prEN 15978:2011 the LCA impact categories to be considered when assessing the environmental impacts of building are: Abiotic Depletion (ADP); Fossil Fuel Depletion Potential (ENR); climate change expressed as Global Warming Potential (GWP); Destruction of the Stratospheric Ozone Layer (OD); Acidification of Land and Water Resources (AP); Eutrophication Potential (EP); Formation of Ground Level Ozone Expressed as Photochemical Oxidants (POCP). The developed database covers all abovementioned impact categories allowing project teams to estimate the whole building life-cycle impacts based in the environmental performance of its macro-components. The analysis follows the variant "cradle-to-grave" of the LCA method. The system boundaries included the extraction of raw materials, needed to produce the material or building solution and its disposal and/or final treatment.

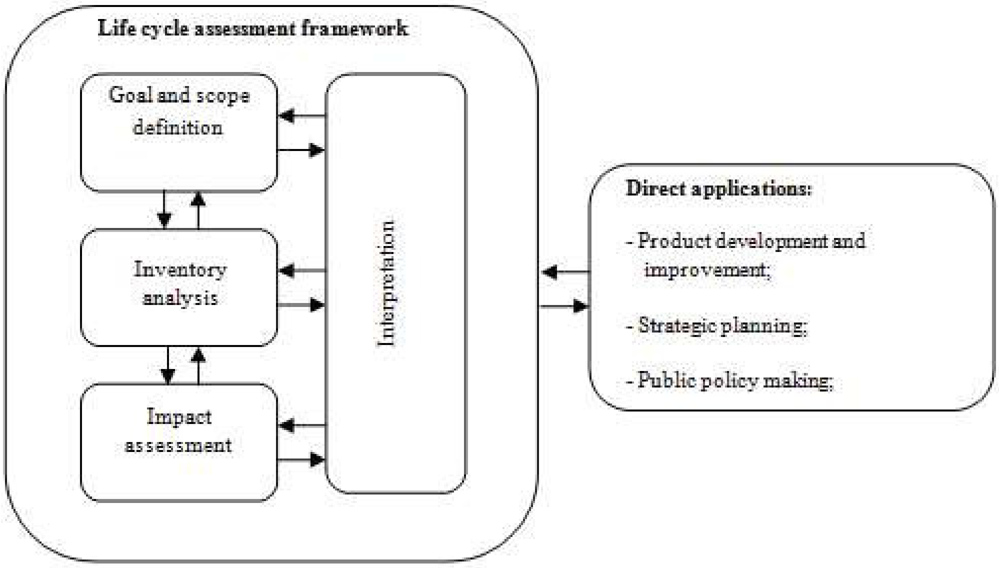

Figure 1: Stages of an LCA in ISO 14040:2006

The second step, life-cycle inventory, involves collecting data for each unit process regarding all relevant inputs and outputs of energy and mass flow, as well as data on emissions to the air, land and water. This phase includes calculating both, the material and energy input and the output of a building system. For the environmental impacts assessment it was necessary to collect information concerning the various phases of the building's life-cycle. For the construction phase it was necessary to quantify the materials used in building elements and to identify the location of companies that manufacture the materials. The quantification of the materials and other inputs was based on the documents published by the National Laboratory of Civil Engineering, LNEC (Manso et al, 2007).

The third step is aimed at understanding and evaluating the magnitude and significance of potential environment impacts of the material or system under study. This phase consists of three mandatory elements: selection of impact categories assignment of LCI results (classification) and modelling category indicators (characterization). Classification of the LCI results involves assigning the emissions, waste and resources used to the impact categories chosen. The converted LCI results are aggregated into an indicator result, which is the final result of mandatory part of an LCIA. Normalization, grouping, weighting and additional LCA data quality analysis are additional steps. In this phase there are essentially two methods: Mid-points: problem oriented methods, and end-points: damage-oriented methods. As it was mentioned before, in this study, two methods used, mid-point methods. The impact assessment methods were chosen according to the considered environmental categories. In this case, and to be in conformity with EPD- environmental product declaration, two methods were applied: CML 2 baseline 2000 and Cumulative Energy Demand. It is important that the database is in accordance to EPD because this enables the integration of data from the EDP in the life-cycle analysis carried out in any building.

At last, but not the least, in the fourth step significant issues are identified, findings are evaluated to reach conclusions and recommendations are formulated. The interpretation may be described as the systematic procedure to identify, qualify, check, and evaluate the results of the LCI and LCIA. The main aim of interpretation is to analyze the results of the goals and scope and to formulate the conclusions that can be drawn from LCA. It can comprise five different kinds of analysis (Heijungs et al, 2000): contribution analysis, perturbation analysis, uncertainty analysis, comparative analysis and discernibility analysis.

In relation to this fourth step, the main purpose of this study is to use this methodology to compare different material or different constructive solutions.

2 DATABASE DEVELOPMENT

2.1 *Database elements and waste scenario*

As aforementioned, this study is based on ITE50, so only the most common solutions in Portuguese construction, that are mentioned in this book, were studied.

This analysis could illustrate only the almost seventy constructive solutions referenced on ITE50, but it would limit the application of the database. It was chosen to study the constructive solutions based on four common phases: support, insulation, coatings and transport, Figure 2. This kind of study provides this database a larger coverage spectrum and it is still easier to the application of LCA methodology.

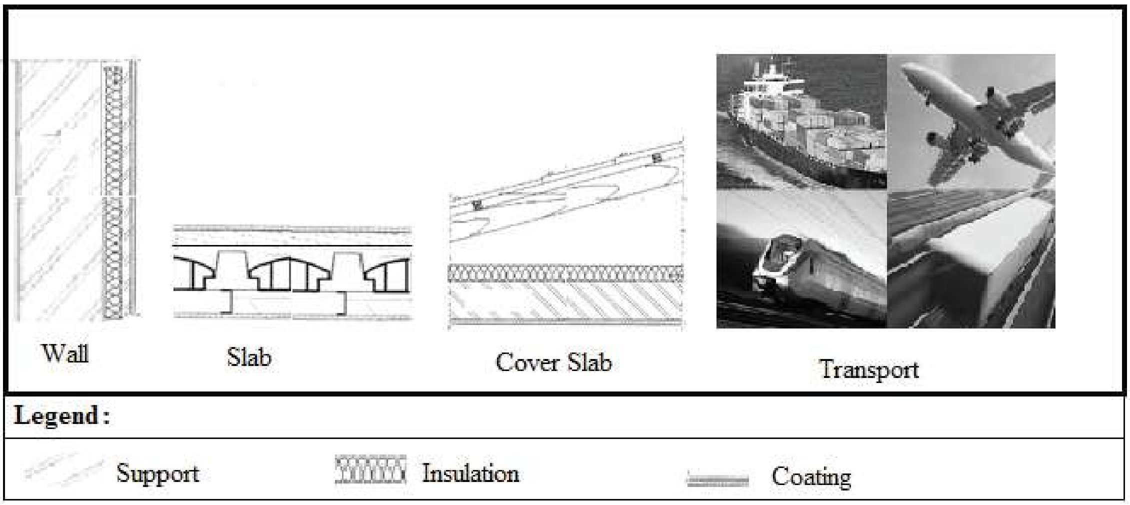

Figure 2: Macro processes contributing to the environmental impacts of building solutions

The support of a building solution it is the skeleton. There can be insulation elements or not and the coating element is commonly result of a combination of several materials.

A building solution can be made by different kinds of material. Using a simple wall, as an example, it can be a wall made of stone blocks or bricks. For this reason, it was needed to find a way to cover all several materials and processes presented in building technologies. In the research processes some materials and procedures were gathering that were deemed as the most widely used. The data of these materials and procedures were accounted for $1m^3$. The element of transport was counted in tons per kilometre and all types of transportation- air, water, rail and land - were considered. These units were chosen just to simplify the application of LCA method. Figure 3 shows all the elements that were analyzed.

All the data analyzed was processed into software, SimaPro, using preferentially "Ecoinvent" database. This database is very complete as it contains over 4000 industrial processes and is fully integrated in SimaPro. When it's not possible the use of database, it seeks other databases or it seeks for another identical material present in "Ecoinvent".

<table>
<tr><td rowspan="7">Components</td><td rowspan="4">Support</td><td>Single wall</td><td>Bored brick</td><td>Normal concrete block</td><td>Lightweight concrete block</td><td>Stone</td><td>Concrete wall</td><td></td></tr>
<tr><td>Double wall</td><td>Panels of bored brick</td><td>Bored brick + Solid brick</td><td>Panels of normal concrete blocks</td><td>Panels of lightweight concrete blocks</td><td>Stone + single wall</td><td>Concrete + single wall</td></tr>
<tr><td rowspan="2">Slabs</td><td rowspan="2">Massive slab</td><td colspan="3">Lightweight slab</td><td rowspan="3" colspan="2"></td></tr>
<tr><td>Ceramic blocs</td><td>Normal concrete blocks</td><td>Lightweight concrete blocks</td></tr>
<tr><td colspan="2">Thermal insulation</td><td>Agglomerate of expanded cork (ICB)</td><td>Mineral Wool (MW)</td><td>Polyurethane rigid foam (PUR)</td><td>Expanded molded polyesthyrene (EPS)</td></tr>
<tr><td colspan="2">Coatings</td><td colspan="6">Plaster, stone, mosaics, woods, metalic plates,stucco, plasterboard, screed, bedding mortar, cork, gravel, carpet, fibre cement, waterproofing PVC membrane, plastic plates or pipes, parquet, ceramic tiles, vegetal soil, paint and glass.</td></tr>
<tr><td colspan="2">Transports</td><td colspan="6">Intercontinental aircraft, European aircraft, rail, lorry (16t,28t, 32t e 40t), tractor and trailer, van (<3,5t), transoceanic, barge tanker and municipal waste collection.</td></tr>
</table>

Figure 3: Description of analyzed materials

Besides the construction phase this database covers the potential environmental impacts of the end-of-life phase. In the definition of the waste scenario, the common Portuguese practice was considered. In this context, the building materials that are normally recovered after demolition are the steel-based. Table 1 presents the considered waste scenario.

Table 1: Consider waste scenario

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

2.2 *Considered environmental impact categories*

The goal of the work is to develop a LCA database that simplifies the application of LCA methodology. 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 (EPD).

LCA database covers 8 environmental indicators. Table 2 presents the indicators and the LCA method used in their quantification.

Table 2: Quantified indicators for environmental impacts/aspects covered by the LCA database

Environmental impacts expressed with the impact categories of LCA	– Abiotic depletion (ADP) – Climate change expressed as Global Warming Potential (GWP); – Destruction of the stratospheric ozone layer (ODP); – Acidification of land and water resources (AP); – Formation of ground level ozone expressed as photochemical oxidants (POCP); – Eutrophication (EP).	CML Baseline 2000
Environmental aspects expressed with data derived from LCI and not assigned to the impact categories of LCA	– Use of non-renewable primary energy; – Use of renewable primary energy.	Cumulative Energy Demand

2.3 *Database structure*

This database can be applied as a decision maker method in order to improve the sustainability in the construction sector/industry. In total, 33 wall solutions, 21 slab solutions, 16 types of insulation with variable thickness and 28 types of coatings were studied. Once combined, it was possible to obtain several constructive solutions.

The database is subdivided in the following chapters: support, insulation materials, coatings and transportation.

Figure 4, presents how the information is organized in the LCA database for a building element and the list of environmental indicators and LCA methods used to quantify it. 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 values are available 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.

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 transport (Table 3) it is possible to estimated the transportation impacts of the building technology. Figure 5 resumes the methodology used to estimate the environmental impact resulting from the transportation of the materials used in a building technology.

Adding the transportation impacts to the figures presented in Figure 4 is possible to estimate the overall life-cycle impacts of a building technology.

Building element	Concrete Slab								
		Environmental impact categories derived from LCA						Embodied energy	
	Life-cycle stage	ADP	GWP	ODP	AP	POCP	EP	ENR	ER
	Cradle-to- gate	2,1E-01	3,2E+01	2,2E-06	1,3E-01	9,2E-03	2,4E-02	3,7E+02	9,4E+00
	End of life	5,1E-04	6,8E-02	1,4E-08	4,0E-04	1,6E-05	8,1E-05	1,1E+00	5,5E-03
	Total	2,1E-01	6,2E+01	2,2E-06	1,3E-01	9,2E-03	2,4E-02	3,8E+02	9,4E+00

Comment: **Considered materials:** Concrete and steel A400

Method(s) LCA: CML 2 baseline 2000 and Cumulative Energy Demand

LCI library: Ecoinvent system process

Figure 4: Part of the environmental database covering a building element.

Table 3: Transportation impacts

Type of transportation	Transportation Impacts (per ton.km)							
	Environmental impact categories						Embodied Energy	
	ADP	GWP	ODP	AP	POCP	EP	ENR	ER
Intercontinental Plane	7,0E-03	1,1E+00	1,4E-07	4,2E-03	1,8E-04	7,1E-04	1,6E+01	1,4E-01
European Plane	1,3E-02	1,9E+00	2,5E-07	7,1E-03	3,1E-04	1,2E-03	2,9E+01	1,2E+00
Train	9,7E-05	1,4E-02	1,3E-09	6,8E-05	4,0E-06	1,2E-05	1,8E-01	3,1E-01
Lorry 16t	2,2E-03	3,2E-01	5,0E-08	1,7E-03	5,3E-05	3,6E-04	4,9E+00	9,0E-02
Lorry 28 t	1,6E-03	2,2E-01	3,6E-08	1,2E-03	3,5E-05	2,6E-04	3,5E+00	5,6E-02
Lorry 32 t	1,2E-03	1,7E-01	2,3E-08	9,6E-04	3,2E-05	1,9E-04	2,7E+00	4,2E-02
Lorry 40t	1,2E-03	1,7E-01	2,7E-08	8,7E-04	2,5E-05	1,8E-04	2,7E+00	4,1E-02
Tractor and trailer	2,1E-03	2,9E-01	3,6E-08	1,7E-03	7,6E-05	3,3E-04	4,3E+00	4.5E-01
Van(< 3,5t)	7,8E-03	1,2E+00	1,6E-07	4,0E-03	5,6E-04	5,8E-04	1,7E+01	6,1E-01
Municipal waste collection	8,4E-03	1,3E+00	2,0E-07	5,8E-03	2,3E-04	1,2E-03	1,9E+01	1,4E-01
Ship	2,6E-04	4,2E-02	4,5E-09	3,1E-04	6,2E-06	6,7E-05	5,6E-01	8,5E-03

Material	Dist.* (km)		Weight (ton)		Type of transportation		Total
Material 1	D1	x	P1	x	Type of transport 1	=	T1
					ADP GWP ODP AP POCP EP ENR ER		ADP GWP ODP AP POCP EP ENR ER
Material 2	D2	x	P2	x	Type of transport 2	=	T2
					ADP GWP ODP AP POCP EP ENR ER		ADP GWP ODP AP POCP EP ENR ER
Material 3	D3	x	P3	x	Type of transport 3		T3
					ADP GWP ODP AP POCP EP ENR ER		ADP GWP ODP AP POCP EP ENR ER
		x			...	=	...
					ADP GWP ODP AP POCP EP ENR ER		ADP GWP ODP AP POCP EP ENR ER
Material n	Dn	x	Pn	x	Type of transport n	=	Tn
					ADP GWP ODP AP POCP EP ENR ER		ADP GWP ODP AP POCP EP ENR ER
							TG =T1+T2+T3+...+Tn
							ADP GWP ODP AP POCP EP ENR ER

* Distância da fábrica onde se produz o material ou do local de venda à fábrica

Distance between work and recycling/ managemenet center	=	m
Type of transportation during this distance – TRET	=	ADP GWP ODP AP POCP EP ENR ER
Global transportation impacts	=	TG +TRETx m
		ADP GWP ODP AP POCP EP ENR ER

Figure 5: Methodology for assessing the transportation environmental impacts of a building technology.

3 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.

The sustainable construction has higher advantages compared to conventional practice and the ability to make a simplified analysis of the environment impacts of a project was the main goal of this research work. The study of the life cycle of several building materials, products and technologies allows a better understanding of the environmental consequences of different design approaches. Other positive aspect of this research is that now designers have a new "tool" that links the environmental performance of the most common building technologies in Portugal with their thermal performance.

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