LCA Database for Portuguese Building Technologies

Luís Bragança
University of Minho, Guimarães, Portugal

Ricardo Mateus
University of Minho, Guimarães, Portugal

ABSTRACT: The aim of this paper is to present one solution to integrate more accurate environmental assessment methods in rating systems and that could be used to support the design teams' decisions that aim the implementation of low impact building solutions. The solution is the development of a LCA database that is based in the EPD's (Environmental Product Declarations) approach and that gathers the quantification of several environmental impact categories of the most common building solutions used in Portugal. This database is in continuous update and now covers about 50 building solutions for floors and exterior walls, 40 building materials and the impacts related to the use of 12 systems for acclimatization and hot water.

1 INTRODUCTION

1.1 *State-of-the art and goals*

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

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 (ISO14040-42). 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;
- toxic releases to air, water and land.

It is widely recognised in the field of Building Sustainability Assessment that Life Cycle Assessment (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 of existing 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 (Carmody, et al, 2007).

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. The integration of more accurate environmental assessment methods is needed to verify if the required performance has really been achieved, to accurate compare solutions and to compare the results from different rating systems (Bragança et al, 2008).

In order to standardize, facilitate the interpretation of results and comparison between different building sustainability assessment methods developed within the European Countries, CEN (European Centre of Normalization) started on the Technical Committee 350 (CEN/TC 350). The working document (TC 350 WI 002) 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.

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

1.2 *The LCA approach*

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 (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal.

LCA is very important to compare several possible alternative solutions, which can bring about the same required performance but that differ in terms of environmental consequences. For constructions, such bridges, the embodied environmental performance of the building materials as well 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 specific to set the framework and requirements of a LCA that replaced the former four LCA standards (ISO 14040, ISO 14041, ISO 14042, ISO 14043) in 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, 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.

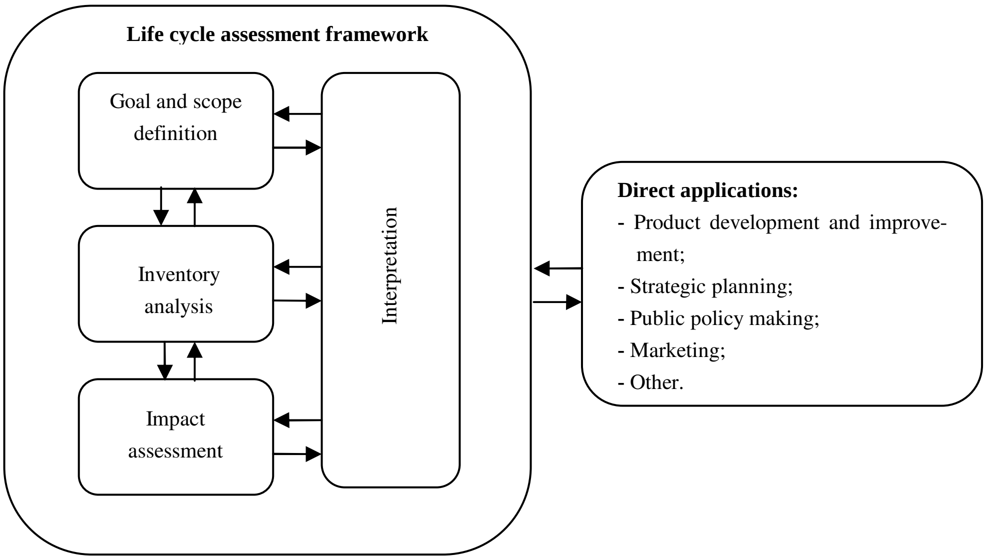


Figure 1. Stages of an LCA in ISO 14040:2006.

LCA can be applied to a single product or to an assembly of products, such as a building. For building and other constructions (B/C) the general framework for LCA involves the following goals and LCA steps (Kotaji, Schuurmans & Edwards, 2003):

1) The lifecycle of the B/C is described. What is included in the study will depend on the scope. It may include how the B/C is constructed, used, maintained and demolished and what happens to the waste materials after demolition. These are processes that contribute to the life-cycle performance of a B/C, but which will not be included in all studies.
2) The B/C is “broken down” to the building material and component combinations (BMCCs) level. This is the composition of the B/C to be analysed. The way in which the BMCCs are defined is not necessarily important; what matters is that the B/C is completely described through the addition of the BMCCs.
3) For each BMCC, the LCA of the production process (cradle-to-gate) is carried out. Their LCAs may include the transport processes to the B/C site, the construction process, the operation and maintenance processes, the demolition processes, and the waste treatment processes for each of the waste materials defined in the B/C model. This would be a cradle-to-grave analysis.
4) The BMCC-LCA results are added together, resulting in the LCA of the B/C. The various BMCC-LCAs should be carried out consistently according to the goal and scope.

2 THE DEVOLOPMENT 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, are the measures 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 in the cause-effect chain to limit the uncertainties. Midpoints uses to 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 B/C'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 (iiSBE, 2007). User can both select the LCI data or an external LCA tool to calculate the embodied energy (Larsson, 2007).

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 (GBI, 2008). However, documentation describing the methodology in which points are awarded based on LCI data is not publicly available.

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 (BRE, 2008). 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 (Anderson & Howard, 2006).

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 (Brown, 2008).

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 – 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. The working document (TC 350 WI 002) sets 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. As referred in Table 2, according to the future CEN standard the assessment of the environmental performance of an building should be made through the evaluation of five quantified indicators for environmental impacts expressed with the impact categories of the life cycle impact assessment (LCA) and nine quantified indicators for environmental aspects expressed with data derived from LCI and not assigned to the impact categories of LCA.

The assessment approach of this future CEN standard 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 (EPD).

Table 1: SBTool, Green Globes and Code for Sustainable Homes LCA-based Environmental Performance Criteria (Optis, 2005).

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.

Table 2. Quantified indicators for environmental impacts/aspects assessment according to CEN TC 350 WG1 N002 – Working Draft.

Environmental impacts expressed with the impact categories of LCA	Environmental aspects expressed with data derived from LCI and not assigned to the impact categories of LCA
• Climate change expressed as Global Warming Potential; • Destruction of the stratospheric ozone layer; • Acidification of land and water resources; • Eutrophication; • Formation of ground level ozone expressed as photochemical oxidants.	• Use of non-renewable resources other than primary energy; • Use of recycled/reused resources other than primary energy; • Use of non-renewable primary energy; • Use of renewable primary energy; • Use of freshwater resources; • Non-hazardous waste to disposal; • Hazardous waste to disposal; • Nuclear waste (separated from hazardous waste).

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 future standard. Therefore the developed LCA database covers the five environmental indicators expressed with the environmental impacts of LCA together with the embodied energy in the materials and construction technologies.

2.2 *Considered life-cycle phases*

A typical life cycle of a building can be separated into three distinct phases, each consisting of one or several life cycle stages, as illustrated in Figure 2. 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.

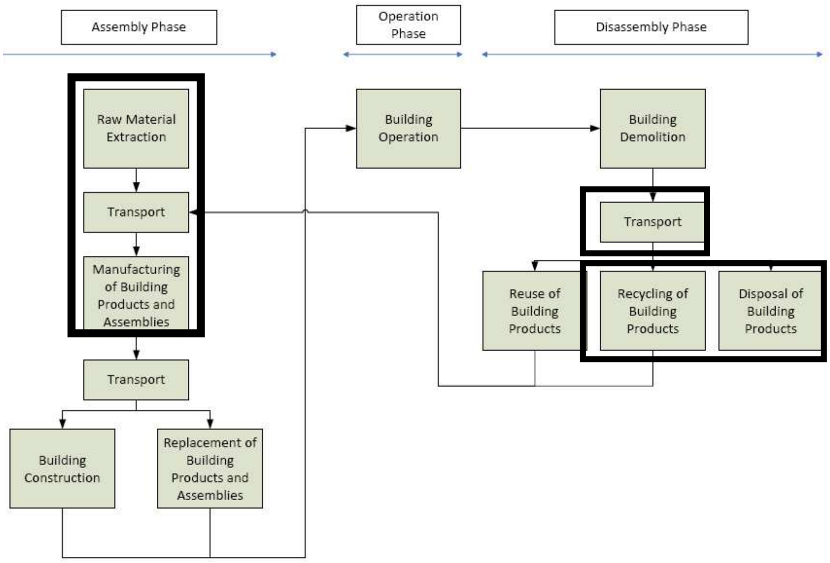


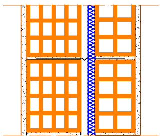
Figure 2. Life cycle of a building (Optis, 2005).

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.

2.3 *Quantification of the environmental indicators*

The two most important barriers to 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 (EPD) 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 future 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. The solution proposed to overcome this problem is to develop and use databases with the LCA data of the most used building materials and components. The developed database is continuously updated and covers common building technologies for each building element (floors, walls, roofs and windows, doors), the most used building materials and the impacts of operating most common acclimatization equipments.

The environmental indicators were quantified using the SimaPro software and several LCI databases with the average environmental impacts of each used building material (e.g. EcoInvent, IDEMAT 2001, etc.). Figure 3, presents how the information is organized in the LCA database for a building component 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". SBTool^{PT} uses a bottom-up up approach in the quantification of the whole building environmental performance. The quantification begins at the level of the embodied environmental impacts in building materials and ends at the whole building scale. Table 3 illustrates the principle of calculation of the total environmental of the building life cycle using the data issued in the SBTool^{PT} LCA database.

Building component:	Hollow brick cavity wall (15cm+11cm) with thermal insulation in the air cavity								Ref: Wall 1
	Life cycle stages	Environmental impact categories of LCA						Embodied energy	
		ADP[1]	GWP[2]	ODP[3]	AP[4]	POCP[5]	EP[6]	NR[7]	R[8]
	Cradle-to-gate	3.70E-01	9.53E+01	1.02E-04	1.91E-01	1.13E-02	2.54E-02	8.68E+02	1.01E+02
	Dismantling and disposal	2.08E-01	3.17E+01	5.00E-06	1.42E-01	5.40E-03	2.95E-02	4.75E+02	2.83E+00
	Total	5.78E-01	1.27E+02	1.07E-04	3.33E-01	1.67E-02	5.49E-02	1.34E+03	1.04E+02
	Comments:	**Considered materials:** Hollow brick, XPS (thermal insulation) and Portland cement mortar **LCA methods:** CML 2 baseline 2000 method (version 2.04, to quantify the environmental impact categories of LCA) and Cumulative Energy Demand (version 1.04, to evaluate the embodied energy) **LCI librarie(s):** Ecoinvent system process							

Notes:

[1] Abiotic depletion potential in kg Sb equivalents;

[2] Global warming potential in kg CO_2 equivalents;

[3] Ozone depletion potential in kg CFC-11 equivalents;

[4] Acidification potential in kg SO_2 equivalents;

[5] Photochemical ozone creation potential kg C_2H_4 equivalents;

[6] Eutrophication potential in kg PO_4 equivalents;

[7] Non-renewable embodied energy in MJ equivalents;

[8] Renewable embodied energy in MJ equivalents.

Figure 3. Part of the SBTool^{PT} LCA database.

Table 3. Principle of the 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	NR_1/m^2	R_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	NR_n/m^2	R_n/m^2
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts			ADP'_e	GWP'_e	ODP'_e	AP'_e	$POCP'_e$	EP'_e	NR'_e	R'_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	NR_e	R_e
			+	+	+	+	+	+	+	+
Environmental impacts of the maintenance scenario /m^2.year			ADP_m	GWP_m	ODP_m	AP_m	$POCP_m$	EP_m	NR_m	R_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	NR_o	R_o
			=	=	=	=	=	=	=	=
Total life cycle impacts of the whole building /m^2.year			**ADP**	**GWP**	**ODP**	**AP**	**POCP**	**EP**	**NR**	**R**

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.

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.

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