Global Methodology for Sustainability Assessment: Integration of Environmental LCA in Rating Systems

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ABSTRACT: Sustainable construction is a multidimensional concept that is based in the performance of a construction through the three dimensions of sustainable development: environment, society and economy. Sustainability assessment and rating systems are intended to foster more sustainable building, design, construction, operation, maintenance and disassembly/deconstruction by promoting and making possible a better integration of environment, societal, functional and cost concerns with other traditional decision criteria. The use of improved materials and building technologies can contribute considerably to better environmental life cycle and then to the sustainability of the constructions. Although, life-cycle assessment (LCA) is considered the best method to evaluate the environmental impacts, most of the sustainability rating systems are not comprehensive or consistently LCA-based. The reason is mainly linked to the complexity of the stages of a LCA. Based in the harmonization work that is being carried out by the European Centre of Normalization (CEN) and by the iiSBE Portugal in the development of the Portuguese rating system (SBTool^{PT}), this paper will discuss the difficulties and solutions to turn possible the integration of more accurate environmental assessment methods in rating systems.

1 INTRODUCTION

Building sustainability assessment (BSA) and rating tools comprise the ways in which built structures and facilities are procured and erected, used and operated, maintained and repaired, modernised and rehabilitated, and finally dismantled and demolished or reused and recycled.

It is widely recognized in the field of the Sustainability Assessment that Life Cycle Assessment (LCA) is a conceptually preferable method for determining the environmental effects of materials, rather than relying on singular material proprieties or attributes, such as recycled content, recycling potential or distances travelled after the point of manufacture (Carmody, 2007). There are several international recognized LCA tools.

LCA is internationally recognized 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.

All of the mentioned above environmental impacts or aspects are indicators of the environmental loadings which may occur from manufacture, transportation, use and disposal of a product. However, these indicators do not directly address the ultimate human health and ecosystems effects, a much more difficult and uncertainly task, they provide good measures of environmental assessment. It is given that reducing any of these effects will result in a better environmental performance. The results of an LCA depend, above all, in the list of environmental categories that are considered in the assessment.

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.

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 discuss the environmental indicators that should be considered in rating systems and solutions to integrate LCA-based methods in rating systems without turning unpractical its use by most stakeholders.

2 STEPS IN THE LCA OF BUILDINGS AND CONSTRUCTIONS

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.

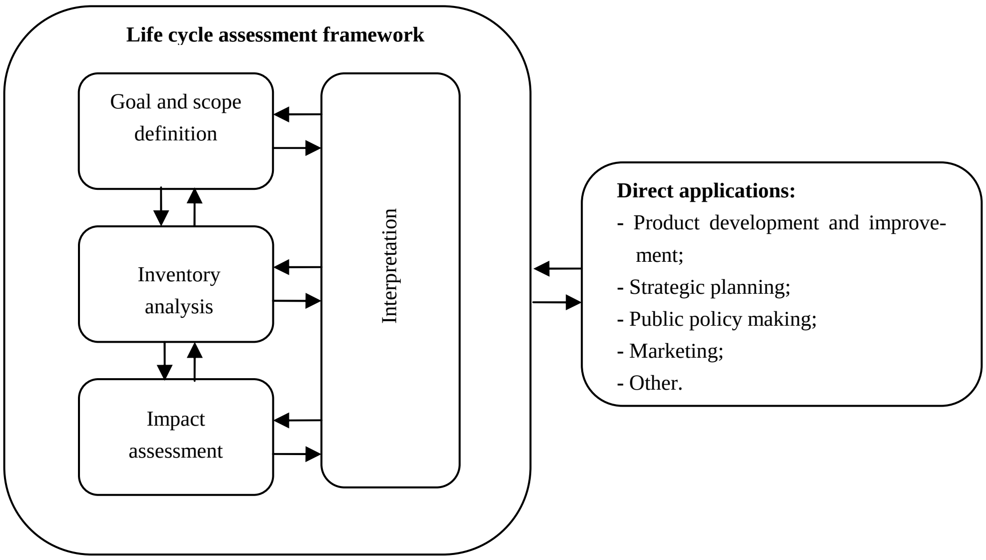


Figure 1. Stage of an LCA in ISO 14040:2006.

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.

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.

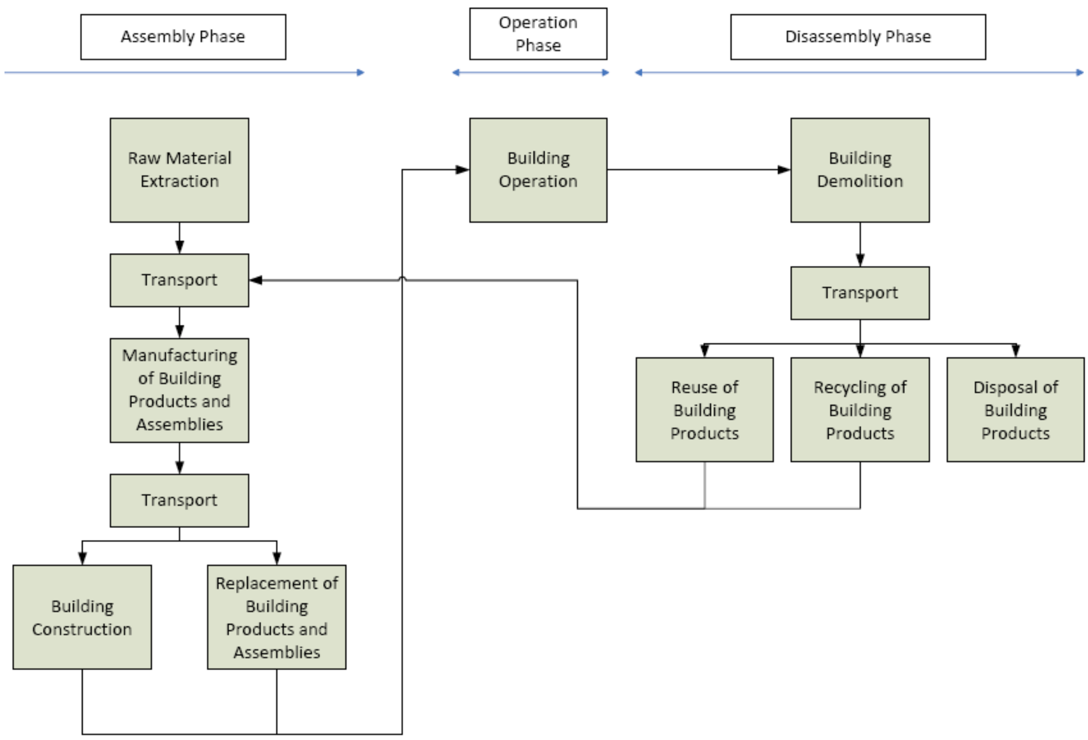


Figure 2. Life cycle of a building (Optis, 2005).

3 INTEGRATION OF LCA IN RATING SYSTEMS

3.1 *Sustainability assessment indicators*

The sustainability rating and certification systems and tools are intended to foster more sustainable building design, construction, operation, maintenance and disassembly/deconstruction by promoting and making possible a better integration of environment, societal, functional and cost concerns with other traditional decision criteria.

These systems and tools can be used both to support the sustainable design, since they transform the sustainable goal into specific performance objectives and to evaluate the overall performance. There are different perspectives in different sustainable building rating and certification, but they have certain points in common. In general, these systems and tools, deal in one way or another with the same categories of building design and life cycle performance: site, water, energy, materials and indoor environment (Bragança, Mateus & Koukari, 2007).

The sustainability indicators of the construction and real estate sector give information about the influences of the industry as a whole and about the impacts of construction and operation of buildings and other built assets. Different approaches for indicators exist due to differences between societies, industrial traditions, environment and geography. The industry-specific indicators may be developed in the framework of national and European sustainability strategies that define high-level indicators. In some countries, the industrial indicators have been developed collaboratively with the stakeholders and consumers which can be regarded as the most advanced sustainability strategy (Agenda 21 by CIB 1999). Typically, the industrial indicators are related to issues of economy and occupational health, and customer satisfaction. The sustainability indicators for a building project can be selected from governmental, sectoral and community lists of indicators.

As an example of the sustainability categories and indicators in building sustainability assessment, Table 1 lists the indicators of the building sustainability rating method SBTool Portugal ($SBTool^{PT}$), developed by the Portuguese Chapter of the International Initiative for a Sustainable Built Environment (iiSBE Portugal).

Table 1. List of categories and indicators used in the building sustainability assessment method $SBTool^{PT}$.

Environmental Performance	Societal Performance	Economic Performance
• **Climate change and outdoor air quality:** Greenhouse gas emissions; Destruction of the stratospheric ozone layer; Potential acid deposition onto the soil and in water; Local tropospheric ozone formation (smog); Addition of mineral nutrients to the soil or water. • **Biodiversity:** Urban density; Re-use of previously developed sites; Contaminated land re-use; Use of native plants; Heat Island Effect. • **Energy efficiency:** Non-renewable energy consumption; On-site production of energy from renewable sources. • **Materials use and solid waste:** Materials depletion; Re-use of salvaged materials; Use of recycled materials from off-site sources; Responsible sourcing of materials; Use of cement substitutes in concrete; Design features and local constrains to minimize waste during building construction and operation phases. • **Water efficiency:** Consumption of water resources; Rainwater retention and grey water recycling.	• **Occupants health and comfort:** Effectiveness of ventilation in indoor occupancies; Off-gassing of pollutants from interior finishing materials; Thermal comfort; Lightning comfort; Acoustic comfort. • **Accessibility:** Public transport accessibility; Accessibility to key amenities;	• **Costs:** Market value; Affordability of the rental or life-cycle's costs; • **Building adaptability and flexibility** Maximization of flexibility and adaptability of the building to future changes

LCA is an important tool for sustainable assessment since it is used to assess the environmental performance in a more accurate and straightforward way. As it is possible to understand from Table 1, LCA is an important aspect in building sustainability assessment; nevertheless it is only used to assess the environmental performance of a product.

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 2. 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 2. 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 3, 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 2: 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 3. 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.

3.2 *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.

There are numerous different types of building products manufactured by myriad manufacturers in Europe. Each building product is manufactured using a specific set of materials and technologies and has unique transportation requirements due to the locations of primary resources, the manufacturing facility and the building. LCI data are thus unique for each individual building product. To incorporate LCA into a rating system in a comprehensive manner would necessitate a LCI database containing data for every type of building product available in the market.

Such a database is not a present reality given the lack of LCI data for many building products. Current LCI databases, rather, are based on national, European or world averages for building products taken from one or a few data sources. Averaged data could cause some distortions in results when comparing different products.

The inherit subjectivity of LCA is related to the fact that a fair comparison of environmental performance of building products would require a standardized procedure for conducting an LCA that is applicable across the entire building industry, and such standardization currently does not exist (Optis, 2005).

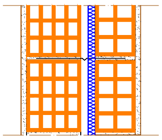
Environmental Product Declarations (EPD) are a good source of quantified information of LCI environmental impact data. In order to potentiate their use, rating systems should be based in the same LCA categories, as stated in the future CEN standard. Nevertheless, at the moment, there are important limitations on this approach, since there is only a small number of companies either having or making publicly the EPD of their products.

One solution to overcome this problem, when the EPD for the used materials are not available, is to import the results that come from the use of external LCA tools and methods (e.g. SimaPro tool and CML2 baseline 2000 method). One important drawback of this process is that LCA procedures are very time consuming and complex and therefore most design teams do not have the necessary expertise to perform it. This is one important constrain in the implementation of more sustainable practices in building and construction.

The best solution is to develop and use databases with the LCA data of the most used building materials and components. In order to facilitate the quantification of the environmental indicators of the whole construction, SBTool^{PT} uses this approach. Therefore a database, with the quantified values of the same environmental indicators used in the EPD, was developed and is continuously updated. This database covers the common building technologies for each building element (floors, walls, roofs and windows, doors), the most common maintenance procedures and the most used building materials.

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. Therefore the first step is to quantify the number of total square meters of each type of construction component and multiply it with the environmental impacts per unit of area (that are in the LCA database). After, the impacts related to the operational energy use and to the maintenance are added in order to quantify the whole building indicators. Table 4 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 4. 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**

3.3 *Aggregation and global performance*

As stated before, the assessment of the environmental performance of a construction across different fields and involves the use of numerous LCA indicators. Nevertheless a long list of indicators with its associated values will not be useful to assess a product or to compare the global environmental performance. The best solution is to combine indicators with each other in order to obtain the global performance of the solution (Allard, 2004).

The SBTool^{PT} methodology uses a complete aggregation method for the global environmental performance (G_{EP}), according to Equation 1.

$$G_{EP} = \sum_{i=1}^{n} w_i . \overline{I_i} \tag{1}$$

$\overline{I_i}$ is the normalized value of the i^{th} indicator and w_i is the weight of the same indicator. The sum of all weights must be equal to 1.

The objective of the normalization is to avoid the scale effects in the aggregation and to solve the problem that some parameters are of the type "higher is better" and others "lower is better". In several endpoint LCA methods normalization is done using a normalization factor. In SBTool^{PT} normalization is done using the Diaz-Balteiro *et al.* (2004) Equation 2.

$$\overline{I_i} = \frac{I_i - I_{*i}}{I_i^{*} - I_{*i}} \quad \forall_i \tag{2}$$

In this equation, I_i is the quantified value of i^{th} environmental indicator per net floor area and per year in the solution under assessment. I_{*i} and I^{*}_{i} are the benchmarks of the i^{th} environmental indicator. I_{*i} corresponds to the conventional practice and is the quantified value per net floor area of the i^{th} indicator in a virtual building that as the same shape of the building under assessment, but that uses the conventional building technologies and materials in the region or country. I^{*}_{i} matches the best practice and corresponds to the quantified value per net floor area of the i^{th} indicator in a virtual building that has only 25% percent of the impact of a building that uses the conventional building technologies and materials. This is a similar approach to the one used in the energy labeling of buildings in Portugal.

Normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values between best and conventional/reference practices into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: "higher is better" and "lower is better".

For example, the normalization of the Global Warming Potential for a hypothetical building is done as presented in Table 5 and Equation 3.

Table 5. Example of benchmarking for normalization

Indicator	Global Warming Potential per net floor area and year
Notation	GWP
Unit	kg CO_2.eq./m^2/year
Value	100
Conventional practice	140
Best practice	35

$$\overline{GWP} = \frac{GWP - GWP_*}{GWP^* - GWP_*} = \frac{100 - 140}{35 - 140} = 0{,}38 \tag{3}$$

In what concerns to the weight of each environmental parameters, there are not national impacts scores for each environmental parameter, according to its relative importance to overall performance. Additionally, European Environment Agency did not have studies on it yet. However, there are some international accepted studies that allow an almost clear definition of it. Two of the most consensual lists of values are based on the US Environmental Protection

Agency's Science Advisory Board study (TRACI) and a Harvard University study (Norberg-Bohm, 1992).

SBTool^{PT} uses the TRACI approach, allocating the considered environmental parameters in the impact categories of that method. Table 6 presents the relative importance of each impact category, according to the US EPA's Science Advisory Board study.

Table 6. Relative importance - weight (%) - of each impact category according to TRACI method (EPA, 2000)

Impact category	Relative importance weight (%) 8 impacts	12 impacts
Global warming	24	16
Acidification	8	5
Eutrophication	8	5
Fossil fuel depletion	8	5
Indoor air quality	16	11
Habitat alteration	24	16
Water intake	4	3
Criteria air pollutants		6
Smog		6
Ecological toxicity		11
Ozone depletion		5
Human health		11

4 CONCLUSIONS

Sustainable design, construction and use of buildings are based on the evaluation of the environmental pressure, functional aspects (related to the users and the local building codes) and life-cycle costs. There is an environmental effect when something is taken from the environment as a resource or returned to it as waste or emissions, which weakens or threatens the availability of resources, the livable environment and the human health. The sustainable design searches a bigger compatibility between the artificial and the natural environments compromising it with the functional requirements of the buildings and the costs associated.

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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