SUSTAINABILITY OF CONSTRUCTION MATERIALS. AN OVERVIEW

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ABSTRACT

After the Brundtland Commission sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

Initially sustainability was mainly addressed from an environmental perspective, but later the importance of social and economic issues was recognized and so they were integrated in the sustainability concept.

Within the construction sector guidance documents and standards were developed establishing the basis for sustainability of materials and buildings. In this paper a review of documents on sustainability of construction works is presented along with some examples of developed applications, pointing out the difficulties on getting quality data and weighing indicators to support decision-making.

KEYWORDS: sustainability, construction, building, material, life cycle assessment.

1 BACKGROUND

Following the World Commission on Environment and Development (1987), known as the Brundtland Commission, [1] sustainable development is defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Since then several international forums, namely United Nations Conference on Environment and Development in 1992 and 2005 World Summit, have addressed the importance of sustainability.

Given the population growth, the resulting pressure on the environment and the need to preserve the opportunities for future generations, improvement targets that illustrate the extent of changes needed to achieve sustainability were included in the conclusions of the Earth Summit +5, 1997. This is the case of Factor 4 that envisaged doubling welfare and, in parallel, halving resource use by 2050, thereby improving global resource efficiency by a factor of four. For the industrialized countries a Factor of 10 is foreseen in 2050 regarding 2000, this claim for having human wellbeing simultaneously with a 10 times reduction in natural material resources.

Sustainable development calls for the adequate balancing of three pillars: environmental, social and economic. These dimensions are also referred to as the 3 P's – People, Planet, and Profit – because the implementation of sustainability is reflected in challenges for people, as regards the satisfaction of social and equity needs, for the planet, concerning the ability to withstand loads in the ecosystems and to profit, in the sense to establish fair value for customers and stakeholders throughout the global value chain.

The sustainable development concept is becoming increasingly important within the construction industry owing to the several challenges this sector faces like energy consumption and climate change, impact on natural resources, waste management and well being of users.

To overcome these problems the appropriate application of sustainability principles to construction works will contribute to the development and implementation of new solutions at different levels such as the building design, the functional performance or the choice of materials. Nevertheless the fragmentation of the construction sector accounts for a barrier to innovation and therefore it is essential the involvement of the various stakeholders to move forward.

The Lead Market Initiative (LMI) for Europe, launched in 2006 to lower barriers between trade and innovation, recognized sustainable construction as one of the promising emerging markets. Screening of national building regulations identified some limitations that must be overcome: usually they do not apply to existing constructions and/or renovations; the number of topics related to the environmental quality of sustainable construction receives more attention in relation to economic quality or social quality aspects as depicted in Figure 1 [2].

A similar trend, i.e. privileged assessment of environmental dimension, can be found on voluntary schemes already developed for evaluating the sustainability of the built environment, although some of these building labelling schemes have later evolved in order to integrate some economic and social issues.

The existing tools for assessing the sustainability are based on the evaluation of a set of indicators, to which are assigned different weightings, resulting in a rating that determine the overall performance of the construction project. Usually different appreciations are conducted for different buildings - residential, office, industrial – and different calculations were used by the different assessors, resulting on classifications which are not comparable.

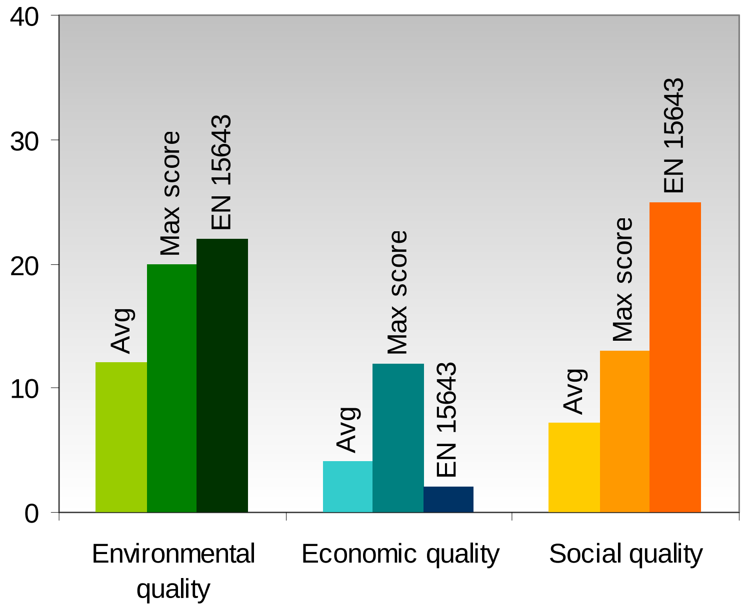

Figure 1 Number of topics regarding sustainable construction on building regulations – Avg refers to the average number of topics per country and Max score refers to the number of different topics in the countries analysed – and number of indicators on the European standard EN 15643

Table 1 [3] emphasizes the differences of two established methodologies, the Building Research Establishment Environmental Assessment Method (BREEAM) and the Leadership in Energy and Environmental Design (LEED); although some categories seems to cover identical issues they embrace distinct parameters and different weightings.

To avoid technical barriers related to Member States regulations and voluntary schemes, the formal mandate M350 to CEN was issued by the European Commission in 2004. The scope of M350 is to “provide a method for the voluntary delivery of environmental information that supports the construction of sustainable works including new and existing buildings”.

Based on this mandate the technical committee CEN/TC 350 assumed the task to develop European horizontal standards for environmental assessment of sustainability on construction works, and extended it to the social and economic dimensions.

The activity carried out within CEN/TC 350 used an interdisciplinary approach to account for other standards, namely the ISO standards developed in TC 59/SC17, Sustainability in Building Construction and in TC 207 Environmental Management, and EU policies/directives such as the LMI or the Construction Products Regulation (CPR) – specially regarding the Basic Works Requirement 3 – “Hygiene, Health and Environment”, and the Basic Works Requirement 7 – “Sustainable use of natural resources”. Within this context reference should be made to the CEN/TC 351, created in response to European Commission mandate M366, on the subject of release of dangerous substances from construction products.

Table 1 Weightings of BREEAM 2011 and LEED 2009 [3]

BREEAM 2011		LEED 2009		
Environmental Section	**Max. Weighted % Points**	**Environmental Category**	**Weighting**	**Max. Points**
Land Use & Ecology	10%	Sustainable Sites	23.6%	26
Water	6%	Water Efficiency	9.1%	10
Energy	19%	Energy & Atmosphere	31.9%	35
Materials	12.5%	Materials & Resources	12.7%	14
Health & Wellbeing	15%	Indoor Environmental Quality	13.6%	15
Transport	8%	Innovation in Design	5.5%	6
Waste	7.5%	Regional Priority	3.6%	4
Pollution	10%			
Management	12%			
Innovation (additional)	10%			
Total	110%	Total	100%	110

2 THE FRAMEWORK FOR SUSTAINABILITY ASSESSMENT OF BUILDINGS

The recently published European standards EN 15643, parts 1 to 4 [3-6], compose the framework for the sustainability of construction works, regarding assessment of buildings, which is complemented with a set of normative documents at the building level that defines the methods for assessment of the environmental, social and economic performance – EN 15978 [7], pr EN 16309 [8] and WI 017 [9].

As depicted in Figure 2 the quantification follows a bottom-up approach, beginning at the level of the products, i.e. the building materials, and ending at the building level. The required information concerning products is developed on section 3.

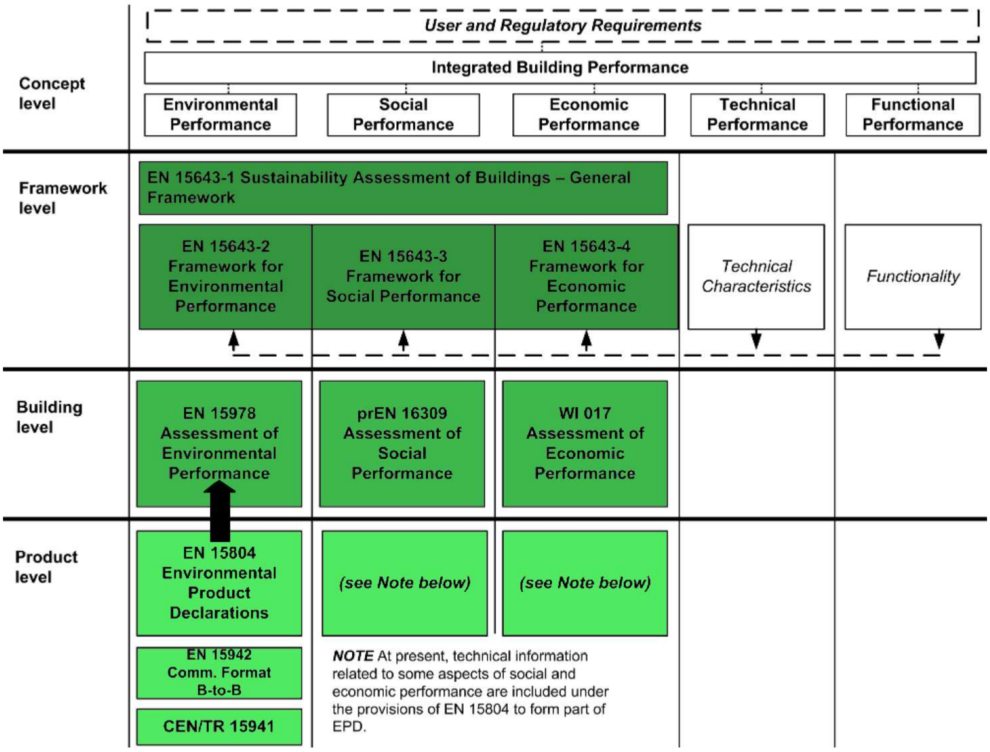

Figure 2 Normative documents from CEN/TC 350 [4]

The assessments methods are based on a life cycle, approach and the environmental, social and economic aspects and impacts are determined by means of quantitative and qualitative indicators, taking into account technical and functional characteristics, which could assist the client, user and designer on decision-making.

According to the definition life cycle assessment, LCA, is a “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”. The LCA process is a phased approach consisting of four components: definition of the goal and scope of the study, life cycle inventory analysis, life cycle impact assessment and interpretation of results.

For the life cycle assessment, LCA a cradle to grave approach is used, i.e. the life cycle includes the product stage, and the construction stage, the use stage and the end of life stage, as indicated in Figure 3 [4]. As an option, it is possible to take into account the benefits and loads associated with reuse, recycling and recovery arising from the net flows of materials and exported energy that leaves the system boundary.

The framework requires setting the object of assessment that comprises the building, new or existing, its foundations and the enclosed area immediately surrounding it and provisional works related to its construction and the system boundary that defines what is included and excluded from the assessment.

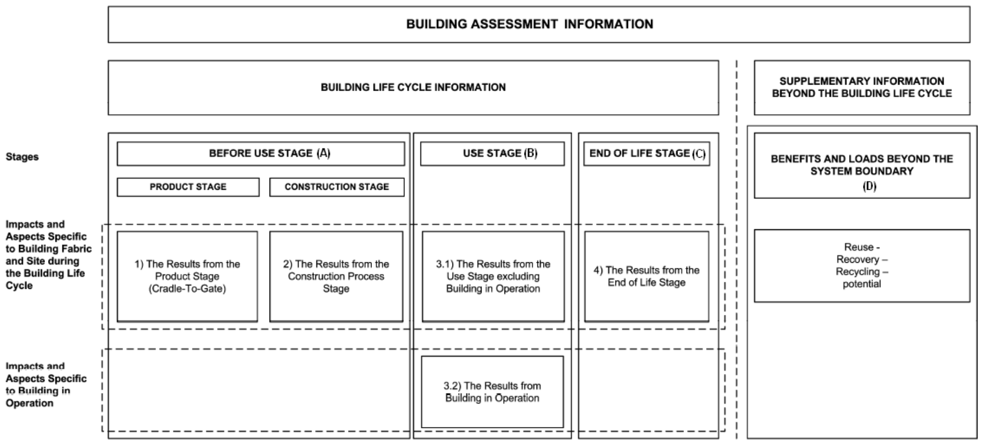

Figure 3 Life cycle stages and corresponding information [4]

For the assessment it is also necessary to set the functional equivalent that is intended to facilitate the comparison of the results of environmental, social and economic assessments of buildings. The functional equivalent for a building is a minimalist description of the object of assessment representing the relevant technical and functional characteristics, required in client's brief or regulatory requirements, given the building type, the pattern of use and the required service life. It should be noted that buildings with different functional equivalents can also be compared making use of a common unit of reference, adimensional or qualified with a dimension as for instance per m² per year.

To perform the assessment it is indispensable to provide the distinct indicators to be used. Indicators subject of national, regional, or local regulation, indicators not regulated and indicators not assessed should be stated in the assessment report according to the rules of data presentation.

The indicators utilized for environmental assessment of buildings are related to the life cycle impact assessment, namely climate change, destruction of the ozone layer and acidification of land and water, or resultant from the life cycle inventory, for example depletion of non renewable resources or use of renewable resources [5].

In what concerns to the indicators for the social assessment although the framework account for the impact/involvement of the users, the neighbourhood and the society in all the life cycle stages of construction works, it is found that at the building level only the accessibility for people with special needs and for building operation, adaptability, health and comfort, loadings on the neighbourhood, maintenance and safety and security, related to the use stage, are considered [6].

For the economic assessment of buildings life cycle costs and other economic aspects should be addressed. The cost and financial value are calculated over the life cycle that begins in the project conception and ends on project decommissioning for new buildings. For the evaluation based on costs the “lowest life cycle cost” is the most economic one while for appraisal based on the financial values the best financial value building is the most economic one, i.e. the building with the highest difference between revenue and cost [7].

The standards EN 15643, parts 1 to 4, do not include valuation methods neither classes of performance; these may be prescribed in the client’s brief, in national codes or in certification schemes.

3 SUSTAINABILITY OF CONSTRUCTION PRODUCTS

The whole European normative framing for construction products – EN 15804 [10], EN 15942 [11] and the technical report CEN/TR 15941 [12] – refers to the provisions/guidelines for the Environmental Product Declarations, EPD, which are focused in the environmental evaluation. The framework for social and economic assessment of products can only be found in national standards of member states, which is the case of the British standard BS 8905, or in established methodologies.

EN 15804 outlines the product category rules, PCR, for assessing the environmental performance of construction products based on a LCA approach. Figure 4 evidences the types of EPD as a function of the stages covered: “cradle to gate” EPD include information from modules A1 to A3; “ cradle to gate with options” EPD comprise the product stage and optionally other stages; “cradle to grave” EPD hold information from all stages within the system boundary.

Similarly to what was observed for buildings it is possible to assess the benefits and loads related to material reuse and recycling and to energy recovery by including information for the module D.

The format to express EPD, detailed in Annex A of EN 15942, follows a specified template, designated by Information Transfer Matrix, ITM, which covers all the life cycle stages or merely distinct life cycle stages. Aggregation of data could only be used for the modules A1-A3 of the product stage.

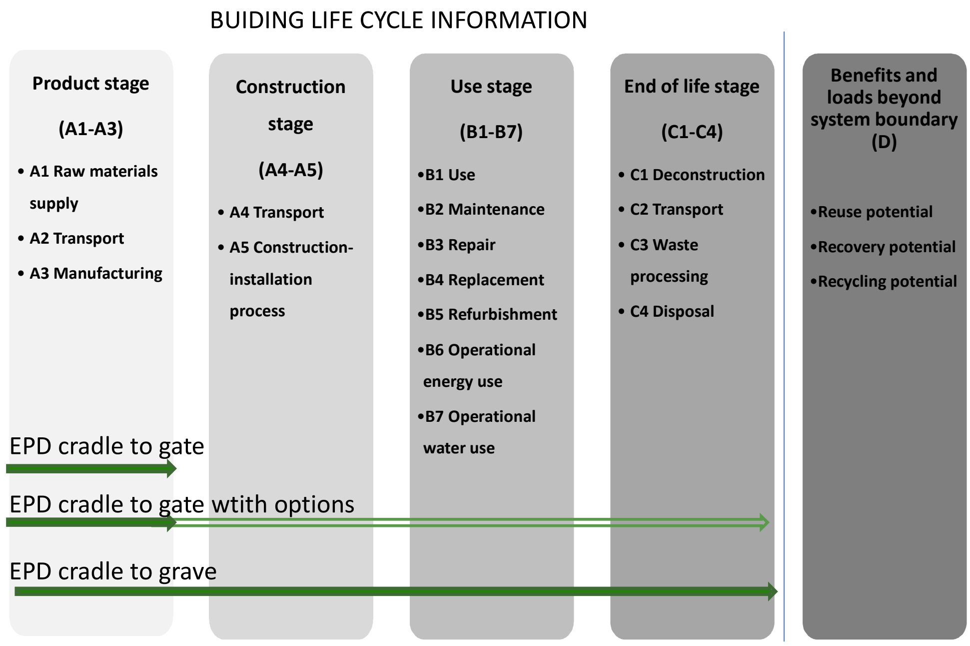

Figure 4 Types of EPD with respect to life cycle stages: mandatory information in dark green and optional information in light green.

Owing to the utilization of EPD in building assessment it is necessary to ensure consistency of data by adopting common issues like system boundary, calculation rules or indicators. The application of data, generic or specified, is assigned to different modules, Table 2.

The indicators for environmental assessment of products are ascribed to the following four groups:

– Indicators describing environmental impacts – Global warming, ozone depletion, acidification for soil and water, eutrophication, photochemical ozone creation, formation potential of tropospheric ozone, depletion of abiotic resources-elements and depletion of abiotic resources-fossil fuels.

– Indicators describing resource use – 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, Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials, 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), use of secondary material, use of renewable secondary fuels, use of non renewable secondary , net use of fresh water.

– Indicators describing waste categories – Hazardous waste disposed, non hazardous waste disposed and radioactive waste disposed.

– Indicators describing the output flows leaving the system – Components for reuse, materials for recycling, materials for energy recovery and exported energy.

Table 2 Use of generic and specific data

Modules	A1 - A3		A4 and A5	B1 - B7	C1-C4
	Production of commodities, raw materials	Product manufactured	Installation processes	Use processe s	End of life processes
Process type	Upstream processes	Processes the manufacture has influence over	Downstream processes		
Data type	Generic data	Manufacture's average or specific data	Generic data		

Until now the incorporation of sustainability issues in product standards is unusual, except in what concerns the release of dangerous substances from construction products that is included in a few number of product standards as an outcome of the essential requirement 3 of Construction Product Directive. With the publication of the Construction Product Regulation, in 2011, and of the 2012 Draft ISO Guide 82 it is expected that the future product standards will enclose information related to other environmental aspects and also the social and economic ones.

In this context it should be noted that the basic requirement 7 of CPR state that “for the assessment of the sustainable use of resources and of the impact of construction works on the environment Environmental Product Declarations should be used when available” and that it come into force in July 2003.

ISO Guide 82 intends to promote inclusion, in the drafts of new standards or in the revision of existing standards, of all relevant and related sustainability issues taking into account the short, medium and long term repercussions, by selecting one of the approaches indicated on this guide. The product standards should address issues like the resource used to manufacture the product and the consequent greenhouse gas emissions involved in the manufacture of the product or the health and safety impacts related to the use of the product.

4 LIFE CYCLE ASSESSMENT OF CONCRETE

Being concrete the second most used material in the world it is particularly relevant the application of the sustainability concept during its production and use. For achieving a better environmental performance of concrete it is possible to act for instance at the materials chain, mainly on cement production.

Cement industry fit in the energy intensive industries primarily responsible for green house gas emissions, GHG. The principal GHG from cement industry is CO_2 in the form of direct emissions, due to decarbonation of raw materials and combustion of fuels, and indirect emissions, owing to power consumption of different stages of the process.

According to International Energy Agency the CO_2 emissions on cement plant by using better thermal and electric efficiency technologies, by shifting to alternative fuels, by replacement of clinker by supplementary cementitious materials and by implementation of carbon capture and storage technologies will be halved by 2050 as indicated on Table 3.

Table 3 Cement roadmap [15]

Cement Roadmap Indicators	2012	2015	2020	2025	2030	2050
Thermal energy consumption per tonne of clinker GJ / tonne	3.9	3.8	3.5-3.7	3.4-3.6	3.3-3.4	. 3.2
Share of alternative fuel & biomass use (1)	5-10%	10-12%	12-15%	15-20%	23-24%	37%
Clinker to cement ratio	77%	76%	74%	73.5%	73%	71%
CCS						
no. of pilot plants	2	3				
no. of demo plants operating		2	6			
no. of commerical plants operating				10-15	50-70	200-400
Mt stored	0.1	0.4	5-10	20-35	100-160	490-920
Tonne CO_2 emissions per tonne cement (2)	0.75	0.66	0.62	0.59	0.56	0.42

Notes: (1) assumes 25 to 30 Mtoe of alternative fuel use in 2015 and 50 to 60 Mtoe in 2030, and excludes energy from CCS and electricity use, (2) includes reduction from CCS
Source: IEA, 2009

The results of life cycle assessment rely on the confidence of the used data. LCA of concrete require data from its component. Regarding cement it has been reported discrepancies in the definition of system boundaries used in the life cycle impact assessment, LCIA, for various types of cements produced in Europe, using a cradle to gate approach and a reference unit of 1 kg of cement [16]. These inconsistencies will probably be decreased with the implementation of EN 15804 leading to more accurate evaluation of the impact of concrete and subsequently of the building.

As mentioned before it is relevant the choice of the adequate reference unit. Functional units that include relevant aspects for concrete, i.e. strength and durability are usually used in LCA of concrete. Reference units like 1 MPa and 1 year of life could be useful for example when comparing concrete from the viewpoint of sustainability incorporating different components that leads to worst performance in terms of compressive strength and better performance regarding durability.

More complex functional units, for instance the amount of binder per m3 of concrete necessary to deliver 1 MPa of strength, or the amount of concrete necessary to produce a structural element with a predefined service life in a specified environment under a know mechanical load [17] could also be found in the literature.

5 DATA QUALITY

The quality of a life cycle assessment is directly correlated to the accuracy of inventory data, which is often gathered on existing databases regarding building materials. The reliability, related to the use of measured or estimated data, the completeness, corresponding to the representativeness of the sample including adequate quantity of data, the temporal correlation, covering a period of time close to the period of study, the geographical correlation, concerns to data for the same area under study similar and technological correlation, connected to type of processes and technologies used, are important parameters to verify the quality of data.

EN 15804 indicate characteristics of the data that ensure quality, namely use of recent data sets, data averaged at least for 1 year, generic data shall have been updated in the last 10 years whereas the deadline for specific data is the last 5 years. Guidance related to selection and use of generic data is provided in CEN/TR 15941.

6 FINAL REMARKS

The framework developed by CEN/TC 350 represents a breakthrough in the identification of indicators which must be used to assess the sustainability of construction works.

This new approach will allow a better comparison of the Environmental Product Declarations although it is deemed to have more accurate data on the existing databases for building materials and to gather local data in order to improve the LCA

Still pending is the valuation part of the assessment. In fact various weighting judgements are used in different countries but it is desirable to define at a global level weighting values together with the possibility of having different weightings to account for specific aspects at regional or local level.

When a constructive solution or material is not advantageous in all aspects of sustainability, decision-making becomes complicated and in the search for an adequate balance the economic assessment turns out to be the most important one.

Going from construction products to buildings represent an enormous challenge on the LCA owing to the fact of increased process complexity and use of premises which can only be confirmed after long periods of time, which obliges the use of adequate scenarios.

Even using the traditional products and systems, the sustainability of construction works may be improved through an adequate control of construction works execution and the proper use of products.

It is expected that this new harmonized approach, still in the beginning, will contribute to the development of a more sustainable construction.

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