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The Evaluation of Sustainability Performance Indicators

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Abstract
The sustainability concept has been progressively recognized as an important pillar in the construction industry. This yields from the intense efforts already undertaken by some countries on the creation of tools capable of its incorporation in the current approaches for design decisions. In this paper a first approach for the integration of some of these aspects in a Design Quality Assessment Method for housing buildings developed at FEUP will be presented. The proposed classification reviews two of the stages of the materials life cycle – the mining and the production ones - where a comparison is performed among the diverse construction materials in terms of their embodied energy, following the established organization matrix for the assessment method. This work aims to provide procedures that allow a more careful choice of the materials, taking in consideration the needs of the upcoming generations.

1 Introduction

1.1. General Concepts

The sixties and the seventies were marked by an awareness of the society related to environmental issues. This theme began to be politically debated in various activities and events. In 1987, the United Nations World Commission on Environment and Development has defined this concept as "development which meets the needs of present generations without compromising the ability of future generations to meet their own needs" [1]. Indeed, this is an important parameter to be taken into account by all those who are involved in the construction process. Thus, the decisions taken in the project should also be based on the sustainability concept.
In the recent years, there has been growing awareness on the environmental aspects in the construction sector. The conscientiousness on the emission of greenhouse gases and the energy consumption in manufacturing processes has caused a major concern on the monitoring of environmental impacts. The

energy requirements for the production of different building materials, the CO_2 emissions and their implications on the environment have already been studied by different authors [2].
The Life Cycle Assessment is a type of evaluation technology of the environmental factors related to the product and its function, including producing input and output inventory. Many methods of appraisal of the project's sustainability are based in this concept. Its analysis becomes even more burdensome when it is remembered that each resource has to be analyzed from its place of origin on the environment to its ultimate reabsorption (following demolition of the building or complex) into biosphere (Fig. 1).

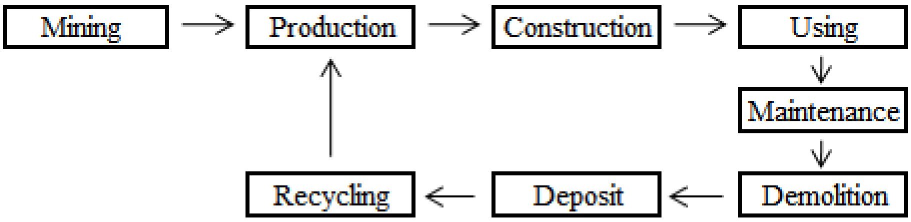

Figure 1: Materials Life Cycle.

The energy cost of a design system must be considered in the broadest sense - over the course of its entire life cycle. In fact, it is very difficult to evaluate the energy cost in all the stages of the materials life cycle. Therefore, in this article we are only going to study two of these stages – the mining and the production ones.

1.2. Sustainability Assessment Methods

There are many sustainability assessment methods all over the world. In the eighties, CASBEE – Comprehensive Assessment System for Building Environmental Efficiency was created in Japan. CASBEE is composed by four assessment tools corresponding to the building lifecycle - CASBEE for Pre-design, CASBEE for New Construction, CASBEE for Existing Building and CASBEE for Renovation, to serve at each stage of the design process. Each tool is intended for a separate purpose and target user, and is designed to accommodate a wide range of uses (offices, schools, apartments, etc.) in the evaluated buildings. Under CASBEE, there are main assessment categories, evaluated separately, defined as Building Environmental Quality & Performance, Q and Building Environmental Loadings, L. The environmental label obtained by this methodology is the BEE – Building Environmental Efficiency - and it is calculated according to Fig. 2 [3].

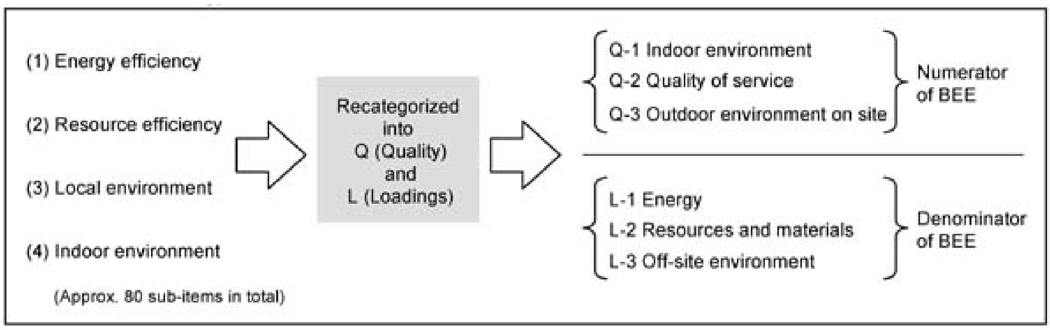

Figure 2: Classification and rearrangement of assessment items into
Q (Building environmental quality and performance) and L (Building environmental loadings) [3].

Another sustainability assessment method is the LEED – Leadership in Energy and Environmental Design – which was created in the United States in 1993. LEED is an internationally recognized green building certification system, providing third-party verification that a building or community was designed and built using strategies that aim to improve the performance across all the metrics that matter most. It promotes a whole-building approach to sustainability by recognizing performance in key areas presented in Fig. 3. LEED points are awarded on a one hundred-pointed scale, and credits are weighted in order to reflect their potential environmental impacts. Additionally, ten bonus credits are available, four of which address regionally specific environmental issues. A project must satisfy all prerequisites and earn a minimum number of points to be certified [4].

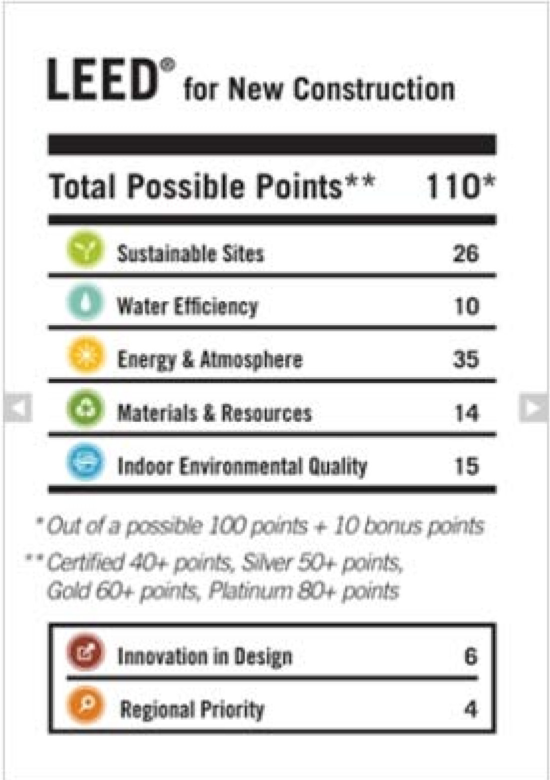

Figure 3: LEED Classification and assessment items [4].

The Code of Sustainable Homes is an environmental assessment method for new homes based upon Building Research Environmental (BRE) Global's Ecohomes and contains mandatory performance levels. It was based in the sustainable assessment method BREEAM, created in 1990, in England. This methodology evaluates seven main credit categories: Energy, Transport, Pollution, Materials, Water, Land Use and Ecology, Health and Wellbeing and Management. For each one, it is attributed a given number of credits according to the characteristics of the construction and their sum determinates a certain performance level. The Code aims to protect the environment by providing guidance on the construction of high performance homes built with sustainability in mind [5].
There are much more sustainability assessment methods – Habitat & Environment (France) [6], Lider A (Portugal) [7], HK-BEAM (Hong-Kong) [8]. The ones presented in this chapter are the most used and known all over the world.

2 Materials Selection

There is a number of factors to take into account when selecting materials. If we are approaching design with concerns for environmental consequences, we must thoroughly analyze and quantify the energy and materials resource requirements of a building. Designers must also go beyond functionalism when selecting materials and energy forms for use in their projects. One design criterion should be the environmental impact.

In fact, there are three general objectives for implementing sustainability in construction materials selection [1]:

- Minimizing the consumption of matter and energy;
- Maintaining some reasonable degree of human satisfaction;
- Causing minimal negative environmental impacts.

Thus, consuming as little matter and energy as possible, or "doing more with less", is a fundamental objective of sustainability and of sustainable material selection.

Production and materials selection for the designed system should be according the following steps [9]:

- Identification of the material categories;
- Identification of the building material options;
- Gathering of technical information;
- Review of the submitted information for completeness;
- Evaluation of the options based in some criterions;
- Selection.

The criteria for the selection of materials should take into account its potential for recycling, its embodied energy and its place of origin.

Thus, a measure of sustainability for material selection reflects the level of resource consumption, the degree to which human satisfaction is achieved, and the net level of negative environmental impacts.

3 Sustainability Performance Indicators

It is important to have some indicators to facilitate the analysis of the environmental impact. In this article it is proposed a classification where a comparison is performed among the diverse construction materials in terms of their embodied energy, following the organization matrix established for the Design Quality Assessment Method for housing buildings developed at FEUP, MC.FEUP.

This assessment method proposes an Hierarchy of Objectives describing, in an extensive way but compatible with a practical use, the various components of a housing building, both in the construction and services' fields and in the domain of space modeling and organization.

This Hierarchy is associated to several Evaluation Criteria, based on parameters which may be obtained directly from written or drawn design specifications (Fig. 4) [10].

Main Objective	Objectives' Complexes	Superior Objectives
DWELLING QUALITY	**Efficiency of Constructive Aspects**	Structural Safety
		Safety Against Fire
		Environmental Confort
		Durability of Non-Structural Materials

	Facilities' Efficiency and Maintenance
	Sustainability
Efficiency of Spatial Uses	Spatial Conception of Private Areas
	Uses of Building's Common Areas

Figure 4: Hierarchy of Objectives of the assessment method MC.FEUP.

In Fig. 2, Sustainability is already incorporated as a Superior Objective. This one is, like the others, in the assessment method, subdivided into Performance Indicators (Fig. 5).

Superior Objective	Partial Objectives	Criteria	Performance Indicators
SUSTAINABILITY	**Embodied Energy**	Finishing and Coverings	Wall Finishing and Covering Materials' Embodied Energy
			Floor Finishing and Covering Materials' Embodied Energy
		External Openings	Frame Materials' Embodied Energy
			External Protection Materials' Embodied Energy
		Opaque Areas	Thermal Insulation Materials' Embodied Energy
			Wall Panel Materials' Embodied Energy

Figure 5: Superior Objective Sustainability and its Performance Indicators.

3.1. Methodology – Construction Materials' Embodied Energy

Similar to the methodology MC.FEUP, five quality levels were created, on a scale of zero to four, where zero corresponds to materials with higher energy consumption in their manufacture, and four to those who need less energy to be produced.
A list of materials' embodied energy [11] was grouped by function and the different sets were divided into five intervals, using percentiles, for the subsequent allocation of classification.

3.1.1 Finishing and Covering Materials' Embodied Energy

The Objective-Criterion Finishing and Coverings was divided into Wall Finishing and Covering Materials' Embodied Energy and Floor Finishing and Covering Materials' Embodied Energy. Despite this subdivision, the classification proposal is the same (Table 1), since the materials used in these two areas are similar.

Table 1: Classification Proposal of Sustainability Performance Indicators of Finishing and Covering Materials' Embodied Energy.

Level	Situation	Material Examples
4	Embodied Energy < 20 MJ/m^2	Paint, Wood, Paper
3	20 MJ/m^2 ≤ Embodied Energy < 40 MJ/m^2	Tile, Natural Stone, Aluminum
2	40 MJ/m^2 ≤ Embodied Energy < 80 MJ/m^2	Plaster, Plasterboard
1	80 MJ/m^2 ≤ Embodied Energy < 120 MJ/m^2	MDF, Ceramic Brick Glazed,Vinyl
0	Embodied Energy ≥ 120 MJ/m^2	Fibre Cement Board, Linolium, Zinc

3.1.2 External Opening Materials' Embodied Energy

In these Criteria there were analyzed two Sustainability Performance Indicators. The first one is related to the frame materials' embodied energy and the second to the openings external protections.
Once more, and for the same reason, it was not made, in terms of classification, a distinction of these two Sustainability Performance Indicators (Table 2).

Table 2: Classification Proposal of Sustainability Performance Indicators of External Opening Materials' Embodied Energy.

Level	Situation	Material Examples
4	Embodied Energy < 30000 MJ/m^3	Wood
3	30000 MJ/m^3 ≤ Embodied Energy < 200000 MJ/m^3	Reciclated Steel, PVC
2	200000 MJ/m^3 ≤ Embodied Energy < 370000 MJ/m^3	Virgin or Galvanised Steel
1	370000 MJ/m^3 ≤ Embodied Energy < 550000 MJ/m^3	Virgin or Extruded Aluminium
0	Embodied Energy ≥ 550000 MJ/m^3	Factory Painted or Anodised Aluminium

3.1.3 Opaque Areas Materials' Embodied Energy

In the Opaque Areas Objective-Criterion, two Sustainability Performance Indicators were considered – the Thermal Insulation Materials' Embodied Energy and the Wall Panel Materials' Embodied Energy.
In this Objective-Criterion, in contrast to the previous ones, it was proposed a classification for each Sustainability Performance Indicators (Table 3 and 4). On the other hand, since there are not as many materials in these areas as in the earlier, the classification has only three levels of performance.

Table 3: Classification Proposal of Sustainability Performance Indicators of Thermal Insulation Materials' Embodied Energy.

Level	Situation	Material Examples
4	Embodied Energy < 200 MJ/m^3	Cellulose, Wool
2	200 MJ/m^3 ≤ Embodied Energy < 650 MJ/m^3	Polyester
0	Embodied Energy ≥ 650 MJ/m^3	Fibreglass ou Polystyrene

Table 4: Classification Proposal of Sustainability Performance Indicators of Wall Panel Materials' Embodied Energy.

Level	Situation	Material Examples
4	Embodied Energy < 2000MJ/m^3	Stone, Wood
2	2000 MJ/m^3 ≤ Embodied Energy< 3000MJ/m^3	Concrete (17,5 MPa),
0	Embodied Energy ≥ 3000 MJ/m^3	Ceramic Brick, Concrete (30 MPa or 40,0 MPa)

4 Development of the Proposed Assessment Method

One of the multiple analysis that can be made in this area is the quantification of the embodied energy per unit of construction area, in other words, calculate the ratio between the sum of all energies involved in the manufacture of different materials and the area of each fraction. This could be achieved by multiplying the embodied energy value by the respective material's volume or the area. If the embodied energy value has as units MJ/m^3 must be multiplied by the volume of corresponding material, if this parameter has as units MJ/m^2 must be multiplied by the global area [12]. The global embodied energy is given through the equation (1).

$$E.E._{global} = \left[\sum\left(E.E._{material} \times A_{material}\right) + \sum\left(E.E._{material} \times V_{material}\right)\right] / A_{dwelling} \qquad (1)$$

This can also be made with the classification of the proposed assessment method. In this case, the global level is obtained using the materials' areas and volumes as weighting through the equation (2) where S.L. means Sustainability Level, presented in the tables of the methodology.

$$S.L._{global} = \frac{\sum\left(S.L._{material} \times A_{material}\right) + \sum\left(S.L._{material} \times V_{material}\right)}{\sum A_{material} + \sum V_{material}} \qquad (2)$$

The purpose of these analysis is to get a final value which characterizes the dwelling's embodied energy.

5 Concluding Remarks

This work aims to provide procedures that allow a more careful choice of the materials, taking into account the sustainability concept. In fact, there are other criteria that we have to take in consideration when selecting materials. Ideally, the materials should be selected according to the amount of energy consumed in its production and in their transport, of greenhouse gases over their life cycle and the ability to be reused or recycled. All of these criteria cause environmental impacts. On the other hand, the embodied energy impacts decreases if a material could be reused or recycled – the concrete embodied energy is less than the steel embodied energy, but is more difficult to recycle concrete than steel.

However, this evaluation would constitute a highly complex analysis and it is much less objective than the quantification of embodied energy.

The analysis proposed in chapter 4 can only be obtained if we have a classification for all the material's functions in a building. In this article, we only presented six different Sustainability Performance Indicators, being this is a first approach for a Design Sustainability Assessment Method.

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