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EXPLORING THE NEED FOR AN EVALUATION MODEL TO ASSIST IN THE ECO-EFFICIENT SELECTION OF BUILDING SYSTEMS

Belinda López-Mesa[1], Teresa Gallego[1], Elena Mulet[1], Ángel Pitarch[1] and Ana Tomás[1]
[1] Dep. of Mech. Engng. & Construction, Universitat Jaume I, Castellón, Spain

ABSTRACT
With the current practices in architecture and construction, buildings use more than a half of the energy consumed in the world. Designers have an important stake in this respect, being of great importance the selection of materials and building systems. The objective of this paper is to explore the need of assisting in the eco-efficient selection of building systems and to propose an evaluation model with this purpose. A bibliography analysis of norms on the protection of the environment, a study through questionnaires, and a bibliography analysis to study the theoretical base for the decision model proposed are realised in this paper.

Keywords: design for sustainability, building systems selection, life cycle analysis, environmental costs, environmental legislation

1 INTRODUCTION

With the current practices in architecture and construction, buildings use more than a half of the energy consumed in the world [1]. Many are the factors that have an influence on the impact that buildings construction has on the environment, and the responsibility for this is shared by developers, owners, architects and engineers, finance institutions, government authorities, contractors, material suppliers, labourers, tenants, building managers, operation and maintenance personnel, recyclers salvagers, and landfill/incinerat managers [2]. Designers (architects and engineers) have an important stake, though, being of great importance the selection of materials and construction systems.
The objective of this paper is to explore the need of assisting in the eco-efficient selection of construction systems and to propose an evaluation model with this purpose.

2 RESEARCH METHODOLOGY

The need of the model is studied by means of:

- Analysis of the evolution of design criteria in the building industry. This is done by:
    - A bibliography study of the evolution of the environmental legislation in Europe and Spain applicable to the building industry.
    - A study, through questionnaires, of the aspects that designers take into account to select construction materials and systems, and how they have evolved with time.
- Study of the gaps regarding environmental information of materials and construction systems through bibliography analysis.
- Bibliography study of the sources that can be used as theoretical base for the new model

Finally, a model is proposed based on the results from these studies.

3 EVOLUTION OF THE ENVIRONMENTAL LEGISLATION APPLICABLE TO THE BUILDING INDUSTRY

3.1 European legislation

Europe has an extensive environmental legislation. For this reason, only the most important events of the last 50 years are here referred.

The initial environmental policies adopted **in the 60s** in Europe were sanctioning. The laws were not useful to foresee the damage, but to correct what was already damaged.
The celebration in Stockholm **in 1972 of the United Nations Conference on the Environment** marked a before and an after in the fight for the environment. Enjoying an adequate environment is declared as a fundamental right of human beings, and the obligation of the States to preserve it and protect it is acknowledged. As a consequence from this conference, the legislative production on the environment increased in all the European countries.
In 1973 the First Environmental Programme was initiated. The first directives published included norms for the marketing, use and labelling of pesticides and toxic waste. The directives and norms did not have a strong weight in the national legislations and not much attention was paid to them [3].
In the 90s, several countries created national laws regarding the protection of the environment, and the EU created the European Environmental Agency (EEA) with the objective of obtaining information regarding the state of the current and future environment in Europe.
Also in the 90s, norms regarding Environmental Management Systems were developed. The first one was written by the British Standard Institution in UK (Norm BS7750), which was experimentally approved in 1992 and published in 1994 in its definitive version. This norm was used as a model for the rest of the norms developed in European countries. In Spain, the "Asociación Española de Normalización y Certificación" (Spanish Association of Standardisation and Certification) AENOR designed the norm UNE 77801:94 Environmental Management Standards, which is very similar to the British one and was approved in 1994.
The first draft of a European regulation regarding the Eco-Management and Audit Scheme (EMAS) was presented in 1991 and definitively approved in 1993 as the Regulation 1836/93/EEC. The Regulation is designed to urge industrial firms to behave in an environmentally responsible manner. The reward for firms is that they can exhibit the EC's Eco-Management and Audit logo. Once the efficiency of the model was observed, it was extended to any kind of firms by the Regulation 761/2001/EEC, which derogated the previous one.
At an international level, from 1991 the Strategic Advisory Group on the Environment (SAGE) of the International Organisation for Standardisation (ISO) has worked on initiatives regarding the regulations of the environmental management. In October 1996, ISO approved the international Norm ISO 14001:1996 Environmental management systems Specification with guidance for use, derogated today by ISO 14001:2004.

3.2 Spanish legislation

The most important events are referred to next.
In the 70s, the first environmental legislation is concerned with emissions to the atmosphere. In 1984, a regulation is approved regarding asbestos hazard at work, and later regarding lead poisoning prevention at work, but it is not until 1989 when funding is given for the application of the National Plan for Industrial Waste.
In the 90s, the Law 21/10/98 is approved, defining the responsibility of the Autonomous Regions of developing autonomic plans for waste management, and their responsibility in the authorisation, monitoring, inspection and sanctioning of manufacturing activities and waste management. This law considers construction sites waste as urban waste if they come from minor construction works. Otherwise, the management of waste from constructions demolitions is a responsibility of the Autonomous Region.
In 2001, the Agreement at the cabinet meeting approves the National Plan of Waste from Construction and Demolition 2001-2006.
In March 2006, the Spanish Council of Ministers approved a new construction standard through Royal Decree 314/2006 of 17 March 2006, known as the **Technical Buildings Code (CTE – Código Técnico de la Edificación)** [4]. This updates the old decree dating from the 1970s and partially transposes the EU Directive 2002/91/CE on Energetic Efficiency in Buildings.
Among all these changes, the one that is causing the most important change in the Spanish building industry is the recently approved CTE**.** The new standard establishes new quality, security, energy efficiency and habitability requirements for new or renovated buildings, creating a legislative framework that harmonises Spanish building standards with those of the European Union.
The standard includes the following basic requirements for energy efficiency of buildings:

- Limitation of the general energy demand of a building. Buildings must be designed taking into consideration insulation, air permeability, exposure to solar radiation, and the local climatologic conditions, and using the necessary materials and techniques to limit the gain and loss of energy.

- Performance of the thermal facilities. The thermal facilities of a building (heating, ventilating, air-conditioning, etc…) must have a minimum energy efficiency target, established by current legislation.
- Energy efficiency of the lighting facilities. The lighting facilities of buildings must be appropriate to meet the lighting requirements of users and at the same time must be energy-efficient. To this end, there must be a control system that optimises the use of natural light and adapt their use depending on the occupancy of the area.
- Minimum contribution from solar powered systems. A minimum percentage ranging from 30% up to 70% of the annual energy requirements for the production of Domestic Hot Water (DHW) demand must be met with solar thermal energy. The percentage depends on geographical location and the specific demand of the building for domestic hot water. This minimum contribution can be lowered under certain conditions and if environmental impact reduction is guaranteed in some other way.
- Minimum contribution from photovoltaic systems to the total electric energy consumption. In certain buildings, photovoltaic systems will be introduced to transform solar energy into electric energy for personal or community use.

The still more recent **Royal Decree 47/2007 of 19 January** approves the methodology to certify the energetic efficiency of buildings of new construction. The methodology to produce objective information regarding the environmental efficiency of the building is defined, as well as the energetic efficiency label, similar to the energy saving label of domestic appliances. The reward (and obligation) for contractors who decide to certify their buildings is to show the label to clients and users.
Given these recent changes, the consideration of environmental aspects in the design phase of buildings has become a must in Spain, and information regarding the environmental performance of materials and building systems is required.

4 MATERIALS CHARACTERISTICS CONSIDERED IN THE SELECTION OF BUILDING SYSTEMS

4.1 Profile of the study participants

A study by means of questionnaires, sent to architects, building engineers and industrial engineers has been done with the aim to know the materials characteristics they consider and whether or not they are environmental conscious. Twenty-seven professionals have participated. Almost half of the participants were architects with a professional experience longer than 10 years (Figure 1). Most of them work for themselves in an office of architecture. Other participants were building engineers and industrial engineers working mainly in construction companies or education.

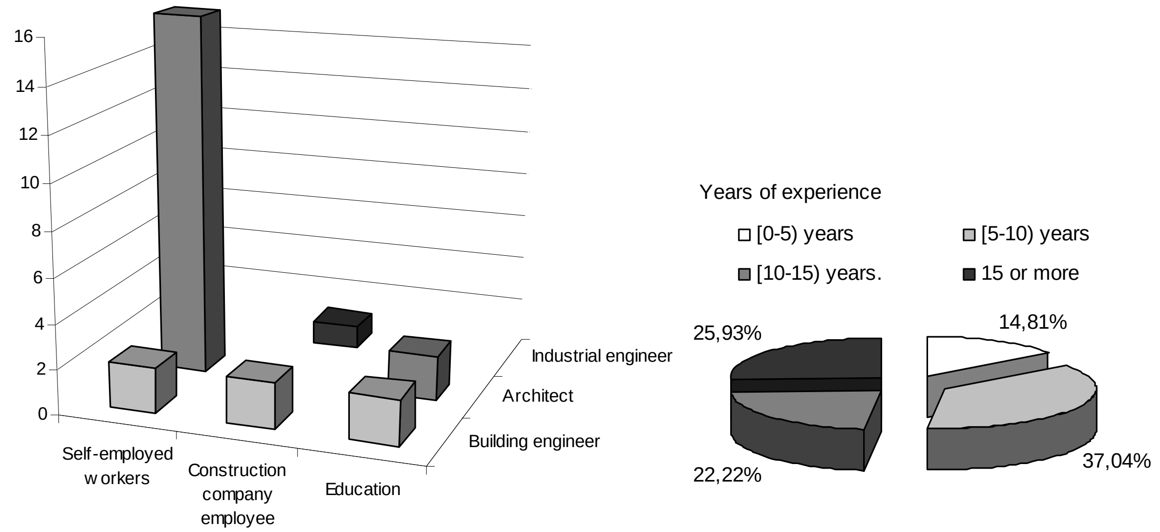

Figure 1. Profile of the study participants

4.2 Materials characteristics considered in the selection of construction systems

In the questionnaire, the participants were asked which of the following materials characteristics they never consider, they consider as a quite important criterion, or they consider as a key criterion:

- Technical characteristics: thermal performance, acoustic performance, mechanical resistance, resistance to sliding, environmental performance.
- Aesthetics
- Cost
- Others

The results from this question are shown in Figure 2. It shows that the characteristics considered more important when selecting a material or building system are aesthetics, costs, and mechanical resistance. It is important to point out that regarding the characteristic "others", different materials characteristics were evaluated, according to what each participant added in this category.

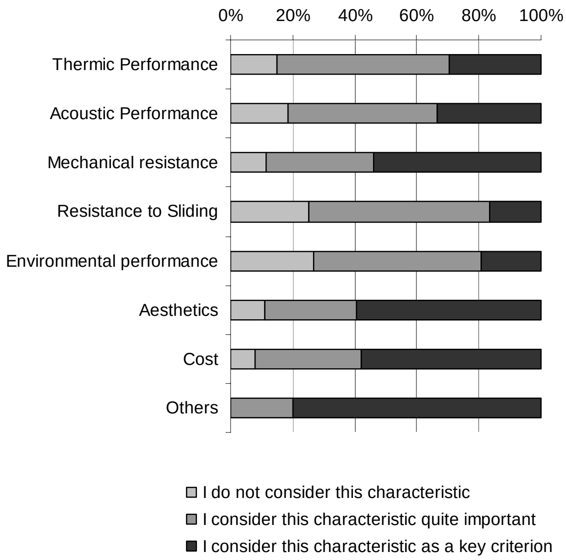

Figure 2. Assessment of the importance of materials characteristics nowadays

Specifically, the materials characteristics added in the category "others" were: durability and maintainability, luminosity, respectfulness with a historical building being restored, availability on time in the construction site, time to be put into place, clients' preferences, coherence regarding characteristics between materials in the project, innovativeness of materials, and urban laws restrictions.

The environmental performance of materials is the one with the highest percentage of professionals not considering it.

4.3 Evolution of the importance given to the environmental performance of materials

In the questionnaire, the participants were asked to evaluate the different materials characteristics in different moments in time: nowadays, 5 years ago, 10 years ago, and 15 or more years ago. Here, the evolution of the importance given to the environmental performance of materials is studied. Figure 3 shows that the main difference revealed is that progressively a higher percentage of professionals are moving from not considering the environmental performance of materials at all to considering it as a quite important criterion; whereas the number of people considering it a key criterion remains about the same.

The number of people who answered for the different moments in time varies: 26 answered for nowadays, 20 answered for 5 years ago, 11 answered for 10 years ago, and 7 answered for 15 or more years ago. For this reason, the evolution is further investigated. Table 1 shows the individual evolution in the importance that participants give to the environmental performance of materials. In the table, 1 is used for "I do not consider this characteristic", and 3 for "I consider it as a key criterion". The participants that have given different importance to the environmental performance in different moments in time have been marked with "Y" in the "Change of view" column. The participants that have not, have been marked with "N". When observing the total number of participants in these two categories, it can be concluded that about half of the participants have changed of view, and the other half has not. In Table 2, it can be observed that less experienced (and younger) professionals tend to give more importance to environment than more experienced ones. For this reason, it can be said that the observed progressive increase in importance given to environment in Figure 3, is due to both the change of view of about half of the professionals and the progressive incorporation of new professionals that are more environmental conscious.

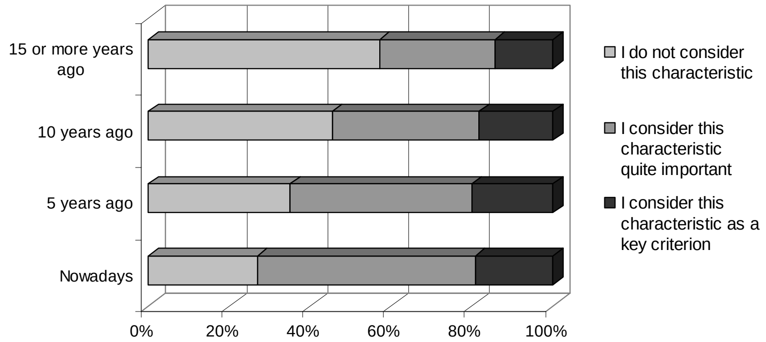

Figure 3. Evolution of the importance given to the environmental performance of materials

Table 1. Individual evolution in the importance that participants give to the environmental performance of materials

Participant	15 or more years ago	10 years ago	5 years ago	Nowadays	Change of view Y/N
1				2	
2			3	3	N
3			1	2	Y
4			2	3	Y
5	1	1	3	1	Y
6			2	2	N
7		2	2	2	N
8			2	2	N
9	1	1	1	1	N
10			1	1	N
11				3	
12	2	3	3	3	Y
13	1		1	2	Y
14				1	
15		1	1	2	Y
16		1	2	2	Y
17					
18	2	2	2	2	N
19				2	
20		1	1	1	N
21	1	2	2	2	Y
22	3	3	3	2	Y
23		2	2	2	N
24				3	
25			2	2	N
26			1	1	N
27				1	
No. of participants considered for the study of individual evolution					20
No. of participants that have changed their view with time					9
No. of participants that have NOT changed their view with time					11

Table 2. Mean importance given to the environmental performance of materials by participants according to their different years of experience

	15 or more	[10-15)	[5-10)	[0-5)
Mean importance	1,6	1,4	1,7	2

4.4 Way of use of materials characteristics in the selection of construction systems

In order to provide building agents with a suitable tool to select between materials and building systems, it is necessary to know how they use the materials characteristics as criteria. In the questionnaire, the participants were asked whether they use the different characteristics as:

- A restriction.
- An optimisable criterion.
- Depending on the project, sometimes as a restriction and others as an optimisable criterion.

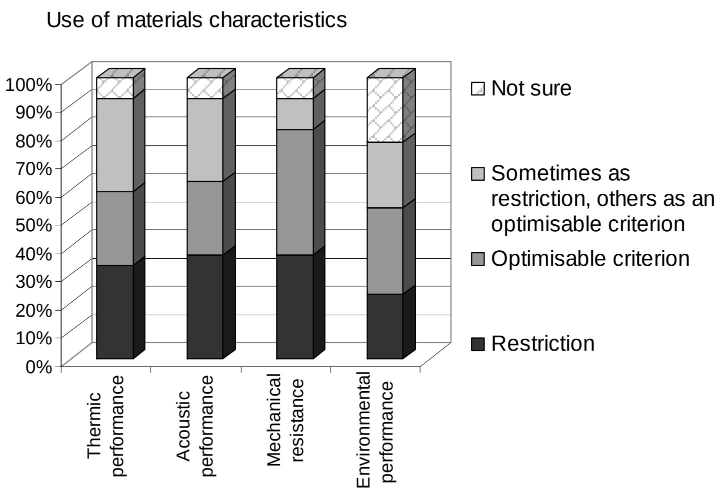

Figure 4. Way of use of materials characteristics in the selection of construction systems

Figure 4 shows the ways in which different materials characteristics are used. It can be concluded from it that the tool should adapt for all characteristics to both, their use as restrictions and as an optimisable criteria.

Knowing the way of use of materials characteristics in the terms expressed in Figure 4 is not the only information that will be required to know how to support designers regarding the selection of materials. A closer look to the way in which they design and take decisions regarding materials will have to be taken to design a tool that can support them.

5 LITERATURE STUDY ON TOOLS FOR THE ENVIRONMENTAL ANALYSIS OF MATERIALS AND BUILDING SYSTEMS

Databases have been developed with the objective to assist in the selection of building materials. Examples of these databases are “100 Materiales Sostenibles” (100 sustainable materials) developed by ICARO/CTAV (Professional Association of Architects in Valencia, Spain) [5] and Ecoespecifier, jointly developed by Natural Integrated Living Pty Ltd and RMIT University’s Centre for Design (CfD) in Australia [6].

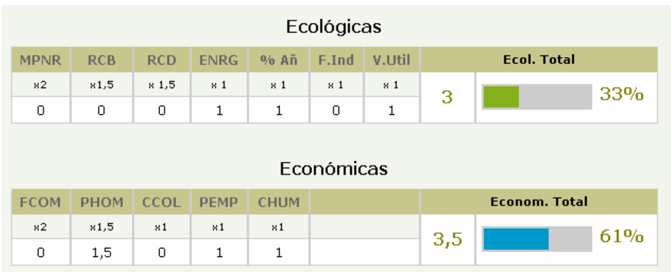

Figure 5. Snapshot of the database of [5]

The database of [5] (Figure 5), has as advantage the fact that it can be easily interpreted. Figure 5 shows the performance of a given material regarding its environmental behaviour (top bar) and its cost (bottom bar). Its environmental performance is 33 out of 100 and its economical performance is 61 out of 100. These numbers are obtained by means of calculating the mean of the scores given to the material with respect to some identified environmental criteria which can score either 0 or 1. The simplicity and intuitiveness with which the information is provided is desirable. However, some drawbacks have been observed in these databases which require further understanding of the impacts of materials in the construction field. For example, the way in which the scores are given and summed up is **not based on broadly researched methods**. The materials are **studied as individual elements**, and not as elements that work jointly with other elements to achieve a certain function. In this non-functional way of working, a sustainable material may be considered for implementation, but the reality could be that it requires other polluting materials to perform the function. The information provided to building professionals is more significant and easier to handle when it refers to the function performed, and therefore to the building system. A building system can be defined as a number of materials arranged in a certain way which perform a given function as a group, e.g. an external masonry wall composed of a layer of bricks, a hollow, a layer of insulating material and a second layer of bricks, performing the function of thermal and acoustic isolation from the exterior.

What is more, the environmental impact of a construction material does not only depend on the material itself and the rest of elements that perform the function with it, but also on the way they are put into place, on the maintenance requirements, on the system longevity, on the distance from where they can be purchased to the construction site, etc. This means that the selection of materials, or of functional building systems, requires the **rigour of Life Cycle Analysis (LCA)**, as also pointed out by other authors [7].

Figure 6 shows the phases for a LCA of building products as suggested by the Athena Institute [8]. The LCA of building systems differ from other products since buildings have a relatively long life. The environmental impacts are mainly related to the use of energy during the occupancy of the building [6]. The impacts due to building construction are summarised in Table 2.

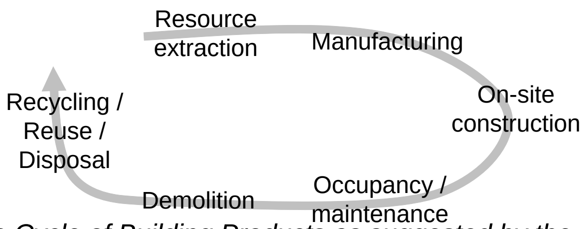

Figure 6. Life Cycle of Building Products as suggested by the Athena Institute [8]

The notion of LCA has been generally accepted by the scientific community as the only one in which to base the comparison of materials, systems, services, and complete buildings. Many tools for the assessment of buildings impact have been developed, such as Eco-Quantum (The Netherlands), Eco-Effect (Sweden), BREEAM (Great Britain), ENVEST (UK), ATHENA (Canada), ESCALE (France), LEED (US), BEAM (Hong Kong), LEGEP (Germany), Casbee (Japan), VERDE (Spain), and GBC (International) [6]. Some of these tools follow the rigour of LCA. In Spain, a specific tool to follow the requirements of the new CTE has been developed, known as LIDER, as well as an application to produce the objective information required for the energetic certification, known as CALENER.

All these tools have been proved efficient in buildings assessment, even if some of them are difficult to use [2, 6, 9, 10, and 11]. However, the disadvantage is that they do not support the early phases of buildings design. The assessment requires to have already designed the building.

To conclude it can be said that, on one hand, there are tools to assess the environmental impact of designed buildings with the rigour of a LCA, and, on the other hand, there are tools to support the building agents' decision-making with little rigour. This is why a tool to support decision-making with the LCA rigour at the functional building system level should be useful.

In order to build such a tool, applications such as SimaPro which can support in the assessment of building systems can be used. In decision-making it is important to know how to compare the environmental performance of functional building systems to other characteristics. In the 5th National Congress on the Environment, it was concluded that it is necessary to incorporate the environmental costs of building into the cost analysis because this would give a vision closer to reality hidden by price [12].

Table 2. Impacts due to construction materials or building systems (adaptation of information in [2])

	PHASE				
	Resource extraction	Manufacturing	On-site construction	Occupancy and maintenance	Demolition and disposal
Emissions to atmosphere and water	Emissions during the extraction, the consumption of energy, and transport	Emissions in the manufacturing process, the energy consumption, and transport	On-site construction emissions, the energy consumed, and transport	Emissions during maintenance activities, the energy consumed during occupancy and maintenance, and transport; indoor emissions	Emissions during demolition and landfilling /incineration, energy consumed, and transport
Resources depletion	Fossil fuels for the energy consumed and natural resources for the materials	Fossil fuels for the energy consumed and natural resources for manufacturing materials	Fossil fuels for the energy consumed and natural resources for construction equipments	Fossil fuels for the energy consumed during occupancy, and natural resources for maintenance products, water waste	Fossil fuels for the energy consumed during the demolition and disposal, and natural resources for demolition and disposal equipment
Waste	Waste from the extraction	Industrial waste from the manufacturing	Waste from the construction	Waste from maintenance activities	Waste from the demolition, release of hazardous materials
Noise	Due to the extraction machines	Due to the manufacturing processes	Due to the construction equipment	Due to the maintenance activities, and facilities noise during occupancy	Due to the demolition equipment
Soil			Landscape alteration	Soil compaction and contamination	

To evaluate the costs for society the most suitable methods are Full Costs Environmental Accounting (FCEA) and Life Cycle Cost Assessment (LCCA) [13]. For each type of environmental impact, the availability of information varies, making different methods of estimation of economic impact more appropriate than others. The costs to society can be estimated by means of the techniques summarised in Table 3 [14].

Table 3. Ecomic estimation methods for external costs [14]

External costs estimation methods	Description
Damage costs	Estimated amount of economic losses produced by an impact
Hedonic methods	Estimation of the effect produced in the market price by an environmental benefit. For example, the increase in the price of a city area for not being noisy
Contingent valuation (WTP)	Estimation of the price that the population is prepared to pay (Willingness To Pay - WTP) to avoid a given environmental impact.
Control or prevention costs	Costs of the implementation of alternatives or of prevention measures
Compensation rates	Economic value resulting from legal compensation rates for the suffered damages

Among the different methods, the external costs estimation can be useful because it provides a framework of reference to compare impacts without the subjectivity of other methods, such as the contingent valuation. Normally, different cost concepts are applied. Examples are shown in Table 4.

Table 4. Examples of cost concepts considered in the external costs estimation methods

Impact	Estimated costs	Method of estimation
Noise	Cost of the equivalent amount of time in a person's life to the prejudice produced in his/her health	Value of a fragment of life according to willingness to pay [15]
Atmospheric pollution	Cost of the chronic mortality and morbidity due to breathing diseases + Cost of harvest losses + Cost of materials reparation	Impact Pathway Approach (IPA), using Concentration-Response (CR) equations. To translate it into economic units, the value of life year lost (VLYL), the economic value of the harvesting, and rates of costs of materials reparation can be used [16, 17].

7 MODEL PROPOSAL AND FUTURE RESEARCH CHALLENGES

The building agents in Spain increasingly need more support regarding how to select sustainable building systems.

The tools to provide information regarding materials should be provided at the building system level and should have the rigour of LCA. Nowadays, there are tools that support the assessment of already designed buildings. However, more support is needed at the selection of building systems in the early stages of design.

Decision-making regarding building systems includes the consideration of costs, technical performance, environmental impact, and aesthetics. The evaluation of building systems regarding their environmental impact would be more appropriate if it could be translated into costs. The proposed model is shown in Figure 7.

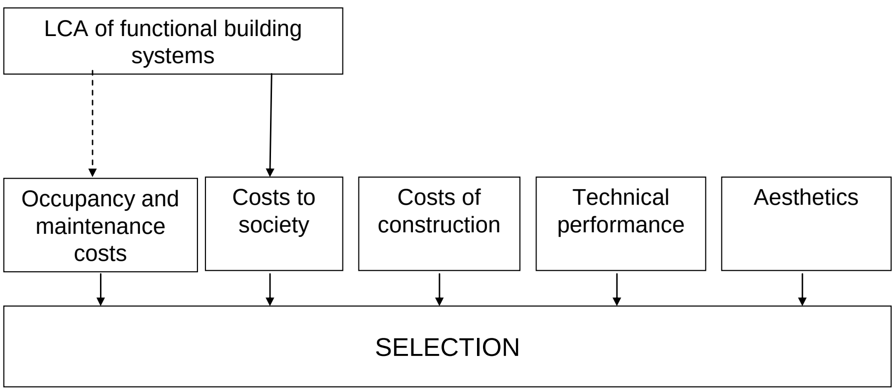

Figure 7. Model proposed for eco-efficient selection of construction systems

The model suggests that to support decisions regarding materials and building systems based on reliable information, it is necessary to provide information about:

1. Aesthetics. In this case, the information should be graphical. It would be judged by the designer.
2. Technical performance. It should include thermal and acoustic performance, mechanical resistance, resistance to sliding, and other characteristics such as durability, maintainability, luminosity, respectfulness with a historical building being restored, availability on time in the construction site, and time to be put into place.
3. Cost of construction, which includes from the purchase cost to the installation cost.
4. Cost to society, which includes the costs due to the environmental impact assignable to the chosen system.

5. Use and maintenance costs, which include the cost of maintaining and using the building that can be assigned to the chosen system.

The costs of construction nowadays are widely available. However, the information regarding cost to society, and use and maintenance costs are practically inexistent.

In order to produce these types of cost information, first a detailed inventory of the system's inputs must be made, as it is done in the first stages of a LCA. Then, impacts and costs must be assigned to each input.

Since it is necessary to offer to building agents, information which is ready-to-use, homogenous and comparable, and preferably referred to the local building practices, it is important to base the analysis on local data and broadly accepted methods. However, when the building LCA literature is studied, e.g. [18, 19, 20], it can be seen that there are methodological differences regarding:

- The functional unit.
- The overall assessment method.
- The scope of the inputs considered, especially in the occupancy and maintenance stage. For example, inputs such as water consumption, solid waste generation or impact due to maintenance are not always considered [21].
- Materials' or building systems' expected lifespan.
- Etc.

Therefore, it will be necessary to define homogenisation criteria adapted to local practices in Spain for the LCA inventories of building systems and to further develop the method to carry out a LCA of a building system by means of defining homogeneous criteria to be used.

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Contact: Belinda López-Mesa, Universitat Jaume I, DEMC, 12071, Castellón, Spain.
Tel: +34 964 72 91 58, Fax: +34 964 72 81 06, Email blopez@emc.uji.es