Approach to the Use of Global Indicators for the Assessment of the Environmental Level of Construction Products

M.V. Montes-Delgado*[,1], D. Monterde Pereira[1] and P. Villoria Sáez[2]

[1]*University of Seville, Building Engineering Technical School Reina, Mercedes 4A, 41012, Seville, Spain*

[2]*Polytechnic University of Madrid, School of Building Engineering Juan de Herrera 6, 28040 Madrid, Spain*

Abstract: The European construction industry is supposed to consume the 40% of the natural European resources and to generate the 40% of the European solid waste. Conscious of the great damage being suffered by the environment because of construction activity, this work tries to provide the building actors with a new tool to improve the current situation. The tool proposed is a model for the comprehensive evaluation of construction products by determining their environmental level.

In this research, the environmental level of a construction product has been defined as its quality of accomplishing the construction requirements needed by causing the minimum ecological impact in its surrounding environment. This information allows building actors to choose suitable materials for building needs and also for the environment, mainly in the project stage or on the building site, contributing to improve the relationship between buildings and environment.

For the assessment of the environmental level of construction products, five indicators have been identified regarding their global environmental impact through the product life cycle: CO_2 emissions provoked during their production, volume and toxicity of waste generated on the building site, durability and recycling capacity after their useful life. Therefore, the less environmental impact one construction product produces, the higher environmental level performs.

The model has been tested in 30 construction products that include environmental criteria in their description. The results obtained will be discussed in this article. Furthermore, this model can lay down guidelines for the selection of eco-efficient construction products and the design of new eco-competitive and eco-committed ones.

Keywords: Construction industry, construction products, environmental assessment, global indicators, waste.

1. INTRODUCTION

Currently, there are many phenomena which show the increasing damage that our environment is suffering; global warming, the ozone layer hole, desertification, water shortage, air and water pollution are just some examples that highlight the danger to which welfare, health and even the existence of the human species are exposed to. This situation requires the adoption of new sustainable production and consumption patterns.

The construction industry, due to its large impact on the environment as a predator of natural resources and generator of waste, must undergo a huge transformation in order to prevent nature from being damaged. In the European Union, it is estimated that the building industry is responsible for 40% of the natural resource and primary energy consumption and generates 40% of its solid waste [1]. The problem is that raw materials, water, energy resources and the planet's capacity to absorb waste are not limitless.

Therefore it is compulsory to define and implement new models of sustainable construction in order to promote a rational use of natural resources and energy and a proper management of construction and demolition waste, thereby ensuring the satisfaction of current needs without compromising the capacity of future generations to satisfy their own needs [2]. This paper is focused on the development of a model to assess the environmental level of construction products throughout their life cycle. This model is to be tested in 30 construction products which include sustainable criteria in their specifications. The results obtained will enable to quantify and compare their level of sustainability and, at the same time, identify opportunities for their improvement by reducing their environmental impact. Hence, the proposed model can be a useful tool for building actors, mainly in the project stage or on the building site, to choose construction products with better features that perform in a more respectful way with the environment. Only by considering environmental aspects during the design process of buildings a real sustainable construction can be achieved.

Fortunately, the Spanish government, aware of the necessity of a sustainable construction model, and a responsible waste management is developing regulations to promote the commitment with the environment in the construction industry, such as the Building Technical Code in 2006 [3], and the Royal Decree 105/2008 which regulates the production and management of construction and demolition waste [4] at a national level, and the Eco-efficiency Decree of the Catalonian Government in 2006 [5] at a regional level. Currently, the new Law of waste and

*Address correspondence to this author at the University of Seville. Reina Mercedes 4A, 41012, Seville, Spain; Tel: +34954556398;
E-mail: toya@us.es

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polluted soils has been approved the 14th July 2011 by the Spanish Congress.

1.1. The Eco-efficiency Concept

The term eco-efficiency is a compound word formed from ecology and efficiency. Ecology is defined by the Spanish Royal Academy dictionary as the science that studies the relationships of living beings with each other and with their environment. Therefore, when applying this concept to the building industry, it is being assumed that buildings are similar to living organisms in constant interaction with their surrounding environment. On the other hand, the efficiency of a productive system is defined as the ratio between results obtained and costs incurred, as shown in Equation 1 (Eq.1).

$$\text{Efficiency} = \text{Results} / \text{Costs} \quad (1)$$

Hence, the optimization of a productive system is achieved by maximizing its efficiency throughout its life cycle, i.e. obtaining expected results at a minimum economic, environmental and social cost (Eq.2).

$$\text{Optimization} = \max(\text{Efficiency}) = \max(\text{Results}) / \min(\text{Costs}) \quad (2)$$

Therefore, an eco-efficient construction model can be defined as one that accomplishes the objectives of building safety and habitability whilst producing minimum economic, environmental and social impact throughout the building life cycle. In the same way, an eco-efficient product is one that meets technical requirements with minimum economic, environmental and social costs throughout its life cycle.

The eco-efficiency term dates back to 1992 when it was coined by the World Business Council for Sustainable Development (WBCSD) in its publication "Changing Course". As defined by the WBCSD, eco-efficiency is achieved through the provision of goods and services that satisfy human needs at a competitive price, and bring quality of life, while progressively reducing ecological impacts and resource consumption in order to pay heed to the bearing capacity of the earth [6].

Later, in 2002, Michael Braungart and William McDonough went into greater depth with the concept of eco-efficiency and its practical applications in the book "Cradle to Cradle: Remaking the Way We Make Things", establishing itself as a reference manual on the subject [7].

1.3. Life Cycle Analysis of Construction Products

The environmental impact of a construction product extends from the extraction of its raw materials to the management of the waste generated by its demolition. Based on this idea, methodologies such as the Life Cycle Analysis (LCA) of a product aim to identify, characterize and quantify the various potential environmental impacts associated with each stage of its life cycle [8, 9]. The ISO 14040:1997 norm [10] explains how to develop an LCA by compiling the outstanding inputs and outputs of the system, evaluating their potential environmental impacts and interpreting the results according to the objectives of the study [11].

Hence, LCA can provide valuable information for building actors to make decisions aimed at improving the environmental performance of their products and services by identifying improvement opportunities. For this reason, we have made use of LCA philosophy to address the assessment of the environmental level of construction products. Thus, the first step to be followed is to identify the different phases of the life cycle of construction products (Fig. **1**) in order to evaluate their environmental impacts.

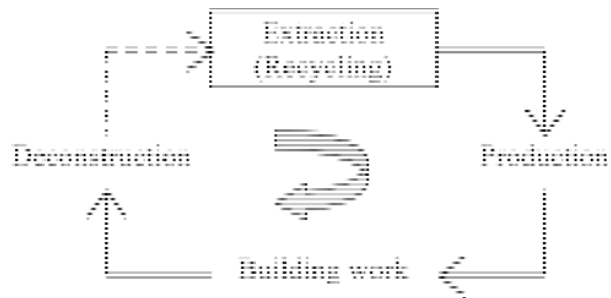

Fig. (1). Life cycle of a construction product.

- Extraction phase: At this early stage, the raw materials that make up the product are obtained. Main impacts lie in the transformation of the environment caused by the consumption of non-renewable and limited materials and the energy consumption and emissions generated by their transport to the factories where they are going to be manufactured.
- Production phase: This second stage focuses on the design, manufacture, packaging and transport of the product to the building site where it will be applied. Its environmental impacts are derived from its energy consumption and generation of emissions. Most of these emissions come from the transport and consequently are directly proportional to the distance between the distribution warehouse of the product and the building site where it is going to be used.
- Building work phase: This third phase includes stockpiling, transporting and applying the product on the building site. Its main environmental impact is associated with the generation of construction and demolition waste. This waste comes mainly from wreckage, packaging and demolition processes [12].
- Deconstruction phase: Finally, when the life cycle of a construction product ends it can become dumped waste or can be reborn as a new product by being reused or recycled. From an environmental point of view the second option is much more sustainable than the first one. The environmental impacts that have to be controlled are the generation of emissions during the deconstruction, transport and recycling processes, and the wasting of potential raw materials that implies the lack of recycling.

2. AIM

Although the term of eco-efficiency considers not only the environmental impact of a system, but also its economic and social impact, this research focuses on the analysis of the environmental performance of construction products, considering the analysis of their economic and social performance to be developed in another research project.

This article not only proposes a model for the identification and quantification of the environmental impacts caused by construction products, but also shows the results obtained from its application to 30 products which include some sustainable aspects throughout their life cycle.

3. METHODOLOGY

3.1. Ecological Indicators

As discussed above, it is essential for building actors to know the environmental level of construction products in order to be able to choose the most suitable ones for each project. In order to measure the environmental level of the construction products, it is necessary to establish a set of ecological indicators [13] to weigh their environmental impact. Therefore, the lower impact a construction product causes, the higher environmental level it obtains.

Many researchers have studied the energy consumption in terms of embodied energy of the construction products considering it the most representative indicator of the environmental performance [14-16]. In this work, the strength of the environmental assessment has been put on the ancillary results (emissions and waste) derived from the handling of construction products. The ancillary results of the construction system are the outputs obtained in parallel to the building product, i.e. emissions and waste. This definition broadens the one of the ISO 12006-2:2001 norm [17] of construction results considering not only the construction objects which are formed or changed in state as the result of one or more construction processes utilizing one or more construction resources but also the emissions and waste derived from them.

Hence, from the different impacts that could be produced by a construction product throughout its life cycle, the following five global indicators have been chosen to measure its final environmental level.

- Indicator 1: Quantity of emissions generated during the production phase (measured in kg CO_2 / kg material).
- Indicator 2: Quantity of waste generated on the building site (measured in m^3 waste / kg material).
- Indicator 3: Toxicity of waste generated on the building site (measured as high or low level).
- Indicator 4: Product durability (measured in years of useful life under normal maintenance conditions).
- Indicator 5: Product waste recycling capacity (measured in kg recycling waste * 100 / kg generated waste).

For the calculation of CO_2 emissions during the production of construction products, the program TCQ2000 developed by the Institute of Construction Technology of Catalonia [18] is used. For the estimate of the waste volume generated on the building site this program is applied together with the quantification method developed by Ramirez de Arellano *et al.*, [19].

3.2. Estimate of the Environmental Level (E_L)

The method to obtain the environmental level of construction products involves giving a value, 1 or 0, to every ecological indicator assessed that represents its contribution (value 1) or non-contribution (value 0) to the increase of the environmental level of the product under study. The higher the environmental level of a construction product performs, the higher its commitment with the environment is.

In order to determine these values, it has been necessary to establish reference limits for the quantitative indicators.

- Indicator 1: Quantity of emissions generated during the production phase.
- Products whose quantity of emissions exceeds 0.35 kg CO_2 / kg material are assigned 0, while products whose quantity of emissions is equal to or lower than 0.35 kg CO_2 / kg material obtain 1.
- Indicator 2: Quantity of waste generated on the building site.
- Products whose quantity of waste generated exceeds 0.0019 m^3 waste / kg material are designated 0, while products whose quantity of waste generated is equal to or lower than 0.0019 m^3 waste / kg material obtain 1.
- Indicator 3: Toxicity of waste generated on the building site.
- Products whose waste is toxic for human health or for the environment are given 0, while products whose waste is non-toxic obtain 1.
- Indicator 4: Product durability.
- Products whose useful life extends to the duration of their function in the building are designated 1. On the other hand, products whose useful life is shorter than the duration of their function obtain 0.
- Indicator 5: Product waste recycling capacity.
- Products whose recycling capacity matches or exceeds 70 % are attributed 1, while products whose recycling capacity is lower than 70 % obtain 0.

Therefore, the environmental level of a product ranges from 0 to 5, whereby value 0 represents the lowest environmental level that can be assessed, and value 5 the highest level, that identifies the most sustainable products in terms of environment respect.

3.3. Development of the Environmental Records

From the proposed model, an environmental record of construction products is designed, whereby technical specifications and the assessment of their environmental level through the ecological indicators are detailed. These environmental records (Table **1**) comprise the following issues:

1. Epigraph: The first paragraph summarizes the main parameters that identify the product assessed (code, name of the product, construction processes where the product is to be applied and environmental level achieved). For the product coding the Classification System of Basic Processes has been used [20].
2. Life cycle analysis (LCA): In this section, the five ecological indicators are assessed throughout the life cycle of the construction product.

Table 1. Example of Environmental Record. Personal Compilation

ENVIRONMENTAL ASSESSMENT OF CONSTRUCTION PRODUCTS			
1. Epigraph		**E_L**	***5***
Process *BRICKWORK*	**Product** **1020100300* AERETED *CONCRETE BLOCK*		

2. Life cycle analysis (LCA)

Phases	Production	Building Work		Deconstruction	
Ecological Indicators	I1	I2	I3	I4	I5
	0.0043	0.00008	Low	50	90%

(I_1) CO_2 emissions in kg CO_2 / kg block 25 cm thick.
(I_2) C&D waste in m^3 waste / kg material (where 75 % comes from breakage and 25 % from packaging).

(I_3) Toxicity.
(I_4) Product durability in years under normal maintenance conditions.
(I_5) Product waste recycling capacity.

3. Environmental level (E_L)	**I1**	**I2**	**I3**	**I4**	**I5**	**Global**
	1	**1**	**1**	**1**	**1**	**5**

4. Technical specifications

Dimensions for exterior walls (cm)	62.5 • 25.0 • e e=20.0 - 36.5
Density (kg / m^3)	400-550
Characteristic compression resistance (MPa)	3.0 – 4.5
Characteristic traction-flex resistance (MPa)	0.50 - 0.75
Coefficient of thermal conductivity λ (W / m•K)	0.12 - 0.18
Acoustic insulation to airborne sound R´w (dBA)	36 - 49
Fire reaction and resistance	REI 90-120-180-360

5. Recommendations for use, maintenance and disposal

* This product can be applied for exterior and interior walls, floors and roofs, providing good insulation features.
* It does not need any particular maintenance.
* By selective withdrawal, the product can be recycled in authorized manager's facilities for new blocks or gravel.

6. Comercial directory (Fair production)	**Location**	**Web site**	**Telephone**
Xella España Hormigón Celular, S.A	El Prat de LLobregat (Barcelona)	www.xella.es	---

7. General description

- The main feature of the structure of the aerated concrete block is the presence of many small cells or alveoli, which represent the 80% of the volume. This characteristic provides this product with lightness and good insulation properties. Additionally, it allows the saving of raw materials, which is one of its ecological properties.
- Its two main ecological goals are controlling the impacts on the external environment while creating a healthy and comfortable interior atmosphere.
- This product does not need much energy for its production: The production of 1 m^3 of aerated concrete block in an autoclave consumes only 250 KWh.
- The chemical resistance of the aerated concrete blocks is similar to that of other concrete products.
- Its ease of cutting reduces the amount of waste to be generated on the building site.
- It can be defined as a neutral product. Furthermore, it does not produce toxic gas and does not pollute water. Its remains can be used as filler on construction sites, without any harm to the soil. Moreover, aerated concrete dust show no risk to human health.
- This product has been qualified with High Environmental Quality by the French Association HQE.

8. Photographs and construction details

3. Environmental level (E_L): The environmental level of the construction product is obtained by adding the score of each indicator, 1 or 0 depending on its level of contribution to minimize its environmental impact. Therefore, the maximum and most eco-friendly score that can be obtained is 5.

4. Technical specifications: This section compiles the main technical specifications of the product assessed,

according to its function in the building construction and the requirements demanded by current legislation.

5. Recommendations for use, maintenance and disposal: The construction product record includes recommendations for its use and maintenance in order to increase its efficiency and useful life in the building. Proper use and maintenance of construction products has a positive effect on the environmental impact of the building, by reducing its waste generation and resource consumption. It also includes recommendations for the disposal of the waste generated in order to optimize their reuse and recycling.
6. Commercial directory: The main suppliers of the product assessed are compiled in a directory where their details are described. In this directory, it is highlighted if the company has a special environmental commitment and fair production is promoted.
7. General description: In this section, the main features throughout the construction product life cycle are summarized.
8. Photographs and construction details: The record is completed with a collection of photographs and construction details that illustrate the main characteristics of the product assessed.

3.4. Experimentation of the Model

The model described is applied to the assessment of 30 construction products. The selection criterion for this sample is based on the search for real construction products which include ecological aspects according to the information from their suppliers. Thereby, an environmental record has been developed for each product.

The evaluation of these products is twofold, first, it allows to test the effectiveness of the model and, secondly, to verify their environmental level.

On Table **1** the record of an aerated concrete block is shown in order to illustrate the structure of the environmental record design.

4. RESULTS AND DISCUSSION

The sample selected covers products involved in the main processes of building construction. The eco-efficiency level of the 30 products assessed is gathered together in Table **2**.

In general, the 30 products analyzed achieve a middle-high environmental level, despite the low levels of the protective oil-based coating with natural resins for wood treatment and the solar roof with non-glazed solar collector for hot water.

The main environmental inconvenience of the products is the high CO_2 emissions generated during their life cycle, because nearly 38% of them perform badly at this parameter.

On the other hand, only 25% of the products analyzed are considered non-sustainable in terms of waste generation volume and only one of them (3%) is supposed to present some kind of toxicity.

One significant ecological property of construction products is their high recycling potential. About 83% of the materials analyzed perform well in terms of recycling capacity due to its inert nature. In order to take advantage of this characteristic is extremely important to implement building solutions that allow to remove construction products separately after their useful life has got to an end.

By categories, the main results are discussed below:

- For foundations and structure, reinforced cellular concrete slab and structural concrete with recycled aggregates are the two materials that attain the highest environmental level. Reinforced cellular concrete slabs generate a low amount of waste because of being a prefabricated product while structural concrete with recycled aggregates counteracts its considerable waste generation with the recycled products that includes, which avoid the environmental impact from other waste disposal and consumption of natural resources.
- For insulation and waterproofing, the flexible hemp-fibre panel is the material with the highest environmental level, followed by the expanded polystyrene and the mineral agglomerated wood-fibre panel. Regarding C&D waste generation, these two products generate a limited volume of waste.
- On the other hand, chipboard-fibre panels, agglomerated cork panels and EPDM and propylene synthetic rubber sheets do not achieve a high environmental level due to the fact that these products have a high rate of CO_2 emissions and a low recovery potential level for recycling because of being composite materials. For instance, EPDM and propylene synthetic rubber sheets may achieve a higher environmental level by replacing synthetic rubber made from oil with natural rubber, because of its lower environmental impact throughout its life cycle.
- Since the information about the CO_2 emissions of the bentonite sheet for elements in contact with the ground has not been available, its evaluation is not complete, although it presents good results in terms of waste generation and durability.
- As far as binders and mortars are concerned, the use of monolayer mortar of pure natural lime reduces the generation of waste and CO_2 emissions in comparison with traditional monolayer mortar of cement, while providing high resistance. Despite these characteristics, its environmental level is not very high because of its toxicity potential that can cause irritation on the skin, the eyes and in the respiratory system and its low recovery level.
- For brickwork, the aerated block, the non-coated brick made of biogas, the precast lightweight concrete block of expanded clay and the ceramic block coated with plaster on all sides achieve the highest environmental value, becoming the most eco-friendly materials from the ones analyzed.
- For instance, the use of ceramic blocks covered with plaster on all sides decreases the amount of plaster waste on the building site in comparison with the

Table 2. Environmental Level (E_L) of the 30 Construction Products Assessed. Personal Compilation

Product		I1	I2	I3	I4	I5	E_L
Foundations and Structure	*1005100100 Structural concrete with recycled aggregates	1	1	1	1	1	5
	*1005200100 Reinforced cellular concrete slab	1	1	1	1	1	5
	*1020100100 Thermal clay block for load-bearing walls	1	0	1	1	1	4
	*1020100200 Wood and cement conglomerate block	0	1	1	1	1	4
Insulation and Waterproofing	*1015200100 Flexible hemp-fibre panel.	1	1	1	1	1	5
	*1015200200 Mineral agglomerated wood-fibre panel.	0	1	1	1	1	4
	*1015200300 Agglomerated cork panel.	0	0	1	1	1	3
	*1015200400 Chipboard-fibre panel.	0	0	1	1	1	3
	*1015200500 Expanded polystyrene.	0	1	1	1	1	4
	*1015300100 EPDM and propylene synthetic rubber sheet.	0	0	1	1	1	3
	*1015300200 Bentonite sheet for ground contact elements.	-	1	1	1	0	3
Mortars	*1016250100 Monolayer mortar of pure natural lime.	1	1	0	1	0	3
Brickwork	*1020100300 Aerated concrete block.	1	1	1	1	1	5
	*1020100400 Non-coated brick made of biogas.	1	1	1	1	1	5
	*1020100500 Hemp-fibre block with lime and minerals.	-	1	1	1	1	4
	*1020100600 Precast lightweight concrete block of expanded clay.	1	1	1	1	1	5
	*1020100700 Ceramic block coated with plaster on all sides.	1	1	1	1	1	5
Boards and Panels	*1025400100 Plaster wall.	1	1	1	1	1	5
	*1025600100 Rigid cellular glass plate made of recycled glass chips.	0	1	1	1	1	4
Roofs	*1030700100 Solar roof with non-glazed solar collector for hot water	0	0	1	0	1	2
Carpentry	*1046300100 Sustainably-managed Iroko wood carpentry.	1	1	1	1	1	5
Glass	*1050100100 Low-emission glass.	0	1	1	1	1	4
	*1050100200 Solar-control glass.	0	1	1	0	1	3
Flooring	*1055500100 Mortar floor tile.	1	0	1	1	1	4
	*1055500200 Cork parquet with a resistant surface varnish.						
	*1055500300 Linoleum made of natural raw materials.	1	1	1	1	1	5
Paints	* 1056000100 Latex-based paint.	1	1	1	0	0	3
	*1056050100 Protective oil-based coating with natural resins.	0	1	1	0	0	2
	*1056150100 Resin-based paint for metal treatment.	1	1	1	0	0	3

traditional plaster applied on brickworks. In addition, the binder employed by this material is made of plaster instead of cement, which contributes to the reduction of CO_2 emitted into the atmosphere.

- Since the information about the CO_2 emissions of the hemp-fibre block with lime and minerals has not been available, its evaluation is not complete, although it presents good results in terms of waste generation and durability.
- In boards and panels, the plaster wall performs better than the rigid cellular glass plate made of recycled glass chips because of its CO_2 emission level. The reduction of CO_2 emissions is significant in comparison with traditional brickwork partitions because of the replacement of cement mortar as a binder.
- The solar roof with non-glazed solar collector for hot water performs badly due to the amount of waste, even though it is mostly recyclable, and CO_2 emissions that its production generates. It must be highlighted that in this analysis it has not been taken into consideration the energy saving that this system can provide, but only the environmental performance of the system as a construction product.
- Sustainably-managed Iroko wood carpentry has a low environmental impact through its life cycle, becoming an environmental-friendly alternative to aluminium and PVC carpentries. By extension sustainably-managed

wood carpentries represent a sustainable alternative for traditional carpentries.

- Low-emission glass performs better than solar-control glass because of its longer durability. The main disadvantage of both glass products is that they emit large amounts of CO_2 during their production. But, on the other hand, they generate a low amount of waste and present low toxicity levels and high recycling potential.
- In flooring, linoleum made of natural raw materials is the product with the highest environmental level due to its good performance through its life cycle.
- On the opposite extreme, the problem of the parquet made of several layers of cork and a resistant surface varnish is its lower durability and higher generation of waste. Its main asset is that it does not use cement mortar and therefore minimizes the emission of CO_2.
- Paints have a medium-low environmental level because of its low durability and poor recycling potential. The use of latex-based and resin-based solvents is recommended on the basis that suppliers must guarantee the lack of Volatile Organic Compounds (VOCs).

CONCLUSIONS

After testing the proposed model, it can be concluded that it is a simple and useful tool for the comprehensive evaluation of construction products according to their environmental final impacts throughout their whole life cycle. The assessment of the environmental level of construction products gives building actors crucial information, especially during the project phase and on the building site, in order to design and choose the best materials for the buildings and for their surrounding environment. The more aspects taken into consideration (technical, economic, environmental and even social aspects), the more accurate and solid the decisions adopted [21].

This assessment also allows to identify the strengths and weaknesses of construction products, thereby enabling their improvement in order to make them more eco-competitive and eco-committed. From this first approach to the assessment of construction products, five good practices to develop a sustainable construction must be emphasized, which coincide with the indicators taken into consideration for the environmental level estimate.

- Production and selection of local construction products that require low energy consumption for their manufacturing in order to reduce the generation of CO_2 emissions during their production and supply to the building site.
- Production and selection of modular construction products with less packaging and with more resistance against breakage in order to reduce the generation of waste on the building site.
- Production and selection of construction products that are innocuous for the environment and for human health and consequently generate non-hazardous waste.
- Production and selection of construction products whose useful life, under normal maintenance conditions, extends to the duration of the function they are supposed to fulfil in the building.
- Production and selection of construction products whose waste can be reused or recycled by competitive technologies that can take advantage of their maximum recycling potential.

All these sustainable strategies can be summarized in the rational production and consumption of construction products. Producers and consumers of construction products are equally responsible of the impact caused by the construction industry on the environment [22], and therefore must assume that they are obliged to preserve it by guaranteeing the existence of healthy environment conditions for life and the continuity of resource supply for the development of human activity. Promotion of these goals and the ways that they can be achieved, i.e. by providing assessment tools, product eco-labels and good practices, is essential for building actors' awareness. Policy makers and scientists must boost these strategies for building actors to commit to the development of eco-efficient construction. Only with this global commitment, it will be possible to achieve a proper balance between construction and environment.

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CONFLICT OF INTEREST

None Declared.

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