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Sustainability assessment of materials used in façade cladding

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During the project process and later construction of a building, many times it will be difficult to assume the price and time of doing a complete life-cycle assessment (LCA) for each material and building system. Because of this, and until the environmental product declarations (EPD) are more extended, an assessment tool is needed in order to give quick and easily enough arguments to select the best façade cladding according to its sustainability. In this paper it is shown a sustainability assessment of ceramics cladding, by comparing its environmental and economical properties with other construction materials used in similar circumstances. As the use of the material is attached to the constructive system, it is also analyzed the most common types of façades cladding, in order to evaluate the contribution of this materials to the sustainability of the whole enclosure.

Introduction

Until the Industrial Revolution, the development of architecture has been taking into account the energy implications of its construction. This is evidenced in the control of resources carried out by tribal architecture, using forms of minimum consumption, adapted to the climate and executed with abundant, next and renewable materials (Araujo, 2009).

Currently, the construction and use of the buildings are responsible for 25% of the extraction of materials from the Earth's crust, 30% of CO_2 emissions, 20% of the drinkable water consumption and between 30% and 40% of the generation of solid waste (Azpilicueta, 2010). The construction sector consumes more raw materials than any other industry, extract more crude than any other sector, and the construction and operation of the buildings are at least 50% of the European energy consumption (Álvarez-Ude, 2010).

We must take into account that the building sector has been an essential component in the development of many countries, for example Spain, where 50% of the economic growth, experienced between 1998 and 2008, is related to construction (Raya et al., 2011). In that period it has been built approximately 30% of all the square meters built by today in Spain, mobilizing large amounts of manpower, generating a demand of materials that allowed industrial development in that area, and holding a financial system intended to enable the economic resources to manage the sector and allow the marketing of their products (Cuchí, 2010).

It is a fact that today there is a particular alliance between market, advertising and ecology, which requires architecture legitimates by its sustainability (Fernández-Galiano, 2005). This has produced an increasing demand of more information related to this and has generated an increase of interest in sustainability assessment tools to determine how sustainable a building is and how could it be made more sustainable (Forsberg & von Malmborg, 2004). As Foster said, architects cannot solve all the world's ecological problems, but if sustainability is to be more than a fleeting fashion, architects in the future must ask themselves some very basic questions.

Background

In the current context of political commitment to sustainable development, it is not surprising that sustainability assessment is frequently used to anticipate the consequences of the possible actions to be implemented. Sustainability assessment can be defined as a process that directs decision making towards sustainability (Bond & Morrison-Saunders, 2011).

The traditional objectives of cost, time and quality are no longer enough arguments and there is a need to develop new techniques and procedures to achieve environmental, social and economic requirements (Fernández-Sánchez & Rodríguez-López, 2010). There is a demand of tools focused on buildings and components performance assessment, which could provide quantifiable information that can be used by agents of the construction sector, to create buildings that improve indoor comfort condition with low environmental impact (Assefa et al., 2007).

Considering the net growth in world population over the last decade, which has reached 7.000 million inhabitants, it is estimated that it must be built about 17 million new accommodations around the world annually. That means around 680 million square meters, like produce over 600 million cubic meters of construction materials, about 1,500 million annual tonnes of materials, building components and construction subsystems (IETcc, 2008).

The placement of materials determines the functional behavior of the building and, with it, the future demand for resources to keep its habitability. About 60% of the materials used are in the structural elements. Between 25% and 30% goes to the primary enclosures (roofs and façades), and the rest to partitions, linings, facilities, etc (Cuchí, 2010). The materials used in the building are a high weight on the environmental impacts caused by the building over its life cycle. These impacts are generated in all transformations suffered from extraction feedstock until his departure from factory as material prepared for use in work.

The choice of a material depends on many factors, such as the duration of their life cycle, its potential for reuse and recycling and their environmental impacts. These impacts can be known through the environmental product declarations (EPD), prepared according to ISO 14025 (ISO, 2006) and ISO 21930 standards (ISO, 2007). If a product does not have an EPD, a life-cycle assessment (LCA) can be carried out, according to ISO 14040 (ISO, 2006) and ISO 14044 standards (ISO, 2006). The life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, which is based on material and energy balance of the studied system. In this way inputs and outputs of the system are identified and, subsequently, different environmental impacts that may cause are evaluated.

During the project process, especially in the initial stages of design, and later construction of a building, many times it will be difficult to assume the price and time of doing a complete LCA for each material and construction system. We must bear in mind that the design process is crucial in the achievement of a sustainable building, since the ability to influence the behavior of a building is greatly reduced throughout the project, at the same time that increases the cost of implementing any strategy (ASHRAE, 2006). Because of this, until the environmental product declarations (EPD) are more extended, an assessment tool has been developed in this paper in order to give quick and easily enough arguments to select the best façade cladding according to its sustainability. Following the structure defined in UNE EN 12973 standard (UNE, 2000) for the product value analysis, understood as the relationship between satisfied needs and the resources used to satisfied them, assessment credits and their related indicators can be established for each stage of the façade cladding life-cycle, evaluating them by weighted comparison.

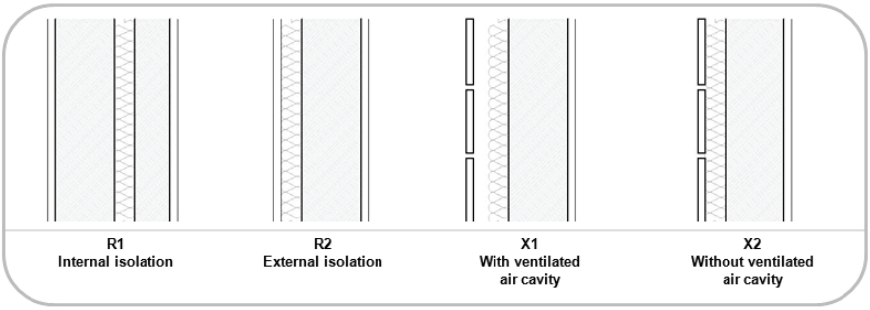

Figure 1. Analyzed façade systems

Methodology

The ISO 14040 standard (ISO, 2006) sets the life cycle stages as the ones consecutive and interrelated in a product system, from its obtention from natural resources to its final elimination.

The product stage includes the processes assumed in the environmental declaration, including the production cost. The construction stage includes material´s transport from the factory to the working place, the waste produced during the construction and its costs. The operation stage includes weight and thickness of the materials and constructive systems, and the operation cost understood as energetic demand. The last stage is end of life and includes the processes of reuse, recycling and waste from demolition.

Four material families and four construction systems have been selected for the assessment development. The materials are extrude ceramic (CE), ceramic tiles (CP), aluminum composite (CA) and precast concrete (HP).

To define the façade systems, each material is analyzed into two different systems, with (1) and without (2) ventilated air cavity, as are sown in Figure 1. Two reference systems defined by the Spanish Edification Technical Code are also used, one of them with the isolate layer situated in the interior side of the wall (R1) and the other one with the isolation on the outside (R2).

Following the exclusion principle for the identical activities in comparative analysis, the substructure and the façade´s interiors layers are considered identical in all systems, so this way they will not interfere in the evaluation.

Table 1. Analyzed categories

Stage	Credit	Indicator	Source
Product	Eco-label	[EPD]	COAATC
	Embodied energy	[MJ/m^2]	BEDEC
	CO_2 emissions	[kgCO_2/m^2]	BEDEC
	Recycled content	[%]	Producer
	Product cost	[eur/m^2]	COAATGU
Construction	Certificate	[DIT]	IETcc
	Transport	[km]	Elaborated
	Construction waste	[m^3/m^2]	BEDEC
	Construction cost	[eur/m^2]	COAATGU
Operation	Overweight	[kg/m^2]	Producer
	Wide	[mm]	Producer
	Operation cost	[kWh/m^{2}a]	Elaborated
End of life	Reuse	[%]	Elaborated
	Recycle	[%]	Producer
	Demolition	[m^3/m^2]	Elaborated

Information

In order to establish how much do the construction products contribute to a sustainable development it is important to consider context: many products which are not in themselves particularly environmentally friendly could be exactly the right products for reducing a building's environmental impact. Creating a low environmental impact building means matching products to the specific design and site in order to optimize overall environmental impact. What is clear from taking a life-cycle thinking approach is that it is not only the type of product used that is important, but also how it is produced (with clear links to environmental management systems) and even more importantly how it is used (and treated when its first life is over) (Edwards & Bennett, 2003).

In each life-cycle stage are defined the needed credits for the definition of the analysis object through specific aspects. Each credit is linked to an indicator which gives a measuring value and its measurement unit.

The selection of credits and indicators is carried out through the analysis of scientific papers, specialized literature and evaluation methodologies such as LEED (USGBC) and VERDE (GBCe). They have to comply with two features: represent the most significant qualities to analyze and have accessible information from the initial stages of the project.

In materials and façade systems selected are analyzed: embodied energy (energy consumption from the extraction of raw materials until his departure from the factory as material ready to use at work), CO_2 emissions in the same period, percentage of recycled material incorporated in their production, cost of production, distance between the factory and the work (which suppose an energy consumption during transport), waste produced during the construction process, construction cost, overload to the structure, thickness (which reduces the available floor area), energy demand of the constructed building, if can be removed to reuse in other buildings, if can be recycled in new applications, the volume of waste from demolition and finally, if they have any environmental declaration or document of technical suitability that present and endorsing its characteristics.

To guarantee the reliability of this tool, all the credits used have indicators that come from official data bases or at least professional recognize. For the credits in which the commercial information was needed to be used, it is guaranteed its reliability by comparing data from enough reliable commercial references and obtaining the mean value.

Table 1 indicators mentioned as elaborated, are the ones whose value cannot be obtained by any of the previous mentioned ways. For example, in the transport credit it is calculated the distance from the factories of the chosen manufactures, to five reference Spanish cities and the mean value is calculated. For the credit of the operation cost, an energetic simulation is done with Design Builder program with every façade, and the annual energetic demand is obtained.

Analysis

The values obtained for the cladding products and façade systems analyzed are reflected in Tables 2 and 3.

When there is no information of credit or it may not be properly proven, is not included in the analysis and is taken into account in the subsequent assessment. The eco-labeling credit (EPD) refers to the material, so it is not taken into account for the analysis of constructive systems. However, technical certificate and operation cost credits are applied only in the analysis of constructive systems.

Table 2. Analyzed cladding materials

Stage	Credit	Indicator	CE	CP	CA	HP
Product	Eco-label	[EPD]	IP	Y	Y	N
	Embodied energy	$[MJ/m^2]$	666,93	252,85	907,00	320,64
	CO_2 emissions	$[kgCO_2/m^2]$	40,61	15,79	-	21,04
	Recycled content	[%]	> 0	> 80	0	-
	Product cost	$[eur/m^2]$	40,08	21,01	77,70	76,77
Construction	Certificate	[DIT]				
	Transport	[km]	695,08	659,04	918,50	476,01
	Construction waste	$[m^3/m^2]$	0,0036	0,0015	0,0002	0,0016
	Construction cost	$[eur/m^2]$	92,34	54,91	122,83	105,69
Operation	Overweight	$[kg/m^2]$	53,85	27,90	5,50	33,00
	Wide	[mm]	33	10	4	14
	Operation cost	$[kWh/m^2a]$				
End of life	Reuse	[%]	100	100	100	100
	Recycle	[%]	0	0	90	0
	Demolition	$[m^3/m^2]$	0,033	0,010	0,0002	0,014

Table 3. Analyzed façade systems

Credit	R_1	R_2	CE_1	CE_2	CP_1	CP_2	CA_1	CA_2	HP_1	HP_2
Eco-label										
Embodied energy	768,91	585,33	1230,4	1230,4	816,33	816,33	1470,5	1470,5	884,12	884,12
CO_2 emissions	84,45	65,89	102,44	102,44	77,62	77,62	-	-	82,87	82,87
Recycled content	0	0	> 0	> 0	11	11	0	0	-	-
Product cost	18,57	14,94	53,58	53,58	34,51	34,51	91,20	91,20	90,27	90,27
Certificate	N	N	Y	N	Y	N	Y	N	N	N
Transport	1240,8	818,12	1513,2	1513,2	1477,1	1477,1	1736,6	1736,6	1294,1	1294,1
Construction waste	0,0190	0,0137	0,0158	0,0158	0,0137	0,0137	0,0124	0,0124	0,0138	0,0138
Construction cost	90,02	68,64	143,21	143,21	105,78	105,78	173,70	173,70	156,56	156,56
Overweight	300,11	213,38	229,04	229,04	203,09	203,09	180,69	180,69	208,19	208,19
Wide	255	185	233	203	210	180	204	174	214	184
Operation cost	37,87	42,14	42,38	41,97	42,38	42,08	42,38	42,08	42,38	41,65
Reuse	0	0	23,5	0	13,75	0	3,05	0	15,85	0
Recycle	0	0	0	0	0	0	3,05	3,05	0	0
Demolition	0,255	0,185	0,203	0,203	0,180	0,180	0,174	0,174	0,184	0,184

Assessment

On the basis of the results obtained in the analysis phase, each cladding product and facade system is valued in comparison with the other analyzed options. The resulting score determines the improvement potential of every analyzed option, so that the option with a lower score will be the most favorable.

When the values in the different options are very close, the highest score may be equal to the number of evaluated alternatives. However, when there is much variation between alternatives, this system of value allocation does not reflect the difference between them. For a more concise assessment, the difference between the more and less favorable of each indicator value is divided into 10 sections and gets the score of each alternative depending on in which section it is included.

Eco-labeling (product stage) and certificate credits (construction stage) will get the most favorable value (V=1) if the material or system has some kind of eco-label (EPD) or certificate, the more unfavorable if they do not (V=10) and intermediate (V=5) if it is in process of obtaining it. The rest of the credits will get better value (V=1) for smaller indicator, according to Equation 1 below, except the credits of recycled content (product stage), reuse and recycling (end of life stage), which are valued in reverse.

$$\begin{cases} V(x) = 1;\ \text{if } x \ni [\min, D1) \\ V(x) = 2;\ \text{if } x \ni [D1, D2) \\ V(x) = 3;\ \text{if } x \ni [D2, D3) \\ V(x) = 4;\ \text{if } x \ni [D3, D4) \\ V(x) = 5;\ \text{if } x \ni [D4, D5) \\ V(x) = 6;\ \text{if } x \ni [D5, D6) \\ \dots \\ \\ V(x) = 10;\ \text{if } x \ni [D9, \max] \end{cases} \qquad (1)$$

where x ≡ indicator value; min ≡ minimum indicator value; max ≡ maximum indicator value; and V(x) ≡ assessment value.

Table 4. Cladding materials assessment

Stage	Credit	CE	CP	CA	HP
Product $Fx_1 = 25\%$	Eco-label	5	1	1	10
	Embodied energy	7	1	10	4
	CO_2 emissions	10	1	10	6
	Recycled content	9	1	10	10
	Product cost	4	1	10	7
Construction $Fx_2 = 10\%$	Certificate				
	Transport	7	4	10	1
	Construction waste	10	4	1	7
	Construction cost	4	1	10	7
Operation $Fx_3 = 60\%$	Overweight	10	4	1	7
	Wide	10	4	1	7
	Operation cost				
End of life $Fx_4 = 5\%$	Reuse	1	1	1	1
	Recycle	10	10	1	10
	Demolition	10	4	1	7

Table 5. Façade systems assessment

Credit	R_1	R_2	CE_1	CE_2	CP_1	CP_2	CA_1	CA_2	HP_1	HP_2
Eco-label										
Embodied energy	2	1	8	8	4	4	10	10	6	6
CO_2 emissions	8	1	10	10	3	3	10	10	6	6
Recycled content	10	10	7	7	1	1	10	10	10	10
Product cost	2	1	6	6	4	4	10	10	8	8
Certificate	10	10	1	10	1	10	1	10	10	10
Transport	2	1	8	8	6	6	10	10	4	4
Construction waste	10	5	9	9	5	5	2	2	7	7
Construction cost	2	1	6	6	4	4	10	10	8	8
Overweight	10	7	9	9	4	4	1	1	6	6
Wide	10	4	9	5	7	2	6	1	8	3
Operation cost	1	6	8	3	8	5	8	6	8	3
Reuse	10	10	1	10	3	10	4	10	2	10
Recycle	10	10	10	10	10	10	1	1	10	10
Demolition	10	7	9	9	4	4	1	1	6	6

All the options have a value between 1 and 10. When two or more alternatives have the same value on some credit of the analysis stage, they are evaluated with the same score. When they do not have the necessary data, it is assumed the worst option and is evaluated with the highest score (V=10). The assessment of the credits of each option, according to Equation 1, is reflected in Tables 4 and 5.

To get the potential improvement in each alternative, Equation 2 is used, in which the credits are the same value in the assessment of each stage, and each of them ponders according to their relevance within the life cycle (Fxi), according to the weights assigned by VERDE tool (GBCe): Fx1 = 25%; Fx2 = 10%; Fx3 = 60%; Fx4 = 5%. Table 6 presents the assessment of the cladding materials and façade systems analyzed.

$$V_T = \sum_{i=1}^{4} Fx_i \left(Vx_i / Cx_i\right) / F_T \Rightarrow \qquad (2)$$

$$V_T = [Fx_1 \sum (Vx_1 / Cx_1) + Fx_2 \sum (Vx_2 / Cx_2) + Fx_3 \sum (Vx_3 / Cx_3) + Fx_4 \sum (Vx_4 / Cx_4)] / F_T$$

where VT ≡ total value; Vxi ≡ indicator assessment value in each life-cycle stage; Fxi ≡ weighting factor of each life-cycle stage; Cxi ≡ number of credits considerer in each stage; and xi ≡ life-cycle stages.

Table 6. Assessment value

Total	CE	CP	CA	HP	R_1	R_2	CE_1	CE_2	CP_1	CP_2	CA_1	CA_2	HP_1	HP_2
Product	6,8	2,4	3,2	5,5										
System					6,7	5,1	8,1	6,6	5,2	4,0	6,2	5,1	7,3	5,4

In order to normalize the assessment and to express it in percentage, two hypothesis are included, representing the best alternative with 0% of possible improvement and the worst, with 100% of improvement potential. The values are reflected in Table 7 and are represented in Figures 2 and 3.

Table 7. % Improvement potential

Total	CE	CP	CA	HP	R_1	R_2	CE_1	CE_2	CP_1	CP_2	CA_1	CA_2	HP_1	HP_2
Product	83	22	33	65										
System					63	45	79	63	47	33	58	46	70	49

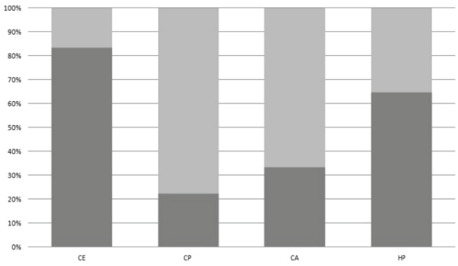

Figure 2. Cladding materials assessment

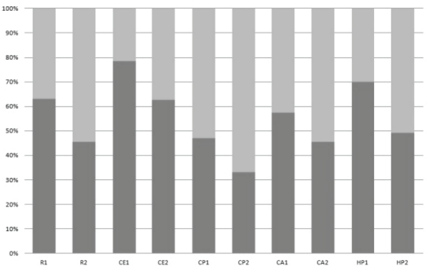

Figure 3. Façade system assessment

Discussion

The proposed assessment methodology is defined by three aspects: the selection of the analysis credits and indicators, the assignment of a value to each alternative depending on the evaluated credits and, finally, assessment of each alternative based on the values of each credit.

The selection of the analysis credit must be argued by the review of specialized documentation, to ensure that considers the necessary credits and in sufficient numbers to characterize each option.

The credit assessment for each option should be considering the difference between the minimum and maximum value, divided into intervals. If the value is assigned consecutively between the better alternative and the more unfavorable, considering n options, assessment would not reflect the dispersion between them and will only be valid when assessing very similar options. The difference between the two systems of assessment is presented in Table 8.

Table 8. Credit assessment

		Indicator	CE	CP	CA	HP
Credit	Embodied energy	[MJ/m^2]	666,93	252,85	907,00	320,64
Value V ☐ [1, n]			3	1	4	2
Value V ☐ [1, 10]			6	1	10	3

For the options assessment (V_T) it should be considered the mean value of each option at each life-cycle stage (∑ Vxi / Cxi) and a weighting factor (Fxi) depending on the importance of each life-cycle stage in the reduction of environmental impacts. If it did not include this weighting factor, it would be considering with the same importance the impacts produced at every life-cycle. Tables 9 and 10 reflects the final assessment of each option and their corresponding improvement potential, depending on if they are not considered mean values either of weighting factors (V_{Ta}), considering mean values but not the weighting factor of the life-cycle stage (V_{Tb}), considering the weighting factors but not the mean values (V_{Tc}) and, finally, considering mean values and weighting factors (V_T).

$$V_{Ta} = \sum_{i=1}^{4} \left(Vx_i\right)$$

(3)

$$V_{Tb} = \sum_{i=1}^{4} \left(Vx_i / Cx_i\right)$$

(4)

$$V_{Tc} = \sum_{i=1}^{4} Fx_i \left(Vx_i\right) / F_T$$

(5)

$$V_T = \sum_{i=1}^{4} Fx_i \left(Vx_i / Cx_i\right) / F_T$$

(2)

Table 9. Value assessment

	CE	CP	CA	HP	R_1	R_2	CE_1	CE_2	CP_1	CP_2	CA_1	CA_2	HP_1	HP_2
V_{Ta}	97,0	37,0	67,0	84,0	97,0	74,0	10,0	110	64,0	72,0	84,0	92,0	99,0	97,0
V_{Tb}	27,7	11,7	16,9	23,1	28,5	22,2	29,1	31,3	19,0	20,9	22,8	24,7	28,1	27,4
V_{Tc}	23,9	7,7	13,7	20,1	22,0	16,5	26,8	22,7	16,9	13,3	21,6	18,6	24,5	18,9
V_T	6,80	2,40	3,20	5,50	6,70	5,10	8,10	6,60	5,20	4,00	6,20	5,10	7,30	5,40

Table 10. % Improvement potential

	CE	CP	CA	HP	R_1	R_2	CE_1	CE_2	CP_1	CP_2	CA_1	CA_2	HP_1	HP_2
V_{Ta}	72	21	46	61	66	48	69	76	40	46	56	62	67	66
V_{Tb}	73	24	40	59	68	50	70	76	42	47	52	57	67	65
V_{Tc}	80	18	41	66	62	44	78	64	45	33	61	51	70	52
V_T	83	22	33	65	63	45	79	63	47	33	58	46	70	49

Conclusions

The comparative assessment method does not give results from the reduction of the environmental impact, although it helps to know easily and quickly the best option for each situation, and gives improvement ideas to help to achieve the ideal hypothesis. This way, client and architect can orientate themselves to more sustainable solutions without having to assume time and economic over cost. This tool could be used with different building elements (structure, facilities, roof, etc.), by adjusting the analysis credits to each of them and by adapting the weighting system.

The selected cladding materials assessment shows that ceramic tile (CP) is the best option from all the analyzed, although it has a little improvement margin compared to aluminum composite (CA).

Reducing its thickness, and with this, its weight, 11% improvement can be achieved. This way is the one followed by the industry, already having achieved important improvements.

The reference system with the outside isolation (R_2) includes the same materials, except for the cladding, as the rest of the alternatives. Because of this, it is the best reference to evaluate the sustainability input coming from the cladding material. From all the studied options, only the one including ceramic tile in a system without ventilated air cavity (CP_2) gets a better score than the reference (R_2), although it is closely followed by the systems without ventilated air cavity of aluminum composite (CA_2) and precast concrete (HP_2).

This is because the Edification Technical Code of Spain, in the document Energy savings DB-HE1 (CTE, 2009), states that the total thermal resistance of an enclosure with a highly ventilated air cavity is obtained neglecting the thermal resistance of the air cavity and the other layers between the air cavity and the outside environment. Therefore, options without ventilated air cavity are better valued because the qualities of the cladding are considered in the calculation of the enclosure thermal transmittance, which reduces energy demand during operation stage and, therefore, the cost of use credit.

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