Environmental, energetic and economic life-cycle assessment from "cradle to cradle" (3E-C2C) of buildings assemblies

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Summary

The sustainability assessment of a building must represent a part of an integrated evaluation of the building performance. The envelope is one of the main parts of the buildings and external walls directly influence its thermal and environmental performance because of their considerable weight in the initial embodied energy, life-cycle energy consumption and whole-life cost. Therefore, this paper proposes an approach to provide the environmental, energetic and economic life-cycle assessment from "cradle to cradle" (3E-C2C) of building assemblies and exemplifies its application in the process of selection of the external wall of a building.

The 3E-C2C approach was developed following the guidelines already included in European draft standards for the sustainability assessment of buildings and construction products that will be in their final version by the beginning of 2012. The environmental performance of the external wall solutions were compared from "cradle to cradle" following a "Life-cycle Assessment" methodology. The energetic performance considered in the 3E-C2C approach corresponds to the estimation of consumption of energy for heating and cooling during a building's operation and the economic module is based on the "Whole-Life Cost" methodology.

The 3E *cost*-C2C approach complements 3E-C2C and provides a common subjectivity-free unit to compare different alternatives in the design of a building by using an "Environmental Impact Assessment Method" with a weighting step (that converts the results of all impact categories in an economic unit). This procedure allows for the addition of the cost associated with the environmental impacts on the economic and energetic whole-life cost and allows selecting alternatives (even if they are not functionally equivalent) by considering all the relevant performance indicators in all the key life-cycle stages.

Keywords: building, cradle-to-cradle, eco-costs, energetic performance, envelope, European standards, external walls, Life-cycle assessment, whole-life cost.

1. Introduction

In Europe, the "Energetic certification of buildings" [1] has already had positive consequences, not only in terms of the thermal performance of the buildings. In Portugal, for example, it is already possible to establish a direct relationship between the energy class and the quality of construction. With the minimization of carbon emissions resulting from the exploitation of buildings, the measures to control and reduce the environmental impacts of the entire production chain of construction have become a priority. For this reason, it is time to begin determining the "carbon invoice" of the production of construction materials and construction of buildings [2]. As soon as this determination has credible and statistically significant data, the theoretical "carbon invoice" can become a real environmental tax to be applied to new constructions (and may be an incentive for rehabilitation works). Even though the European building industry has energy efficiency as its most recent priority, in a desirable future it will be possible to evaluate a building, and make its energetic certification via a balance of the environmental impacts of its materials in its whole life cycle. To fulfil the ISO 15392 general principle "holistic approach" [3], the sustainability assessment of a building must represent a part of an assessment of integrated building performance [4, 5]. In Spain, for example, a simplified "Life-Cycle Assessment" (LCA) methodology to be included in the process of energetic certification of buildings has already been proposed. This method uses the "Environmental Product Declarations" of construction materials that are already available [6]. In Italy, the need to integrate life cycle assessment quantitative indicators in the process of energy certification has also been identified [7].

The envelope is one of the main parts of the buildings. One of its parts, the external walls, directly influence the thermal and environmental performance of the building envelope because of their considerable weight in the envelope's initial embodied energy, life-cycle energy consumption, whole-life cost and users comfort. They can represent up to 15 % of the overall environmental impacts of a building over a 60-year life-cycle [8] cited by [9]. The environmental impacts of each external wall solution result directly from the attributes of the materials used, such as its initial embodied energy and thermal properties and the way the solution is designed and built. A detailed review of LCA results of more than 10 years of international research studies on the environmental impact of a building's external walls has shown that all the studies include the production of the construction materials and the majority (63%) evaluate the embodied energy of each external wall, but just a third include the end-of-life of the building assembly and no more than 42% include the construction, operation and maintenance stages [10]. Therefore, this paper proposes an approach to provide the environmental, energetic and economic life-cycle assessment from "cradle to cradle" (3E-C2C) of building assemblies and exemplifies its application in the process of selection of the external wall of a building.

2. Proposed environmental, energetic and economic life-cycle assessment from "cradle to cradle" (3E-C2C) approach

A methodology to identify optimal levels of performance of building elements that only include construction and energy costs optimization is proposed in the Recast of the "Energy Performance of Buildings Directive" of 2010 [11]. This approach is insufficient since it disregards environmental aspects of the building element in the life-cycle analysis that leads to a "cost-optimal level". Therefore, this paper proposes an approach to provide the 3E-C2C of building assemblies along the guidelines included in European draft standards under development by Technical Committee (TC) 350 of the "European Committee for Standardization" (CEN/TC 350 - "Sustainability of Construction Works"). These standards for the sustainability assessment of buildings and construction products, which have been structured into three horizontal levels (framework, building and product) and into three vertical columns (environmental, social and economic) while always taking into account technical and functional performance characteristics, will be in their final version by the beginning of 2012. This harmonized European system will allow the assessment of the environmental, social and economic performance of buildings based on a life-cycle approach.

The application of the 3E-C2C approach allows for the evaluation and comparison of building assemblies by: Considering their whole life-cycle (C2C); Assessing the 3E-C2C impacts and taking into account all the factors that could affect them (e.g. the performance of the assembly in the use phase of the building, service life and recycling potential).

The experimental application of the 3E-C2C approach to the process of selection of the external wall solution for a new (model) building in Portugal allowed the improvement and refinement of each of its modules and steps. Each part of the 3E-C2C of these assemblies was based on and/or compared with data included in other studies already finished in Portugal concerning the energetic, economic and/or environmental performance of solutions for the building envelope.

2.1 Scope of the study

The 3E-C2C approach was applied to a process of selection of the external walls of a model building called HEXA (developed within the LiderA, the Portuguese building environmental certification system), which has five residential floors (the ground floor is to be used for commerce) [12], represents the most common constructive and architectural practices in Portugal but has not been built yet [13]. The HEXA design drawing can be seen in Figure 1 (the building faces South), and the object of the study is the apartment on the left located on a middle floor without an adjacent building on the East façade. The location chosen for HEXA in this study was Lisbon.

Figure 1 - HEXA design drawing of a middle floor: the object of the study is the apartment on the left, without an adjacent building on the East façade [13]

The external walls under analysis are located in the North and South façades of the flat and the functional unit is a square meter of external wall (the East façade is considered to be wall W1 - see Table 1 - for all alternatives). The reference study period was defined as 50 years [12]. For the wall structure, only masonry solutions were considered (the most common solution in Portugal) and for insulation, the materials studied were Extruded Polystyrene (XPS) (inside a cavity wall) and Expanded Polystyrene (EPS) and Agglomerate of Expanded Cork (ICB) within an "External Thermal Insulation Composite System" (ETICS) (Table 1) [12].
The data of life-cycle stages of the external walls included in each module of 3E-C2C approach in the present case study are summarized in Table 2 and described in detail in sections 2.2 and 2.3.

Table 1 - Characteristics of each external wall solution (North and South façades), including maintenance actions

External wall solution	U-value ($W/m^2.K$)	External cladding (EC)	EC maintenance	Wall structure	Wall insulation	Internal coating (IC)	IC maintenance
W1	0.47	Painted cement plaster	Total cleaning and repainting every 5 years and repair of 35% of the area at 25 years	Cavity wall: 15+11 cm	4 cm of XPS in the air gap	Painted cement plaster	Total cleaning and repainting every 5 years; repair of 5% of the area each 10 years
W2	0.45	ETICS system		Brick wall: 22 cm	6 cm of EPS in ETICS		
W3	0.48	ETICS system		Brick wall: 22 cm	6 cm of ICB in ETICS		
W4	0.4	ETICS system		Brick wall: 22 cm	8 cm of ICB in ETICS		

Table 2 - Data of life-cycle stages of the external walls included in each module of 3E-C2C approach in the present case study

3E-C2C module	Production	Transport to site	Use stage - energy use for heating and cooling	Use stage - maintenance	End-of-life stage - transport and deposition
Environmental performance	x	x			x
Economic performance	x	x		x	x
Energetic performance			x		

2.2 Environmental performance

The environmental performance of the external wall solutions were compared from “cradle to cradle” following “Life-cycle Assessment” methodology (LCA) (based on ISO 14040:2006 and ISO 14044:2006 international standards [14, 15]). This procedure allows LCA results from different studies to be compared and to be used to make meaningful choices [16, 17].

The environmental module of the 3E-C2C approach also followed most of the principles already included in the draft standards FprEN 15643-2:2010: “Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance” and prEN 15978:2010: “Sustainability of construction works - Assessment of environmental performance of buildings - Calculation methods”, as the following ones:

- The assessment of the environmental performance shall apply the LCA approach in accordance with the guidelines and requirements of ISO 14040:2006 [15];
- The results of the assessments shall be organized in three main groups: impacts specific to building fabric and site (results from the product stage and from the construction process stage), impacts and aspects specific to building in operation (maintenance, repair, replacement, water and energy use and all activities with an environmental impact) and results from the end of life stage of the building;
- The quantification of the impacts of operational energy is a direct result of the calculation of the energy used during the use stage of the building according to the “Energy Performance Building Directive” (EPBD) [1] and shall be derived from different energy carriers or LCA databases;
- The impacts and aspects related with benefits and loads beyond the building life cycle, e.g. those that result from further reuse, recycling potential and energy recovery and other recovery operations, may be included as supplementary information. They are essential to promote and allow a C2C approach in the life-cycle of the buildings and corresponding assemblies;
- The default value for the reference study period shall be the required service life of the building and the estimated service life of the assemblies shall take into account rules and guidance included in the standards ISO 15686-1,-2,-7 and -8 [18-21].

2.2.1 Product stage

The LCA from the production of each construction material (“cradle to gate” approach) was calculated using “SimaPro” software and available “Life cycle Inventory” (LCI) databases adapted to the Portuguese reality when adequate. The LCI data used was:

- Mainly “ecoinvent database system processes”, with a modification in the energy source to represent the Portuguese reality (“electricity, medium voltage, at grid PT/U”);
- The “ecoinvent system process” that corresponds to the production of ICB contains data from one major producer in Portugal;
- “CO_2 sequestration” of cork oak tree (which benefits ICB) was estimated in a “conservative" way, by simulating the incineration with energy recovering at the end of life stage and considering the corresponding negative environmental impact right in the production phase [22];
- The environmental impacts of the production of 1 ton of brick were based on the “Environmental Product Declaration” (EPD) of masonry units with vertical hollows developed in 2009 by the “Technological Centre for Ceramic and Glass”, in collaboration with the “Portuguese Association of the Ceramic Industry” (APICER), based on data collected from 11 sites and on international databases [23, 24].

2.2.2 Construction process stage

At this stage, only the environmental impacts of the transportation from factory gate to construction site were considered (brick and mortars from Leiria area - about 150 km from building site - and insulation materials from the corresponding factories - XPS from 273 km, EPS from 30 km and ICB from 85 km away).

2.2.3 Use stage - energetic performance

The energetic performance considered in the 3E-C2C approach corresponds to the estimation of consumption of energy for heating and cooling during a building's operation, because these are the only operational costs that the façade influences (ventilation, hot water and lighting uses are similar between the external wall solutions being evaluated). These energetic needs were calculated following the national regulation related with the "Energetic and interior air quality certification in buildings" [25], which transposes the EPBD. This certification system forces the construction, sale or rental of a building or house to be followed by the corresponding certification of its energetic performance. For residential buildings, this regulation stipulates a maximum consumption of heating (winter) and cooling energy (summer), and also limits the energy for heating sanitary waters and the primary energy consumption [13].

To estimate the environmental impacts of the consumption of energy for heating and cooling, the energetic needs of the apartment (in kWh) in the study period were divided by the total area of the external wall being evaluated (40.27 m^2) in order to achieve a value related with the functional unit of the study. This value (in kWh) was introduced in "SimaPro" software and the corresponding environmental impacts were calculated considering the process which represents the Portuguese electricity supply ("electricity, medium voltage, at grid PT/U").

2.2.4 End of life stage

At this stage selective demolition (or deconstruction) was considered to estimate environmental and economic impacts of transport and disposal of "Construction and Demolition Waste" (CDW) in adequate plants. This technique is increasingly being used in Portugal for environmental (allowing the maximization of CDW reuse/recycling potential) and economic reasons [26]. However, for ETICS solutions, it was considered that the finishing plaster and the insulation material are mixed after demolition and therefore have to be considered as undifferentiated CDW (waste code 17 09 04 - mixed construction and demolition wastes [27]) and sent to landfill. The environmental and economic costs of demolition works were not considered in this approach as they are similar for all the alternatives being evaluated.

The cost and the environmental impacts of the transport and disposal of the CDW generated by each external wall solution were based on Portuguese case studies which used data from waste operators and market values. Therefore, the most probable disposal place (CDW management and recycling plants of the Lisbon area) and final destiny (ex.: landfill, reuse or recycling) were considered for each type of CDW [26]. For example, to estimate the environmental performance, an operation of "rock crushing" and an avoidance of the product "crushed stone" with an output of 80% was considered for the mixture of brick and concrete from mortars (waste code 17 01 07 - mixtures of concrete, bricks, tiles and ceramics [27]) that results from the demolition. However, more studies are necessary in Portugal to evaluate the potential for improving the recycling and reuse of CDW, namely via industrial symbioses, because the end-of-life phase can have a positive contribution to the environmental performance of construction materials [28].

2.2.5 Environmental performance assessment

The LCA results C2C (without weighting or aggregation) for the external wall solutions being evaluated are presented in section 3. Single score should never be used in public comparisons of LCA results [14] and the interpretation and valuation of the results of the assessment are not within the scope of LCA international standards [14, 15]. However, in order to allow for the application of a 3E *cost*-C2C approach, an "Environmental Impact Assessment Method" (EIAM) with a weighting step (that converts the results of all impact categories into an economic unit) was used to allow the addition of the cost associated with the environmental impacts to the economic and energetic whole-life cost. 3E *cost*-C2C may become universal, when the financial implications of each environmental impact have been sufficiently assessed (ex.: the carbon market related with the cost of CO_2 emissions of the production of products). There are already examples of quantification of "natural capital", as the "Canadian Boreal Initiative" that calculated the value of the ecological services of a valley in order to "tax" industries that destroy it [29]. The invisibility of many of nature’s services to the economy results in widespread neglect of natural capital, leading to decisions that degrade ecosystem services and biodiversity [30]. Only the definition of a universal economic value of natural elements and services can avoid the excessive consumption of natural resources. Nevertheless, as the value of nature starts being recognized, a global market for services from ecosystems - the natural capital - emerges at the global level [31].

Concerning the EIAM, most of the academic LCA studies use a "single indicator" which weights the results of each impact category to express them in the same unit: a "damage based" indicator (ex.: *Ecoindicator 99* whose unit is “Points”); a single issue indicator (ex.: global warming potential, corresponding to the carbon footprint with “kg CO_2 eq.” as its reference unit); a "prevention based" indicator (ex.: *eco-costs 2007*, with an economic unit, the euro). All of them are suitable for different types of analysis, but for C2C calculations *eco-costs* give the most satisfactory results. *Eco-costs* defines a prevention based "single indicator" for environmental burdens which is based on the concept of "marginal prevention costs" (e.g. costs required to bring the environmental burden to a sustainable level, by either “end-of-pipe” measures or by “process integrated” solutions). “Marginal prevention costs” include the *eco-costs* of toxic emissions, material depletion and energy. One substance can cause damage in different impact categories but it has only one prevention cost, so should be counted only in one impact category and e*co-costs* model considers it only in the most relevant (most expensive) impact category. This EIAM was built based on the Dutch reality by the “Delft University of Technology” but can be applied to other western European countries [22]. The weighted results of the environmental performance based on the *eco-costs* model are presented in section 4.

2.3 Economic performance

Whole-life cost (WLC) is defined as the “all significant and relevant initial and future costs and benefits of and asset, throughout its life cycle, while fulfilling the performance requirements” [32]. The economic module of 3E-C2C approach is based on the WLC methodology [32] and followed most of the principles already included in the draft standard prEN 15643-4:2010: “Sustainability of construction works - Sustainability assessment of buildings - Part 4: Framework for the assessment of economic performance”, as the following ones:

- Only the cost value was considered to express the economic performance over the life cycle, which means that the “lowest life cycle cost” building is the most economic one;
- To link the results from environmental, economic and energetic performance assessments requires that the functional equivalent is one and the same for all assessments.

The WLC from “cradle to cradle” of the solutions under analysis was estimated taking into account these principles and considering current Portuguese practices. In order to facilitate the choice between the competing alternatives, the “Net Present Value” (NPV) method was chosen. The NPV of an alternative is the summation of all costs that occur during the period of study of the life cycle of the solution under analysis, converted to their present value (using a discount rate) in order to make the NPV of all solutions comparable in year 0 - the present moment which corresponds to the design phase [12]. The NPV of the functional unit of each alternative was calculated for the study period using equation (1) considering constant prices [32] and is presented in sections 3. (economic - *Cec* - and energetic - *Ceg* - costs) and 4. (environmental cost - *Cev*):

$$NPV = \sum_{n=0}^{50} \frac{C_n}{(1+d)^n} \quad (€/m^2) \tag{1}$$

Where

C_n cost in year n (€/m^2);

d real discount rate (without considering risk) applied (3%).

2.3.1 Product and construction process stages

Economic cost in year n per square meter of external wall - Cec_n - includes, before use stage, the market acquisition cost in year 0 (which aggregates the cost of products manufacture and transport to site and the costs from the construction process), the maintenance, repair and replacement costs in the study period. These costs were mainly obtained through market surveys, contacting construction entities, as well as construction material suppliers [12].

2.3.2 Use stage - energetic cost

The energetic cost in the year *n* per square meter of external wall - Ceg_n - corresponds to the expense in energy use for heating and cooling calculated following the methodology described in the national regulation [25, 33]:

$$Ceg_n = 0.1 \times T \times (\frac{Nic}{\eta_i} + \frac{Nvc}{\eta_v}) \times \frac{Aap}{Aew} \quad \text{(€/year*m}^2 \text{ of external wall)} \qquad (2)$$

Where

T cost of 1 kWh of electricity in Portugal for household consumers, with VAT but without fixed taxes (€/kWh) (0.163 €/kWh considering an installation with more than 2.3 kVA [34]);
Nic nominal annual heating needs per square meter of net floor area of the flat (kWh/m^2*year);
η_i nominal efficiency of the heating equipment (1, considering the reference value [25]);
Nvc nominal annual cooling needs per square meter of net floor area of the flat (kWh/m^2*year);
η_v nominal efficiency of the cooling equipment (3, considering the reference value [25]);
Aap net floor area of the apartment being evaluated (129.96 m^2);
Aew total area of the external wall being evaluated (40.27 m^2).

2.3.3 Use stage - maintenance cost

Economic cost in year *n* per square meter of external wall - Cec_n - includes the corresponding maintenance, repair and replacement operation costs that occur in that year. However, the environmental impacts of these operations are not considered in the environmental performance module of 3E-C2C due to their variable and unpredictable nature.

The maintenance, repair and replacement operations defined in the study for each element of the external wall are described in Table 1.

2.3.4 End-of-life stage

The economic costs in year 50, corresponding to end-of-life costs, only include those associated with transport and disposal (gate cost or tipping fee) of the building assemblies and costs and/or revenues from reuse, recycling, and energy recovery ([26]), using the approach described in section 2.2.4.

3. 3E-C2C results

Here the LCA results in five environmental categories (using an EIAM with a mid-point approach - CML 2 baseline method 2000) (Table 3) are presented along with the economic and energetic ones (Figure 2). The environmental performance results are expressed in an economic single indicator, and their combination with economic and energetic performance results, are presented in section 4.

Table 3 - LCA results - C2C of each alternative, without energy use

Environmental category	W1	Results for W2 / % of difference for W1		W3		W4	
1.1. Global Warming potential (kg CO_2 eq.)	6.64E+01	6.10E+01	-9%	5.61E+01	-18%	5.71E+01	-16%
1.2. Ozone layer depletion (kg CFC-11 eq.)	2.03E-04	4.97E-06	-3985%	4.67E-06	-4252%	4.63E-06	-4282%
1.3.Photochemical oxidation (kg C_2H_4)	1.78E-02	2.84E-02	37%	1.74E-02	-2%	1.80E-02	1%
1.4.Acidification (kg SO_2 eq.)	2.40E-01	2.29E-01	-5%	2.15E-01	-11%	2.22E-01	-8%
1.5.Eutrophication (kg PO_4^{-3} eq.)	3.91E-02	8.05E-02	51%	9.28E-02	58%	1.01E-01	61%

Concerning the environmental performance (LCA without energy use), W1 has a better result only in terms of “Eutrophication”, mainly due to the effects of components of ETICS solutions that are sent to landfill in the other alternatives. The worst performance of W2 in the “Photochemical oxidation” category results directly from the environmental impact of EPS production. The production of XPS results in “Ozone layer depletion", making this environmental category significant only for W1. The effect on “Global Warming” of W3 and W4 is mitigated by the consideration of “CO_2 sequestration” of cork oak trees that benefit ICB.

The LCA results of the energy use of each solution do not differ more than 2% from each other and are not significant to help in the choice of the one with the best environmental performance.

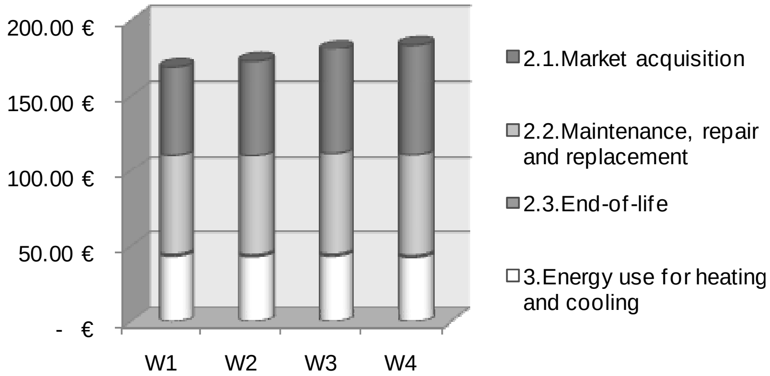

Figure 2 - NPV of the economic (*Cec* - 2.1, 2.2, 2.3) and energetic (*Ceg* - 3.) costs of each option

Concerning the economic and energetic performance (Figure 2), different conclusions can be drawn. The acquisition costs increase from W1 to W4 and this factor really influences the final result, making W1 the best solution in this module of 3E-C2C. However, if the building is not demolished after 50 years, the insulation material starts losing its characteristics and should be replaced. Then, W1 will be the solution for which this operation will be more complicated and expensive because of the location of XPS. W4 has the best energetic performance, which results directly from the lower U-value of this solution.

4. 3E *cost*-C2C results

Section 3. shows that it is important to analyze the results of each module of 3E-C2C separately, but if it were necessary to make a sound choice of the alternatives with a justifiable criterion, what should be the weights that have to be applied for environmental, economic and energetic results? 3E *cost*-C2C provides a common subjectivity-free unit to compare different alternatives in the design of a building. For each alternative, the cost in year *n* per square meter of external wall is the sum of the environmental (*Cev*), economic (*Cec*) and energetic (*Ceg*) cost:

$C_n = Cev_n + Cec_n + Ceg_n$ (€/m^2 of external wall) (3)

The NPV of each alternative is achieved by applying equation (1). *Cev* corresponds to the application of the EIAM *eco-costs* to the LCA results already shown in section 3.

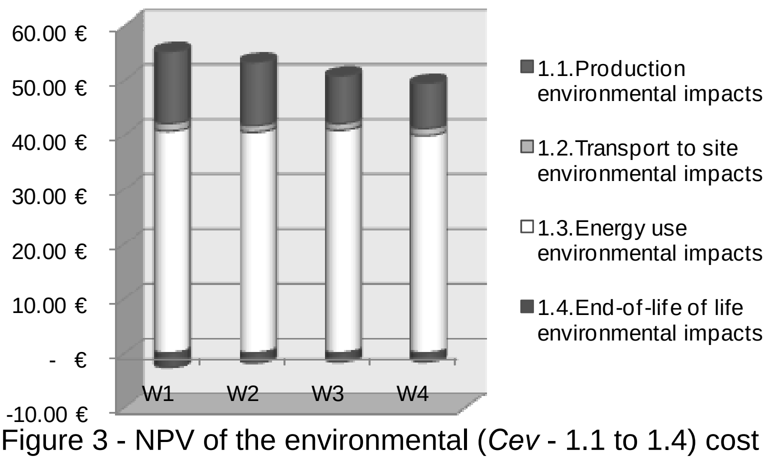

Figure 3 - NPV of the environmental (*Cev* - 1.1 to 1.4) cost

Looking at Figure 3, W3 and W4 show the lowest environmental cost in the production stage, mainly due to the consideration of “CO_2 sequestration” during cork oak tree grown. W1 has the greater environmental cost in the transport to site stage because XPS is produced in the more distant plant between the materials used. Costs of end-of-life environmental impacts are negative for all the alternatives because it avoids “crushed stone” due to the recycling (crushing operation) and reuse of the mixture of brick and concrete from mortars that results from the demolition of the walls and that is more significant for W1 (because it includes a higher quantity of brick and masonry mortar and is the only one that includes exterior render).

5. Discussion

3E *cost*-C2C results (Figure 4) show the importance of economic cost, which represent more than 55% of the total cost for all four alternatives. This fact, along with the small difference in the total cost between the alternatives (4% between the most and the least expensive), makes the result of this study highly dependent on the uncertainty inherent to market prices for acquisition and maintenance operations (the former are more important because they occur in year 0).

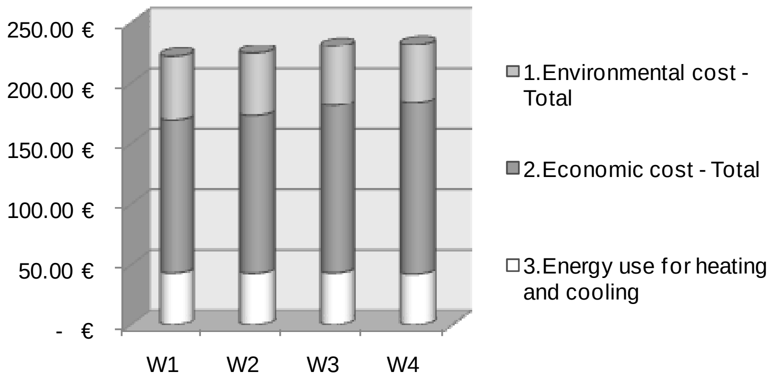

Figure 4 - NPV of the total environmental, economic and energetic cost of each alternative

Concerning the environmental costs, they decrease from W1 to W4 and are inversely proportional to the acquisition cost. Therefore, it is not clear which solution can create a maximum value to the end-user with minimum environmental burden, namely the one with the greater environmental efficiency. However, if the increase of use of ICB results in a decrease of its cost and environmental taxes in products acquisition become a reality, W3 and W4 have a high potential to become the alternatives with the best performance from a 3E *cost*-C2C point of view. The use of ICB also improves the acoustic performance of walls, but it is not ye possible to economically evaluate this positive “social impact”.

Concerning the discount rate used for the calculations, a change of more or less 2% does not significantly affect the final result. However, a value higher than 5% affects mostly W3 and W4, because of their higher acquisition cost.

6. Conclusion

This paper proposes an approach which was developed following the guidelines already included in European draft standards, 3E-C2C, and that allows the comparison of two or more assemblies and to select the best alternative (even between solutions that are not functionally equivalent because of the C2C approach that also considers the use and end of life stages and the reference service life) via a multi-criteria analysis if weights are defined for environmental, economic and energetic results. This subjectivity can be eliminated with the use of 3E *cost*-C2C, which expresses all the results in the same unit and therefore allows choosing alternatives (even if they are not functionally equivalent) by considering all the relevant performance indicators in all the important life-cycle stages.

The 3E-C2C data could be also used in the management of the building to allow a permanent monitoring and update of the 3E impacts of each assembly, namely after each maintenance or refurbishment activity. In the future, this feature can be important to allow the renewal of the energetic and/or environmental efficiency certificates.

7. Acknowledgements

The authors thankfully acknowledge the scholarship of FCT (Foundation for Science and Technology) to support the PhD study of the first author and the support of the ICIST Research Institute from IST, Technical University of Lisbon.

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