Portugal SB07

Sustainable Construction

Materials and Practices

Challenge of the Industry for the New Millennium

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Part 1

Contents

Part 1

Part 2

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Sustainability assessment of building refurbishing operations

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ABSTRACT: The actual development model that gives priority to demolition and new construction in detriment to building refurbishing is not compatible with the aims and objectives of Sustainable Development. The sustainable building refurbishing embraces an endless list of parameters that should be taken into account by all building stakeholders. The individual analysis of these parameters does not allow verifying which solution has the best trade-off between the several sustainability parameters. The aim of this paper is to present a multi-criteria decision based methodology that allows the integrated assessment of all different parameters. At the end, the methodology is applied to a case study, which aim is to select the most sustainable solution between two different refurbishing solutions for a building façade.

1 INTRODUCTION

Sustainable Development searches the best trade-off between three dimensions: environment, society and economy. Construction and mainly the building sector has great influence in that objective. Buildings accounts for the greatest amount of the total residues production and energy consumption. Besides that, buildings are the population's center of life: an adult in a developed country spends almost 90% of its life inside buildings. Globally, buildings construction is responsible for about 40% of raw materials (stone, gravel, sand, etc), 25% of wood, 40% of energy and 16% of water annually spent all over the world (Roodman, 1995). In Portugal, in spite of existing important differences between the reality and the statistical figures, according to national energy directorate (DGGE) and national statistics institute (INE), during operation phase, buildings (houses and offices) accounts for about 25% of the national primary energy consumption, 6,7% of the total water end-use and is responsible for the annual production of 420 millions of cubic meters of residual water. According to INE, construction industry is also responsible for the annual production of about 7,5 millions tons of solid residues. These figures show that buildings are related with strong environmental, social and economical impacts that have great potentialities to be to some extent overcame.

In Portugal, during the last decade of the 20th century it was possible to assist to a huge growth in the construction market, mainly in new buildings and road infrastructures sectors. For instance, in the second half of the 90's the national construction sector's growth rate was ten times higher, compared to the European average rate. From 1999 to 2002 were built an average of 105 000 new residential units per year. These figures are even more significant if they are compared to the reality of the most developed European countries, where the retrofitting/rehabilitation market assumes a higher relative importance. According to Euroconstruct, the retrofitting/rehabilitation market in Portugal represents about 8% of the total construction works, while the Western European average is nearly 45%.

Despite the fact that in an initial phase this mismatch was justified by the relative underdevelopment of Portugal, this unsustainable growth is raising a set of problems that the construction market is facing nowadays, like p.e., overplus number of residential units built to a stagnated and each day older population, urban planning chaos caused by the disorderly growth, progressive degradation and consequent desertification of urban centres.

Building refurbishing in opposition to demolishing and new construction is an important step towards sustainability. Correcting the actual policy of "use and throwaway" it is possible to overcome some economic problems; to increase the occupants and users comfort; to turn down the environmental impacts through the energy consumption, raw materials and residues reduction; and to preserve the city's cultural legacy.

Sustainable refurnishing is based in several different aspects, some times contradictory, related among others to the quality of materials, economic impacts, indoor environment comfort, protection of environment, cultural heritage, etc..

Although there still is an important question that must be solved: to define the sustainable refurnishing concept through tangible goals. Sustainability assessment is a holistic approach that doesn't consider all aspects related to the environmental, economic and social performances of a solution, but only those parameters that better compromises the objectives of the assessment, the type of solution, the available data, among others. The application of the "Sustainable Development" concept is based on the definition of objectives and criteria to be used in the sustainability assessment and comparison of different building solutions. This way it is possible to choose the most sustainable solution, according the considered aspects.

This paper presents the first step for the development of a methodology for the sustainability assessment of building refurnishing processes, which is based in the three dimensions of Sustainable Development. At the end of the paper, the methodology is applied to a case study which aims are the selection of the most sustainable refurnishing solution for a building façade, according to the assessment objectives.

2 SUSTAINABILITY ASSESSMENT METHODOLOGY

The methodology presented in this document is a derivation and adaptation of the Metodology for the Relative Assessment of Building Solutions (MARS-SC) that was developed in order to evaluate new construction solutions (Mateus, 2004). This methodology follows these steps: definition of parameters, quantifications of parameters, normalization of parameters, aggregation of parameters, representation and assessment of the solution.

In the next paragraphs is made a short description of the methodology MARS-SC adapted to refurnishing operations.

2.1 *Definition of parameters*

The sustainability assessment is holistically made, because it is impossible to consider all parameters that express the performance of a solution at the level of the three dimensions of the sustainable development. This way, in this phase the number and type of parameters to be assessed inside each dimension are defined. The definition depends on one hand in all objectives of the assessment, type of solution to be refurnished, local conditions, functional requirements that are necessary to fulfil, available data, and in the other hand in the assessment boundary: the sustainability assessment of a single construction element refurnishing is not based in the same parameters used for a whole building or district. Table 1 presents some parameters that could be considered in a sustainability assessment of a refurnishing solution for a façade.

2.2 *Quantification of parameters*

After selecting the parameters it is necessary to proceed with their quantification. Quantification it is essential to compare different solutions, aggregate parameters and to accurate assess the solution. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation tools, expert's opinions, databases processing, etc. (Cherqui, 2004). In some cases times the parameters to evaluate are quantitative. When assessing qualitative parameters like for instance, aesthetics and maintenance aptitude, the qualitative performance level is transformed in a quantitative scale, using the equivalences presented in Table 2.This transformation is based in the comparison of the performance with the best and conventional/minimal normalized performance.

Table 1. Parameters that could be used in the sustainability assessment of refurbishing solutions for building façades.

Parameters		
Environmental	Social	Economic
Environmental	Airborne sound insulation	Construction cost
Global warming potential	Thermal insulation	Operational cost
Fossil fuel depletion potential	Structural safety	Refurnishing cost
Acidification potential	Fire safety	Dismantling/demolition cost
Chemical oxygen depletion	Water permeability	Residual value
Production of residues	Maintenance aptitude	Residues treatment cost
Embodied water	Preservation of the city's heritage	
Reusing potential	Aesthetics	
Recycling potential		

Table 2. Equivalences between the qualitative and quantitative performances.

Qualitative performance	Score
Best solution	1,00
Good solution	0,75
Slightly better than the conventional solution	0,25
Conventional solution/minimum standard	0,00

It is not easy to evaluate the environmental parameters mentioned above. Although there are some life-cycle inventory (LCI) databases about the environmental pressure related to several construction materials that could be used to support life-cycle analysis (LCA). It is also possible to use LCA tools to evaluate the parameters mentioned above.

To assess the social parameters related to the indoor environment comfort, it is possible to use one of the several normalized methodologies available. Another way is to use and process some available databases that collect common functional performance data related to some conventional refurbishing solutions. Whenever possible, experimental results should be used, because those are the ones that best draw up the real performance of the solution.

Life cycle cost analysis (LCCA) is more straightforward than the environmental performance assessment, since there are different standardized methodologies and published construction costs databases. LCCA is a method that allows the quantification of the global cost of a product for a certain period of service life. In this method all costs are included: construction cost (capital cost), operation cost, maintenance cost and the residual value of the building or of some part of it. LCCA is an important approach whenever it is necessary to compare two solutions that have the same functional requirements but that differ at the level of their initial and operational costs.

2.3 *Normalization of parameters*

The objective of the normalization of parameters is to avoid the scale effects in the aggregation of parameters inside each dimension and to solve the problem that some indicators are of the type "higher is better" and others "lower is better". Normalization is done using the Diaz-Balteiro et al. (2004) Equation.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \qquad (1)$$

In this equation, P_i is the value of ith parameter. P^*_i and P_{*i} are the best and worst value of the ith sustainable parameter.

The normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: "higher is better" and "lower is better".

2.4 *Aggregation*

Sustainability assessment across different fields and involves hundreds of parameters. Each sustainable dimension is characterized by several parameters or indicators. A long list of parameters with their associated values won't be useful to assess a project. The best solution to overcome this situation is to combine parameters with each other to obtain "global indicators", allowing assessing the sustainability of each solution at the level of each sustainability dimension.

The complete aggregation method that is used in this methodology is presented in Equation 2.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \quad (2)$$

The global indicator I_j is the result of the weighting average of all the normalized indicators $\overline{P_i}$. w_i is the weight of the ith parameter. The sum of all weights must be equal to 1.

Equations 3 to 5 present how to aggregate the parameters inside each indicator in order to assess the performance of a solution within each sustainable dimension.

$$I_{Env} = \sum_{i=1}^{n} w_{Env\,i} . \overline{P_{Env\,i}} \text{, environmental dimension} \quad (3)$$

$$I_{Soc} = \sum_{i=1}^{n} w_{Soc\,i} . \overline{P_{Soc\,i}} \text{, societal dimension} \quad (4)$$

$$I_{Eco} = \overline{P_{Eco\,i}} \text{, economic dimension} \quad (5)$$

In the economic dimension, the global indicator as the same value of the normalized economic parameter because the normalized parameter results from the sum of every cost found in the life-cycle costing analysis.

The weight of each parameter in the assessment of every indicator is not consensual, as it is possible to verify when analysing the several different available methodologies for sustainable design assessment and support. This is the major inconvenient of this method, when compared to performance based methodologies, since it is possible the compensation between parameters.

Weights are strongly linked to the objectives of the project: higher weights must be adopted for parameters of major importance in the project.

At the level of the weights of the environmental parameters, there are some international accepted studies that allow an almost clear definition. One of the most accepted studies is the one performed by the EPA's Science Advisory Board (SAB) that developed lists of relative importance of various environmental impacts to help EPA to best allocate its recourses (EPA, 2000).

Whenever there isn't a local or regional available data, it is suggested to use EPA's weights in MARS-SC.

In spite of being easy to quantify the functional parameters, the way as each parameter influences the functional performance and therefore the sustainability isn't consensual. This assessment involves subjective rating and depends, above all, on the type of solution and on the valuator's social-cultural and economic status. This way in a first approach the methodology considers the same weight for all functional parameters. The MARS-SC is being developed in order to accommodate a more consensual distribution of weights.

2.5 *Representation and assessment of the solutions*

One important feature of the methodology is the graphical representation for the monitoring of the different solutions that are analyzed. The representation is global, involving all the considered objectives.

The tool that is used to graphically integrate and monitor the different parameters is the "radar" or Amoeba diagram. This diagram has the same number of rays as the number of parameters under analysis and is called the sustainable profile. In each sustainable profile the global performance of a solution is monitored and compared with the performance of the reference solution. Furthest to the center is the solution, better it is. It is also possible to verify the solution that best compromises the different parameters used in the assessment.

After assessing the performance of a solution within all dimensions (environmental, societal and economics), the next step is to combine the global scores with each other in order to obtain the sustainable score. Sustainable score (SS) is a single index that resumes the global performance of a solution. As nearest to 1 is the sustainable score, more sustainable is the solution. The aggregation method used to calculate the sustainable score is presented in equation 6.

$$SS = I_{Env}.w_{Env} + I_{Soc}.w_{Soc} + I_{Eco}.w_{Eco} \tag{6}$$

Sustainable score, *SS* is the result of the weighting average of each global indicator I_j. w_i represents the weight of the *j*th parameter.

The weight of each dimension in the global sustainability is still not consensual. It depends, among other, in the objectives of the project and local priorities. In MARS-SC it is proposed to use the weights presented in Table 3.

Table 3. Weight of each sustainable dimension in the sustainable score assessment.

Indicator	Weight (w_i)
Environmental (I_{Env})	0,30
Societal (I_{Soc})	0,50
Economic (I_{Eco})	0,20

The *SS* value should not be singly used in order to characterize the sustainability of a solution, since it is possible the compensation between dimensions and moreover the solution has to be the best compromise between all the different aspects: every aspect has to be represented.

3 CASE STUDY

The scope of the case study is the assessment of a refurnishing project related to a multi-storey building with three floors, located in the city's centre of Guimarães. This building was built at the end of the 60's and most of its envelope, mainly the façade, is in a considerable degradation state (figure 1). This building doesn't have any king of heritage value. In the façade it is possible to identify some cracks that are compromising the water permeability of this construction element. The aim of this project is not only to improve the building aesthetics, but also to improve other functional characteristics, mainly the thermal comfort, in order to turn it compatible to the actual comfort demands. Another requirement to fulfil is that the refurnishing solution should be the best compromise between the three dimensions of sustainable development.

After examining the façade it was possible to conclude that the cracks are stable and that the original solution used in the façade is a hollow brick cavity wall without any insulation material, as presented in Figure 2.

The refurnishing solution to adopt should not disturb the indoor living conditions of the inhabitants. This way the two solutions proposed for the façade's opaque area were the ventilated façade (solution 1) and the external thermal composite system – ETICS (solution 2). The cross-section of both refurnishing solutions are presented in Figures 3 and 4.

In order to fulfil the thermal standard valid during the design period (Decrew-Law 40/90) it was necessary to reduce the U-value of the façade in 42%, in relation to the initial value.

Figure 1. Elevation of the façade.

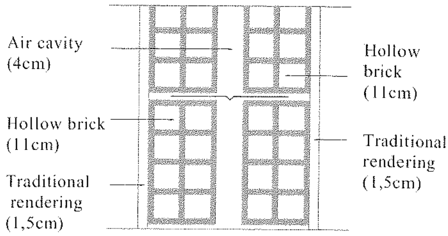

Figure 2. Cross-section of the existing solution.

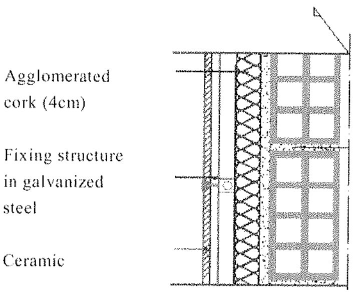

Figure 3. Refurnished façade's cross section after (solution 1).

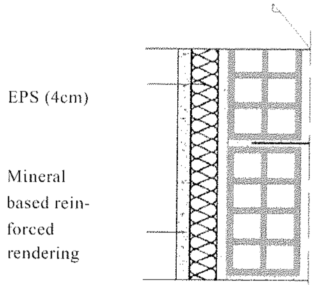

Figure 4. Refurnished façade's cross section after (solution 2).

3.1 *Accessed parameters and related weight*

At the level of the environmental performance, the project team decided that the solution to adopt should have the lowest possible embodied environmental impact. The selected parameters for the environmental performance assessment were: embodied primary energy (PEC), global warming potential (GWP), habitat alteration (HA) - based on the construction mass (M) and quantity of residues produced during materials processing (R), acidification potential (AP) and chemical oxygen depletion (COD).

In which regards to societal performance, the aim was to find the best compromise between the following functional parameters: airborne sound insulation ($D_{n,w}$), U-value (U), maintenance aptitude (MA).

For the economic performance the aim was to choose the solution with lower construction cost. This way it was considered just one economic parameter in the assessment: construction cost (CC).

Table 4 resumes the considered parameters and related weights.

Table 4. Assessed parameters and related weight.

Dimensions	Parameter	Parameter's Weight (%)	Dimension's Weight (%)
Environment	Primary energy consumption (PEC)	11,1	30,0
	Global warming potential (GWP)	33,3	
	Habitat alteration (HA)	33,3	
	Acidification potential (AP)	11,1	
	Chemical oxygen depletion (COD)	11,1	
Societal	Airborne sound insulation ($D_{n,w}$)	33,3	50,0
	U-value (U)	33,3	
	Maintenance aptitude (MA)	33,3	
Economic	Construction cost (CC)	1,00	20,0

3.2 *Quantification of parameters*

Besides the environmental performance of both refurnishing solutions, Table 5 presents, only for information, the environmental performance of the initial solution. In Portugal is not available LCI data related to the building materials' environmental impacts. This way the results are based in the values presented by Berge for Central Europe (Berge, 2000)

Table 5. Environmental performance of the initial and both refurnishing solutions.

Solutions	M[(1)] Kg/m^2	PEC[(2)] kWh/m^2	GWP[(3)] $g*10^3/m^2$	AP[(4)] $g*10^3/m^2$	COD[(5)] $g*10^3/m^2$	R[(6)] $g*10^3/m^2$
Initial	244,05	161,56	39,51	0,40	3,70	15,72
Solution 1	29,60	83,10	14,63	0,13	5,18	3,17
Solution 2	43,00	32,59	5,77	0,04	0,46	0,71

[(1)] Total construction mass per square meter.
[(2)] Embodied primary energy.
[(3)] Global warming potential in CO_2 grams equivalents.
[(4)] Acidification potential in SO_2 grams equivalents.
[(5)] Chemical oxygen depletion in NO_x grams equivalents.
[(6)] Residues that result from the production of the construction materials.

Table 6 presents the results found in the functional and economic performance assessment of both solutions. In order to compare between the initial and refurnished performances, the initial performance is also presented. The construction costs are based in a cost estimation drawn up by three construction companies which head-office is situated in the North of Portugal. They include all direct and indirect costs and profits related to construction works.

Table 6. Functional and economic performances of the initial and both refurnishing solutions.

Solutions	U W/m^2.ºC	$D_{n,w}$ dB	CC €/m^2
Initial	1,40	45	-
Solution 1	0,60	48	100
Solution 2	0,60	46	35

3.3 *Representation and assessment of both solutions*

Table 7 resumes the results found in the sustainability assessment of both refurnishing solutions, using the methodology MARS-SC. Figure 5 presents the sustainable profile of both solutions. Analyzing the results it is possible to observe that refurnishing solution 1 is only better than solution 2 at the level of the functional requirements. This reality is based on the major advantages of this solution: high maintenance aptitude and improved airborne sound insulation. The use of ceramic materials and galvanized steel, two materials that have high embodied energy, turns the environmental performance lower than the ETICS refurnishing solution. Another important drawback of this solution is the high construction cost, almost 285% higher than the solution 2 cost.

This way, in the analysed sample and according to the considered dimensions, parameters and related weights, the most sustainable refurnishing solution is the external thermal insulation composite system – ETICS (solution 2).

Table 7. Results obtained in MARS-SC

Solutions	Performance			Sustainable Score
	Environmental I_{Env}	Societal I_{Soc}	Economical I_{Eco}	SS
Solution 1	0,17	1,00	0,00	0,55
Solution 2	0,83	0,33	1,00	0,61

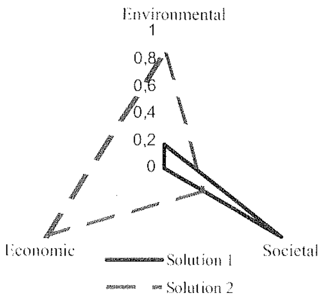

Figure 5. Sustainable profile of both refurnishing solutions

4 CONCLUSIONS

Sustainable building design, construction, operation and refurnishing are based in the assessment of the environmental pressure, societal performance (related to the construction norms, regulations and psycho-social characteristics of building's users, among others) and life-cycle costs. Sustainable construction seeks a better compatibility between natural and artificial environments, nevertheless without giving up the buildings' functional quality and the project's cost-effectiveness.

The rehabilitation of the building stock is an very important aspect in order to increase the sustainability of the construction market: in one hand refurnishing increases the durability of the construction elements, which allows the amortization of the initial environmental impacts in an extended life span, and in other hand, it allows to update the buildings' functional performance, with all societal and cultural advantages, along with the exploitation of the existing structures, with every related economical advantages.

Despite of several studies about sustainable construction indicators, up till now there wasn't a methodology that could assist the project team in the sustainable refurnishing projects. In this paper it was presented a methodology to assess the sustainability of the building refurnishing projects. There are still some important limitations to overcome, like for instance the development of a more consensual list of weights. Although at this step, the methodology could give an important input to project teams in order to turn the refurnishing operations much more compatible to the sustainable development aims, in order that the future generations coould have at least the some conditions as the actual ones.

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