BUILDING REFURBISHMENT: ONE STEP TOWARDS SUSTAINABLE BUILT ENVIRONMENT

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Summary

A sustainable built environment results from the best trade-off between each three dimension of the sustainable development (environment, society and economy). In Western Europe it is usually considered than more than 60% of the buildings to be used in 2050 are already built today and it is expected that the rehabilitation becomes a leading sector in the building industry. To ensure the sustainable rehabilitation of the built environment it is necessary to consider tens of parameters related to the overall impact of the project on the local and global environment as well as preservation of heritage, social trends, economic development, or health and safety of the users. The integration of a huge number of evaluation criteria, some quantitative, other purely qualitative, makes the assessment of such strategy very hard to carry out without a real methodological work. The aim of this paper is to present a multi-criteria decision based methodology that allows the integrated assessment of all different sustainability parameters. The proposed methodology is applied to a case study, which aim is to select the most sustainable solution between different refurbishment scenarios for a building façade.

1. Introduction

The building sector plays a major role in the perspective of a sustainable built environment. 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 are 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 overcome.

Most of the buildings related impacts are linked to the "cradle-to-gate" stage of their materials and products and to the operation phase of the buildings. Rehabilitation allows to increases the life span of a building and therefore the embodied impacts related to the materials and products used in its construction are amortized in a larger time span. Nevertheless, rehabilitation allows updating the comfort of the building users and, on the other hand, the thermal refurbishing is on the basis of higher energy efficiency and therefore it contributes to the reduction of the environmental impacts during the operation phase.

For the reasons stated above, rehabilitation in opposition to demolition 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 reduce the environmental impacts through the energy consumption, raw materials and residues reduction; and to preserve the city's cultural legacy.

Many efforts have been done regarding environmental protection and urban quality, and in recent times, a greater attention has been given to pollution control, energy efficiency, proper waste disposal, landscape preservation, heritage preservation, social integration, etc.. Therefore, more and more, building operation have to consider rehabilitation, partial or complete of a building or a group of buildings, and they have to fit into numerous criteria, sometimes contradictory, concerning quality of materials used, economic pressure, improvement of quality of life and environment.

Although, there still is an important question that must be solved: the definition of the sustainable building rehabilitation concept and actions 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 (Bragança, 2007). 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 steps of a sustainability assessment methodology that is being developed to support the sustainable rehabilitation of buildings, which is based in the three dimensions of the "Sustainable Development". At the end of the paper, the methodology is applied to a case study, whose 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 Methodology 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 a short description of the methodology MARS-SC adapted to refurnishing operations is made.

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. Thus, in this phase the number and type of parameters to be assessed inside each dimension are defined. The definition depends on one hand in the objectives of the assessment, type of solution to be refurnished, local conditions, functional requirements that are necessary to be fulfilled, available data, and in the other hand in the assessment boundaries: the sustainability assessment of a project to refurbish a single construction element 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 refurbishment technology for a façade.

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

Environmental	Social	Economic
Global warming potential	Airborne sound insulation	Construction cost
Destruction of the stratospheric ozone layer	Thermal insulation	Operational cost
Potential acid deposition onto the soil and in water	Structural safety	Maintenance cost
Local tropospheric ozone formation (smog)	Fire safety	Dismantling cost
Addition of mineral nutrients to the soil or water.	Water permeability	Residual value
Abiotic depletion	Maintenance aptitude	
Non-renewable primary energy consumption	Preservation of the city's heritage	
	Aesthetics	

2.2 Quantification of Parameters

After selecting the parameters it is necessary to proceed with their quantification. Quantification 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 the parameters to evaluate are quantitative. When assessing qualitative parameters like for instance, aesthetics and preservation of the city's cultural heritage, 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 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 assessment (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 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 (Equation 1).

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

In this equation, P_i is the value of i^{th} parameter. P^*_i and P^*_i are the best and worst value of the i^{th} 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 will not 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.

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

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 i^{th} 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.

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

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

$$I_{Eco} = \overline{P_{Eco\,i}}$$, economic dimension (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.

Weights are strongly linked to the objectives of the project: higher weights must be adopted for parameters of major importance in the project. Although the weight of each parameter in the assessment of each dimension is not consensual, as it is possible to verify when analysing the several different available methodologies to support and assess the sustainable design. This is the major inconvenient of this method, when compared to performance based methodologies, since it is possible the compensation between parameters.

In what concerns to the weights of the environmental parameters, actually there are not Portuguese impact scores for each environmental parameter, according to their relative importance in the overall environmental performance. Additionally, this issue was not dealt so far by the European Environmental Agency. However there are some international accepted studies that allow an almost clear definition of it. One of the most accepted studies is the one performed by the United States Environmental Agency's Science Advisory Board (SAB) that developed two lists of the relative importance of various environmental impacts to help EPA to best allocate its recourses (EPA, 2000). MARS-SC allocates the environmental parameters in the EPA's impact categories and therefore it considers the same relative importance. Table 4, presents the relative importance of the environmental parameter considered 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 is not 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 relative importance for all functional and societal parameters. MARS-SC is being developed in order to accommodate a more consensual distribution of weights.

2.5 Global Assessment

It is understood that the majority of stakeholders would like to see a single score representing the overall building performance. Therefore, after assessing the performance of a solution within all dimensions (environmental, societal and economics), the next step is to combine the performance at the level of each dimension 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.

$$SS = I_{Env}.w_{Env} + I_{Soc}.w_{Soc} + I_{Eco}.w_{Eco}$$ (6)

Sustainable score, *SS*, is the result of the weighting average of each global indicator I_j. w_i represents the weight of the i^{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

Dimension	Weight (w_i)
Environmental (I_{Env})	0,3
Societal (I_{Soc})	0,5
Economic (I_{Eco})	0,3

The sustainable score is useful to communicate and compare results but it should not be used alone to characterize the sustainability of a solution, since the possible compensation between dimensions could cause some distortions in the results. Moreover the solution has to be the best compromise between all the different aspects: every aspect has to be considered.

3. Case Study

The scope of the case study is the assessment of a refurbishment project related to a multi-storey building with three floors, located in the city centre of Guimarães, Portugal. This building was built at the end of the 60's and most of its envelope, mainly the façade, is at a considerable degradation state, as it is possible to verify in Figure 1. This building doesn't have any kind of heritage value and in the façade it is possible to identify some cracks that endanger 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 updated comfort standards and user 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 refurbishment solution to adopt should disturb as less as possible the indoor living conditions of the occupants. This way, the design team selected three refurbishing scenarios for this project, as presented in Table 4. Table 4 also presents the predicted energy consumption for heating and cooling according to the actual Portuguese Thermal Regulation (Decree-Law 80/2006). The time boundary considered for the project is 25 years.

Table 4 Refurbishing scenarios in assessment

Refurbishing Scenarios	Description	Expected maintenance in the time boundary	Energy consumption during operation (MJ/m^2.year)
Scenario 1	To paint the façade and replace the windows	3x painting	640,8
Scenario 2	To place a ventilated façade and to replace the windows	No maintenance	439,2
Scenario 3	To place an external thermal composite systems (ETICS) replace the windows	3x painting	439,2

Figures 3 and 4 represent the cross section of the refurnishing solution adopted in scenarios 2 and 3, respectively.

Figure 1 Elevation of the façade.

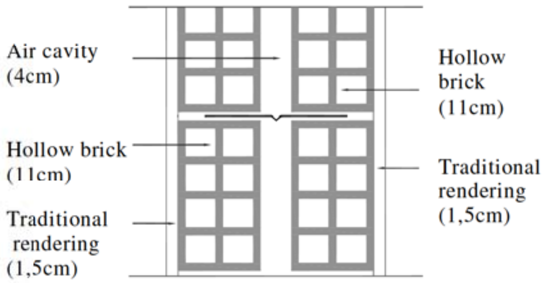

Figure 2 Cross-section of the existing solution.

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 design team selected seven mid point impact categories to assess the environmental performance: abiotic depletion (AP), global warming potential (GWP), destruction of the stratospheric ozone layer (OD), local tropospheric ozone formation-smog (PO), potential acid deposition onto the soil and in water (AP), addition of mineral nutrients to the soil or water (EP) and the non-renewable primary energy consumption (PEC). The environmental performance is analysed in the following life cycle stages: construction, maintenance and operation. During the construction and maintenance stages, the study considers the construction material's embodied environmental impacts, from cradle to factory's gate, according to the material inputs. For the operation phase it considers the impacts related to the energy consumption for heating and cooling, according to the Portuguese energy mix and associated environmental impacts.

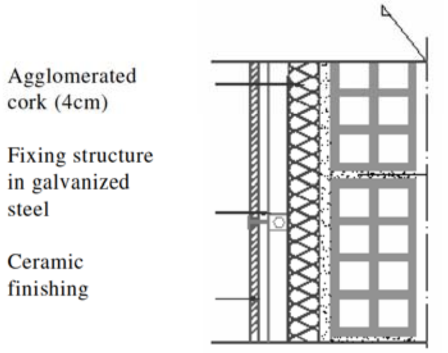

Figure 3 Refurnished façade's cross section after (solution 2).

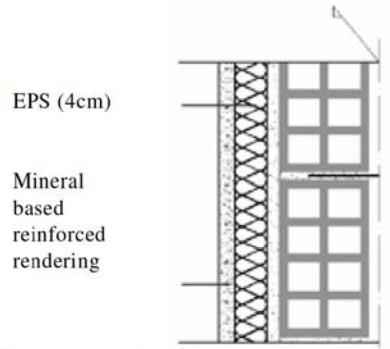

Figure 4 Refurnished façade's cross section after (solution 3).

In what regards to societal performance, the aim was to find the best compromise between two parameters related to the comfort of the building: airborne sound insulation (Dn,w), and U-value (U), related to the acoustic comfort and thermal comfort, respectively.

For the economic performance the aim was to choose the solution with lower life-cycle costs. The considered indicator is the life-cycle costs (LCC) and it considers the costs related to the construction and maintenance of the refurbishing technology as well the predicted energy costs for heating and cooling, according to actual energy costs. Table 4 resumes the considered parameters and related weights.

Table 4 Assessed parameters and related weight

Dimensions	Parameter	Weight of parameters (%)	Weight of dimension (%)
Environment	Abiotic depletion (AD)	13	
	Global warming potential (GWP_{100})	33	
	Destruction of the stratospheric ozone layer (OD)	11	
	Local tropospheric ozone formation-smog (PO)	13	30
	Potential acid deposition onto the soil and in water (AP)	11	
	Addition of mineral nutrients to the soil or water (EP)	11	
	Non-renewable primary energy consumption (PEC)	8	
Social	Airborne sound insulation (Dn,w)	50	50
	Thermal insulation (U-value)	50	
Economic	Life-cycle cost (LCC)	100	20

3.2 Quantification of Parameters

In Portugal it is not yet available the environmental inventory data related to the major part of the building materials, therefore the quantification of the environmental performance was carried out using the SimaPro software. The CML 2 baseline 2000 method was used to assess the first six mid point environmental categories and the "Cumulative Energy Demand" method was used to assess the embodied non-renewable primary energy. Table 5 lists the results of the environmental performance assessment for each refurbishing scenario.

Table 6 presents the results found in the functional performance assessment of the three scenarios and Table 7 presents the Net Present Values of the life-cycle costs. The construction and maintenance costs are based in a cost estimation drawn up by three construction companies which head-office is situated in the North of Portugal and they include all direct and indirect costs and profits related to construction works. The operation costs are base in the actual energy costs fixed by the Portuguese electricity provider - EDP – 0,1131 €/kWh.

3.3 Global Assessment of the Different Refurbishing Scenarios

Table 8 summarizes the results found in the sustainability assessment of both refurnishing scenarios, using the methodology MARS-SC. Analysing the results it is possible to see that refurnishing scenario 1 is the worst and scenario 2 is the best one, since it has the higher sustainable score. Although refurbishing scenario 2 has higher embodied environmental impacts and higher construction costs, those impacts are compensated with the lower environmental impacts and higher comfort during the operation phase. Scenario 3 is almost equivalent to scenario 2 and also a possible refurbishing solution. In fact, scenario 3 compared to scenario 2 has lower life-cycle costs and environmental impacts, but it has the disadvantage of having a lower social/functional performance. Therefore, in the analysed example and according to the considered dimensions, parameters and related weights, the most sustainable refurnishing solution is the ventilated façade (scenario 2).

Table 5 Life-cycle environmental impacts

Refurbishing Scenarios	AD[1] ($kgx10^3$)	GWP_{100}[2] ($Kgx10^3$)	OD[3] (kg)	PO[4] (kg)	AP[5] (kg)	EP[6] (kg)	PEC[7] (GJ)
Scenario 1							
Construction	6,70E-04	70,97E-03	1,03E-05	0,02	0,45	0,10	1,33
Operation	16,73	2214,60	1,31E-01	754,25	20185,25	966,50	11534,40
Maintenance	2,00E-03	2,12E-01	3,09E-05	0,06	1,35	0,30	3,99
Total	16,73	2214,89	1,31E-01	754,33	20187,05	966,90	11539,70
Scenario 2							
Construction	16,73E-03	1,24	1,55E-04	0,80	9,68	0,95	37,68
Operation	11,46	1517,88	0,09	516,96	13834,84	662,43	7905,60
Maintenance	-	-	-	-	-	-	-
Total	11,48	1519,12	0,09	517,76	13844,52	663,38	7942,88
Scenario 3							
Construction	4,87E-03	8,94E-01	3,24E-05	0,51	2,04	0,22	11,65
Operation	11,46	1517,88	0,09	516,96	13834,84	662,43	7905,60
Maintenance	2,01E-03	2,12E-01	3,09E-05	0,06	1,35	0,30	3,99
Total	11,47	1518,99	0,09	517,53	13838,23	662,95	7921,24

(1) Abiotic depletion in Sb equivalents.
(2) Global warming potential in CO_2 equivalents.
(3) Ozone depletion in CFC-11 equivalents.
(4) Smog creation in C_2H_4 equivalents.
(5) Acidification in SO_2 equivalents.
(6) Eutrophication in PO_4 equivalents.
(7) Primary energy consumption in GJ equivalents.

Table 6 Results obtained in the quantification of the functional parameters

Refurnishing Scenario	$D_{n,w}$ (dB)	U ($W/m^2.ºC$)
Scenario 1	29	1,40
Scenario 2	30	0,60
Scenario 3	29	0,60

Table 7 Life-cycle costs of each refurbishing scenario

Cost	Scenario 1	Scenario 2	Scenario 3
Construction	9300€	15075€	10350€
Operation	362372€	248367€	248367€
Maintenance	4500€	0€	4500€
Total life-cycle cost (LCC)	376173€	263442€	263217€

Table 8 Results from MARS-SC

Refurbishing Scenarios	Performance			
	Environmental I_{Env}	Societal I_{Soc}	Economical I_{Eco}	Sustainable Score (SS)
Scenario 1	0,00	0,00	0,00	0,00
Scenario 2	1,00	1,00	1,00	1,00
Scenario 3	1,00	0,50	1,00	0,75

The results also show that it is very important to consider in this kind of assessment all life-cycle stages of a building instead of considering only the initial stage (construction). The initial costs and the embodied environmental impacts are normally insignificant when compared to the same parameters in the operation phase. Therefore a solution with higher capital costs and embodied environmental impacts could be justified if it has higher performance during the operation phase that results on savings.

4. Conclusions

Sustainable building design, construction, operation and refurbishment are based in the assessment of the environmental pressure, societal performance (related to the construction standards, 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 forgetting the functional quality of a building and the cost-effectiveness of a project.

The rehabilitation of the building stock is a very important aspect in order to increase the sustainability of the construction market: refurbishment increases the durability of the construction elements, which allows the amortization of the initial environmental impacts in an extended life span and, on the 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 all related economical advantages.

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

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