Optimization of the Sustainability during the Refurbishment Operation of a Residential Building

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ABSTRACT: Most of the existing buildings have high resources consumption and low indoor environmental quality, leading to the unsustainability of the built environment.
Being aware of this reality and based in the European goal to achieve Nearly-Zero Energy consumption standard in buildings, it is urgent to define guidelines that could support the sustainable refurbishment design since the earlier stages.
This paper intends to illustrate the process of sustainable building refurbishment, supported by different guidelines applied to a case study. To achieve this goal the definition and evaluation of a group of procedures to be implemented, and a cost-benefit analysis applied to a case study was performed, having as final goal its sustainability optimization.

1. INTRODUCTION

1.1 *General introduction*

The refurbishment of the built heritage proved to be the way to achieve sustainability in the urbanity and construction fields, because it preserves the cultural values, the environment and it has severaleconomic advantages.

In Portugal there are several programs that were developed to supportthe refurbishment of buildings, such as REHABITA, RECRIA, RECRIPH, SOLARH and JESSICA, that give incentives through tax benefits.

However, it is necessary that refurbishment is performed according to the sustainability guidelines. The first steps in Portugal towards sustainability were given with the introduction of the RCCTE (regulation for building thermal characteristics). Some guides were also developed related to the thermal refurbishment, but it is necessary to go beyond.Optimizing the buildings in the several strands, such as energy and water consumption, functional adequacy, sufficient natural lighting, good proportion of the interior spaces, preserve the existing materials and use more sustainable materials.

The study object of this paper is the residential buildings located in the Historic Centers. It pretends to analyze the complexity of the architectonic project, of its use and maintenance, to optimize the building sustainability.

1.2 *Aims*

The main goal of this work is to define the best sustainable practices to be applied in the refurbishment of a residential building with cultural value. It is intended to define constructive and spatial solutions, allied to renewable energy, that optimize the sustainability of the residential building, such as:

- Optimize the sunlight (e.g. solar panels);
- Optimize the efficiency of water resources (e.g. collect the rainwater, re-use of the gray water, and to implement systems that minimize the use of water);
- Maximize the preservation and re-use of existing materials;
- Minimize the production of waste;
- Maximize the use of sustainable materials, with low incorporate energy, recycled and recyclable;
- Optimize the thermal comfort conditions (e.g. implement insulation in the exterior walls, efficient acclimatization systems, and insulation of the windows);
- Maximize the natural ventilation;
- Implement shading systems,
- Make a cost-benefit analysis of the previous mentioned approaches.

These solutions will be developed in the refurbishment of a residential building located in the Historic Center of Braga.

As a work method will be adopted methodologies for sustainability assessment, to define and implement the solutions that prove to be more sustainable, analyzing the environmental impact till the cost-benefits of the solutions. It will be use the Thermal Simulation Assessment Tool (Ecotect), the Constructive Evaluation Assessment Tool(SimaPro- Mars-SCMethodologie) and the Sustainability Assessment Tool (Sbtool^{PT}) as the evaluation of the final performance of the building.

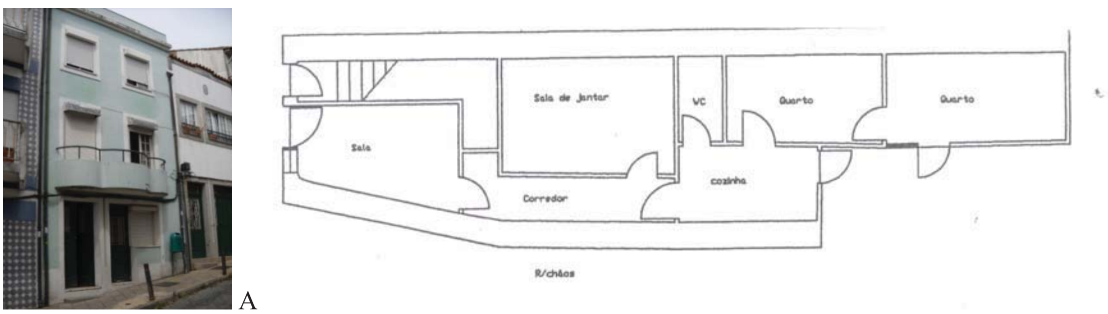
2. CASE STUDY

2.1 *BuildingPresentation*

The residential building (Figure 1),believed to be of the XVIII Century, is located in Braga, morespecifically in the Rua da Boavista, that is integrated in the Urban Critical Area of Recovery and Redevelopment of Braga. The building is divided in three floors, ground-floor, first floor and second floor, and subdivided in three different independent housing (one per floor).

The main entrances are located at the level of the ground floor, there is one that serves the ground floor housing and the other that serves the other independent housing that have a common stair case. The lot has a total area of 180,00 m^2, the exterior area has 111,20 m^2 and the building has a total area of 192,60 m^2. The building is oriented South-North, being the main façade oriented south.

The exterior walls are in stone masonry, plastered and painted white, the pavements are in wood supported by a wood structure, with the exception of the ground floor that is covered in parquet on a cement structure. The interior walls are built in a wood structure and plaster covered with vertical pieces of wood. The windows have a wood frame with simple glass, protect by exterior blinds or with interior iron shutters.



A B

Figure 1 – (A) Picture of the front façade of the house; (B) Ground Floor plan of the existing

2.2 *Intervention Proposal*

The intention of the architectural project is to convert the three independent housing in two, being the first housing (housing I) composed by the ground and first floors and the second housing (housing II) by the second and last floor. It is intended to reorganize the interior spaces in order to capture natural light and have natural ventilation in all of them. Since the existing interior spaces are very narrow and some bedrooms don't even have direct natural light. It will also be implemented a skylight, some new windows will be open and in some situations, will have larger dimensions. The skylight will be located over the stair that connects the ground and first floors, and will have some side adjustable air vents, to ventilate the interior spaces. This solution can have a lot of internal gains in the summer period, and losses during the winter, so the skylight will be built in a thermal frame with double glass, and tight adjustable air vents.

The exterior space of the lot was also intervened in order to better capture the natural light into the interior spaces of the building, for that the levels of the terrain were altered, and a garage with green roof was implemented.

3. ASSESSMENT METHODOLOGIES

3.1 *SustainableImpact Assessment Tool of Constructive Solutions*

The assessment of the environmental impact will be realized with the computer program SimaPro 7.3.

This program is a methodology of Life Cycle Assessment (LCA) that evaluates the environmental impacts of the industrial products, and comprehends an analysis since the raw material extraction till it final disposal.

The SimaPro uses the method CML2 baseline 2000 that allows an evaluation of different constructive solutions represented by ten indicators that are distributed in ten categories, from which were chosen for this study, ADP (potential reduction of the non-renewable resources); AP (acidification potential); GWP (global warming potential); ODP (Ozone destruction potential); PODP (tropospheric ozone destruction potential); EP (eutrophication potential).

The data collected from the SimaPro program will be important for the evaluation of the constructive solutions, where will be used the MARS-SC methodology to assess the sustainability of the constructive solutions (Bragança, Mateus, 2006).

This methodology intends to clarify which constructive solutions are more sustainable, and evaluates the performance of the constructive solutions in three dimensions, environmental (IA), functional (IF) and economic (IE). The intention is to improve the existing constructive solution of the building by evaluating which solutions are more sustainable to do it.

MARS-SC methodology is developed in four steps, such as Quantification of the parameters;Normalization of the parameters;Aggregation of the parameters;Definition of the sustainable level (NS).

The normalization of the parameters is calculated by the equation Diaz-Balteiro (2004), Equation 1:

$$\bar{P}i=(Pi-P^{*}i)/(Pi^{**}-P^{*}i) \square I \qquad (1)$$

Pi= quantification of the solution parameter; P*i= worst value; Pi**= best value.

The evaluation is limited in a scale from 0 (worst) till 1 (best) (Bragança, Mateus, 2006).

To aggregate the parameters is calculated the partial performance of each solution by each indicator (Ii), which is calculated by the respective equations (Bragança, Mateus, 2006):

$$\text{Environmental Performance: } IA = \Sigma WAi.\bar{P}Ai \qquad (2)$$

$$\text{Functional Performance: } IF= \Sigma\ WFi.\bar{P}Fi \qquad (3)$$

$$\text{Economic Performance: } IE = \bar{P}E \qquad (4)$$

After calculating each parameter for each solution, we are able to calculate the sustainable score (NS) by the equation (Bragança, Mateus, 2006):

$$NS = WG1.IA + WG2.IF + WG3.IE \qquad (5)$$

Wi= weight of each parameter; Ns= Sustainable Score, that comprehends the values between 0 (worst) and 1 (best).

The definition and quantification is made according to the objective of the evaluation, in the present work was attempted to find an equilibrium between what is intended and the indicators for which could be possible to find more information (Table 1). Since many manufacturers don't have available data for their products for the several indicators.

The weight that was given to each parameter is based in the study that is intended, normally the weight by defect for each indicator are distributed in the following way, for Environmental (0,40), for Functional (0,40) and for Economic (0,20). Here it was given a bigger weight to the functional component because it has a more direct impact in the comfort of the users,in consequence of the location of the building, that has not much direct light entering into the interior spaces.

Table1 – Weight of the parameters and of the indicators in each parameter.

	Dimensions					
	Environmental		Functional		Economic	
Indicators	Global Warming Potencial (PAG)	0,25	Sound Insulation to the Air Conduction (DnT,w)	0,3(3)	Construction Cost	1,00
	PrimaryEnergyEmbodied(PEC)	0,75	Thickness(Walls) orInsulation of the air percussion Sounds (L' n,w) (pavements)	0,3(3)		
			Termal Insulation (Umed)	0,3(3)		
	0,30		0,50		0,20	

3.2*Thermal Simulation Assessment Tool*

With the simulation of thermal comfort is intended to analyze the building in energetic performance terms, applying the constructive solutions that were analyzed.

The Ecotectas a flexible and easily apprehended software is a 3D simulation system that consists in a range of simulations and thermal analysis, with the goal to improve the energetic performance of the existing and new buildings. In the present work, although the program offers a different possibility of analysis, it will be focused on the thermal performance analysis, calculating the needs of heating, cooling and analyzing the occupation standards, internal gains, infiltration and equipment (Table 2).

Table 2 –Building use conditions

Use Conditions	Housing I
Nº of Persons (P)	6
Ocupation /Use Conditions	20h00 – 08h00 = 6 P 09h00 – 19h00 = 3P(70 W/ P – sedentary)
Clothes (clo)	1,0
Lightningandequipment	Sensible gains = 5 W/ m^2- Latent gains = 2 W/ m^2
Comfort Temperature	18ºC - 25ºC
Interior Humidity (%)	60,0
Air speed	0,50 m/s – Soft breeze
Ventilation	Mix mode – Heating/Cooling - Eficiency = COP 4
AirInfiltration	0,50 exchang/ hr (wellinsulated)

3.3 *Sustainable Assessment Tool*

The assessment of the sustainability of the residential building will be held using the system SBTool^{pt}, which allows the assessment and certification ofthe sustainability of a building (iiSBE, 2011). The evaluation includes not only environmental aspects but also social and economic.

This assessment tool will allow, in the case study, to evaluate the sustainability of the building optimization, in order to verify if all the measures that were implemented will contribute to have a good sustainable score.

The values obtained in each parameter are normalized and converted to a scale from 0 (reference value) to 1 (best value), that are translate in a scale from E (worst) to A+ (Best).

4. EVALUATION AND OPTIMIZATION OF THE SUSTAINABILITY

4.1 *Construction solutions*

The construction solutions that were chosen for the building envelop were different for the front and back facades, due to the street alignments of the front façade. The rehabilitation of the front façade was done on the interior and the back facades were done on the exterior. Different constructive solutions were also taken in consideration for the interior walls and pavements.

Analyzing the different constructive solutions through the Environmental impact assessment tool, it was defined which solutionswere going to be implemented for the front Façade walls, for the back Façade walls, for the interior walls and for the pavements.

4.2 *Systems to be implemented*

4.2.1 *Passive Solar Systems*

To improve passive systems, there were chosen some architectonic measures to be implemented such as, the reorganization of the interior spaces, the introduction of a skylight, new and bigger windows, in order to promote natural ventilation and capture more natural light to the interior spaces. The thermal insulation was improved not only in the walls and roof, but also in the window frames.

4.2.2 *Active Systems*

Apart from the passive systems, there were implemented some active systems. For heating, cooling and hot water of the housing (I), it was chosen a Heat pump connected to a solar panel, and for the housing (II), it was chosen for heating and hot water a Heat recovery system that is also connected to a solar panel. To complement both systems, it will be implemented a system of ventilation with tubs embodied in the soil, functioning as heat recovery system, this allows the new air that enters into the houses to be, during the winter, more warm and in the summer more cold.

A system of collection and treatment of rain and bath water will also be implemented. This water will be used for sanitary discharges, irrigation and pavement cleaning. In a very summary analysis, the implementation of this system with flow controllers will reduce the use of drinking water in about 50%.

To reduce the costs with electricity, all the artificial illumination will be in LED bulbs, and all the electric equipment's will be the most efficient as possible.

A system of photovoltaic panels was thought to be implemented, but due to the location, orientation and surroundings of the building it wouldn't be viable it implementation.

4.3*Thermal Assessment of the Building*

Through the thermal evaluation of the building (Ecotect), it was verified that the housing (I), with the systems that were thought to be implemented, had an annual consumption of 7,75 kWh/m^2 and the housing (II) an annual consumption of 30,4 kWh/m^2. The consumption are higher for the housing (II) than for the housing (I), though the housing (I) has more area, because the systems that were implemented in the housing (I) are more efficient (COP 4), which leads to lower annual consumption.

4.4*Sustainability Assessment of the Building*

For the evaluation of the sustainability it were used the spreadsheets of the SBTool^{pt} methodology. In the analysis were obtain the following values for each parameter in the different categories and in the differentDimensions (Table 3 and Table 4).

The values of each Dimension were normalized and it was obtained the Final Sustainable Score of 0,98 which represents the letter A (Table 5).

Table 3 – Values for the Environmental Dimension

Category	Parameters (PID)	Performance	Category evaluation [A]	Weight Category [B]	Weighted Value [A]x[B]
C1 – Climatic changes and air quality	P1 - Aggregated value of the life cycle environmental impact categories of the building for m2 of useful pavement area per year	B	0,548	12	0,066
C2 – Use of soil and biodiversity	P2 - Percentage of usage of the liquid indicator available	A+	1,080	19	0,205
	P3 - Impermeabilization index	C			
	P4 - Percentage of intervention area previously contaminated and built	A			
	P5 - Percentage of green areas occupied by autochthonous plants	A+			
	P6 - Percentage in plan of area with reflectance equal or superior of 60%	A+			
C3 – Energy eficiency	P7 - Consumption of nonrenewable primary energy in the usage faze	A	0,956	39	0,373
	P8 - Quantity of energy from renewable energy source produced in the building	A+			
C4 – Materials and residual waist	P9 - Percentage in cost of re-used materials	B	0,929	22	0,204
	P10 - Percentage in weight of recycle content of the building	A+			
	P11 - Percentage in cost of organic base products that are certified	A+			
	P12 - Percentage in mass of substitutes of cement in the concrete	A			
	P13 - Potential of the condition building to allow separation and recycle	A			
C5 – Efficient usage of water	P14 - Volume of annual water usage per capita	A	1,069	8	0,085
	P15 - Percentage of reduction of the drinking water	A+			
	S= Performance in the Environmental Dimension				0,934

Table 4- Values for the Social and Economic Dimensions

Category	Parameters (PID)	Performance	Category evaluation [A]	Weight Category [B]	Weighted Value [A]x[B]
C6 – Comfort and health of occupants	P16 - Potential of natural ventilation	B	0,943	60	0,566
	P17 - Percentage in weight of low COV materials	A			
	P18 - Annual level of thermal comfort	B			
	P19 - Average factor of the light in the medium day	A+			
	P20 - Average of acoustic insulation	A			
C7 – Acessibility	P21 - Index of accessibility of public transports	B	0,536	30	0,161
	P22 - Index of accessibility to amenities	A+			
C8 – Education for sustainability	P23 - Availability of the Usage manual of the building	A	0,967	10	0,097
	S= Performance in the Social Dimension				0,823
Life cycle cost	P24 - Initial value cost for m2 of usage area	A+	0,536	30	0,161
	P25 - Actual value of usage cost for m2 of area	A+			
	S= Performance in the Economic Dimension				0,823

Table 5 – Sustainability level of the building

Dimension	Category evaluation [A]	Weight Category [B]	Weighted Value [A]x[B]
D1 - Environmental	0,934	40	0,374
D2 - Social	0,823	30	0,247
D3 - Economic	1,200	30	0,360
∑ = SustainabilityLevel (NS)			0,980

Analyzing the results it was verified that it could have been chosen more sustainable constructive solutions, but there were applied solutions that had a better thermal performance,because of the location and orientation of the building.

Due to the intention to integrate a garage in the back garden, the impermeabilization level related to the best practice was exceeded, but it was tried to maximize the green spaces with a green roof.

The systems of heating and cooling and of collection and treatment of the water, proved to be efficient, having reduced the cost of electric energy and drinking water.

Some of the interior materials couldn't be re-used because of the alterations that were made in the interior to maximize natural lightning.

The natural ventilation in the first floor due to the strait of the lot couldn't be moreimproved, but it was tried to promote some natural ventilation with the adjustable air vents implemented in the skylight.

In general, all the measures implemented promoted the sustainability of the building ,the final score of the building sustainability was A, which means that the building obtained a good level of sustainability, which was what it was intended.

4.5*Economic Viability of the Proposal Solutions*

Some of the system proposal solutions that were implemented revealed to have economic viability.

The system of collection and treatment of rain and bath water, with the flow controllers has a payback time of 6,8 years (Table 6), which is very good taking in consideration the durability of the system that is about 20 years. Due to the 50% reduction of drinking water use, the annual saving cost it is about 457,80 €.

The systems of heating, cooling and hot water implemented, in comparison to a propane system, revealed to havea payback time, for example, for the housing (I) of 6,9years, that it is very good taking in consideration the durability of the system (Table 6).

Table 6 –Payback time of the heating, cooling and hot water system of the housing (I)

Annual Saving (€) –Heat Pump	595,16
Total cost of the system of Heat Pump (€)	9.750,00
Total cost of the propane system (€)	5.600,00
Payback time (years)	6,9**

**considering that the cost is the same along the years, annual tax of 0% and that there is not any cost of maintenance along the years.

With the solution of using only LED bulbs for the artificial lightning, the annual saving concerning the cost with electricity, in comparison to conventional bulbs, is about
702,83€. The payback time of the LED lightning is about 1 year.

5 CONCLUSIONS

In this work it was shown the importance and the steps to the definition and inclusion of sustainable criteria's (environmental, social and economic) since the early stages of the refurbishment project, and how it can be a decisive factor in some situations. It is necessary that there is a planning phase, where can be evaluated all the components that make part of the building and in which we are going to intervene, to have more sustainable buildings.

During the development of the case study, it can be understood that it is the duty of the technicians to help the promoters to turn the buildings more sustainable, with the final goal to turn the society with more sustainable values.

The road to the development of more sustainable refurbishment projects reveals some difficulties, because it takes time to apply all the methodologies that was presented in this work, and some technicians probably will not be available to apply them. A challenge can be made for future development, which is to create a program that includes all the presented methodology and that will be easily apprehended by architects and other technicians.

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