Using the SBTool^{PT}-H to optimize the sustainability during the design phase of a refurbishment operation of a residential building

I. Mateus, R. Mateus & S. M. Silva
University of Minho, C-TAC Research Unit, Guimarães, Portugal

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ABSTRACT: Most of the existing building stock high resources consumption and low indoor environmental quality, leading to the unsustainability of the built environment. It is then urgent to define guidelines that could support the sustainable refurbishment design of buildings since the earlier stages, in order to meet European goal to achieve Nearly-Zero Energy consumption standard in buildings in 2020. This paper presents the process of sustainable building refurbishment, applied to a case study, and defines guidelines to optimize the sustainability of a residential building. 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.

1 INTRODUCTION

1.1 *Context*

The refurbishment of the built heritage proved to be the way to achieve sustainability in the urbanism and construction fields, since it preserves the cultural values, the environment and has several economic advantages.

In Portugal there are several programs that were developed to support the refurbishment of buildings, such as REHABITA, RECRIA, RECRIPH, SOLARH and JESSICA that give incentives through tax benefits (PH, 2012).

However, it is necessary that the refurbishment of the buildings is performed according to sustainability guidelines. The first steps towards sustainability in Portugal were given with the implementation of the building thermal regulation. Some guides were also developed related to the energy refurbishment consumption, but it is necessary to go beyond. Optimizing the buildings not only in terms of energy and water consumption, but also functional adequacy, daylight, adequacy of the interior spaces areas, preservation of the existing materials, and use of more sustainable materials.

This paper is focused in residential buildings located in the Historic Centers. It pretends to analyze the complexity of the architecture project, and the use and maintenance of this kind of buildings, in order to optimize the buildings sustainability.

1.2 *Aims*

The main goal of this study 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 the use of renewable energy to optimize the sustainability of the residential building stock, such as:

- Optimize the solar gains (e.g. daylight and solar thermal and photovoltaic panels);
- Optimize the efficiency of water resources uses(e.g. collect the rainwater, re-use of the gray water, and the implementation of systems that minimize the water usage);
- 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. improvement of thermal insulation of the building envelop, walls, windows and roof, installation of efficient acclimatization systems);
- Optimize the natural ventilation;
- Implement shading systems,
- Perform a cost-benefit analysis of the previous mentioned approaches.

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

The methodologies for sustainability assessment adopted in this study, to define and implement the solutions that shown to be more sustainable, to analyze the environmental impact and the cost-benefits of the solutions. The Thermal Simulation Assessment Tool (Ecotect), the Constructive Evaluation Assessment Tool (SimaPro - Mars-SC Methodologie) and the Sustainability Assessment Tool (SBTool^{PT}) were used to do the evaluation of the final performance of the building.

2 CASE STUDY

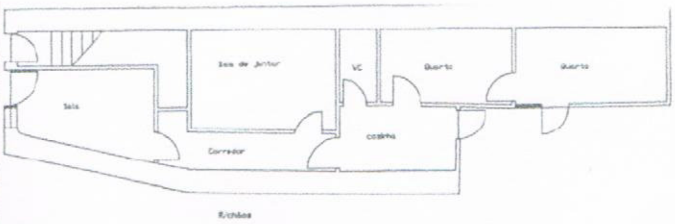
2.1 *Building Description*

The residential building (Fig. 1), from the XVIII Century, is located at Rua da Boavista in Braga, and is integrated in the Urban Critical Area of Recovery and Redevelopment of Braga. The building has three floors, ground-floor, first floor and second floor, with three different independent housings (one per floor).

The building main façade is south oriented. The main entrances are located at ground floor level, there are two entrances: one that serves the ground floor dwelling and one that serves, through a common stair case, the first and second floors dwellings. The plot of ground has a total area of 180 m^2, the exterior area has 111.2 m^2 and the building has a total area of 192.6 m^2.

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

(A)



(B)

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

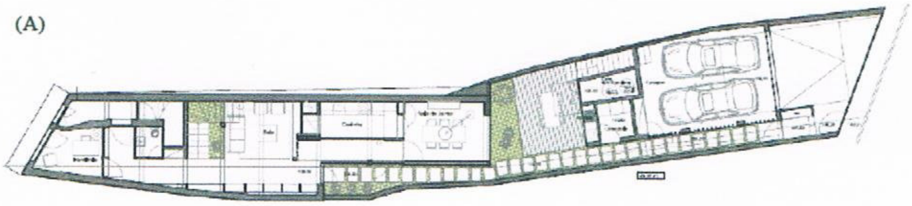
2.2 *Intervention Proposal*

The intention of the design project is to transform the three independent housing in only two, the first housing (housing I) will occupy the ground and first floors and the second housing (housing II) the second floor. It is intended to reorganize the interior spaces in order to improve the daylight and natural ventilation conditions in both housings (Fig. 2).

Since the building is very narrow some bedrooms don't have daylight access. Thus, to improve daylight and natural ventilation conditions a skylight, and new windows will be opened or widened. The skylight will be located over the staircase that connects the ground and first floors, and will have lateral adjustable air vents, to ventilate the interior spaces. This solution could lead to high internal gains in the summer period and losses during the winter, so the skylight will have a frame with thermal cut, double glass, and tight adjustable air vents.

The exterior space of the lot was also intervened in order to improve the use of the daylight in the interior spaces of the building, for that the terrain levels were altered, and a garage with a green roof was implemented (Fig. 2).

(A)



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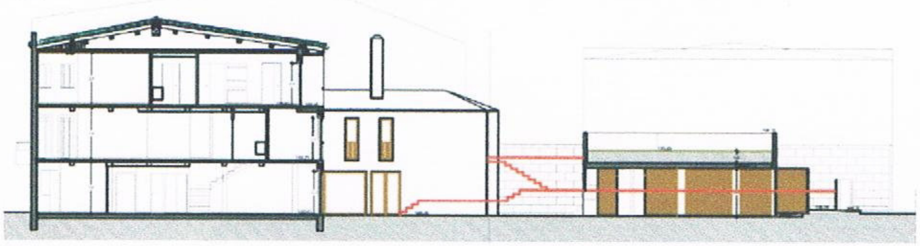


Figure 2 – (A) Ground floor plan of the rehabilitation project; (B) Section of the house (red line represents the existing levels of the terrain).

3 ASSESSMENT METHODOLOGIES

3.1 *Methodology for the relative sustainability assessment of building elements (MARS-SC)*

The methodology used in this study to evaluate the sustainability of the several analyzed building elements follows the stages of a LCA. The aggregation of indicators and the comparative analysis is based in the multi-criteria decision support Methodology for the Relative Sustainability Assessment of Building Technologies (MARS-SC) (Bragança & Mateus, 2006; Mateus *et al*, 2013). This methodology is based in three groups of sustainability indicators: environmental (ND_A), functional (ND_F) and economic (ND_E).According to this methodology, the environmental performance assessment is based in the following six impact categories: i) Global warming; ii) Ozone depletion; iii) Acidification for soil and water; iv) Eutrophication; v) Photochemical ozone creation; and vi) Depletion of abiotic resources-fossil fuels. Compared with the list of the impact categories present in the EN15804:2012 standard (CEN, 2012), MARS-SC does not consider the Depletion of abiotic resources-elements impact category. Nevertheless, for this study we decided to use only the environmental impact category that is considered the most important (EPA, 2000; EPA & SBA, 2000): Global Warming Potential (GWP). Besides this impact category, the primary embodied energy (PEC) was considered. Table 1 presents the considered indicators that describe the environmental performance. To quantify the environmental parameters, this study is based in one of the most internationally accepted generic environmental databases, the Ecoinvent report V2.2 (Hischier et al, 2010). This database covers the average environmental impacts of the main building materials at different regional contexts. The LCI data was converted into environmental impact categories using the following LCA methods: CML 2 baseline 2000 V2.04 and Cumulative Energy Demand V1.0. In order to facilitate the quantification process, a life-cycle analysis software (SimaPro 7.3.3) was used to modulate the life-cycle of the analyzed technologies and to assess the abovementioned life-cycle impact categories.

At the level of the functional performance, this study considers three functional requirements for partition walls: normalized airborne sound insulation (DnT,w); thickness (walls) or normalized impact sound insulation (L' n,w) in case of floors; and thermal insulation (U-value). The airborne sound insulation index was estimated using the analytical method proposed by Meisser (Meisser, 2004). The quantification of the U-value is based in the methodology of the Portuguese thermal code and uses Equation 1.

$$U = \frac{1}{R_{si} + \sum_j R_j + R_{se}} \ (\mathrm{W/m^2.°C}) \qquad [1]$$

Where, R_j is thermal resistance of the layer j ($\mathrm{m^2.°C/W}$) and R_{si} and R_{se} are the interior and the external thermal resistances, respectively.

The economic performance is based in the Construction Cost (CC) and is calculated using the average market price of the used building materials and includes the workmanship and equipment costs during construction site operations.

The next step is the aggregation. In order to avoid scale effects in the aggregation of parameters inside each indicator and to solve the problem of some of the parameters being of the type "higher is better" and others "lower is better". Normalization was done using Diaz-Balteiro [27] Equation 2.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \qquad [2]$$

In this equation, *Pi* is the value of i^{th} parameter. P^*_i and P_{*i} are the best and worst value of the ith sustainability indicator, among the analysed building technologies. In addition to making the value of the indicators considered in the assessment dimensionless, normalization converts the values between best and conventional practices into a scale bounded between 0 (worst value) and 1 (best value).

The methodology uses a complete aggregation method for each sustainability dimension (NDj), according to Equation 3.

$$ND_j = \sum_{i=1}^{n} w_i \cdot \overline{P_i} \quad [3]$$

The indicator ND_j is the result of the weighting average of each normalized indicator inside the sustainability dimension *j*, *wi* is the weight of the ith indicators. The sum of all weights must be equal to 1. This study considered the default weights of the MARS-SC that are presented in Table 1.

The global assessment is based in the quantification of the sustainable score (*NS*). The *NS* is a single index that represents the global sustainability performance of a building element and it is evaluated using Equation 4.

$$NS = ND_A \cdot w_A + ND_F \cdot w_F + ND_E \cdot w_E \quad [4]$$

Where, *NS* is the sustainability score, ND_j is the performance at the level of the dimension j and wj is the weight of the dimension j^{th}. According to the MARS-SC the default weight of the environmental, social and economic dimensions in the assessment of global performance is, respectively, 30%, 50% and 20%.

Table 1 – Weight of the parameters and of the indicators in each parameter.

	Dimensions					
	Environmental		Functional		Economic	
Indicators	Global Warming Potencial (PAG)	0,25	Normalized air born sound insulation index (DnT,w)	0,33	Construction Cost	1,00
	Primary Embodied Energy (PEC)	0,75	Thickness (Walls) or Normalized impact sound insulation index (L' n,w) (floors)	0,33		
			Thermal insulation (Umed)	0,33		
	0,30		0,50		0,20	

3.2 *Thermal Simulation Assessment Tool*

The energy performance of the actual building and of the refurbished building, with the implementation of the refurbishment option defined was assessed with Autodesk ECOTECT.

To perform the thermal performance analysis, the heating and cooling needs were calculated considering the occupation, internal gains, infiltration and equipment (presented in Table 2).

Table 2 – Building use conditions.

Use Conditions	Housing I
N of Persons (P)	6
Ocupation /Use Conditions	20h00 – 08h00 = 6 P /09h00 – 19h00 = 3P (70 W/ P – sedentary)
Clothes (clo)	1,0
Lightning and equipment	Sensible gains = 5 W/ m^2 - Latent gains = 2 W/ m^2
Comfort Temperature	18 C - 25 C
Interior Humidity (%)	60,0
Air speed	0,50 m/s – Soft breeze
Ventilation	Mix mode – Heating/Cooling - Eficiency = COP 4
Air Infiltration	0,50 exchang/ hr (well insulated)

3.3 *Building Sustainability Assessment Tool (SBTool^{PT}-H)*

The assessment of the sustainability of the residential building will be held using the system SBTool^{Pt}, which allows the assessment and certification of the sustainability of a building (Mateus & Bragança, 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).

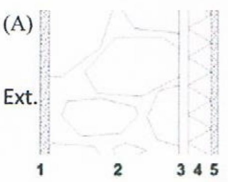
4 ASSESSMENT AND OPTIMIZATION OF THE SUSTAINABILITY

4.1 *Construction solutions*

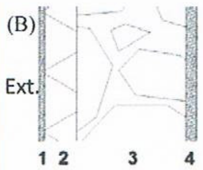
The construction solutions that were chosen for the building envelop were different for the front and back facades, due to the street alignments of the front façade. The rehabilitation of the front façade was done on the interior and the back facades were done on the exterior. Different constructive 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 solutions were going to be implemented for the front Façade walls (Fig. 3), for the back Façade walls (Fig. 3), for the interior walls and for the pavements.

Interior walls will be executed with the solution that proved to be more sustainable, plasterboard with interior structure in wood and mineral wool insulation with 6 cm of thickness; Pavement between floors will be applied the solution in wood covering with false ceiling with mineral wool insulation, and the solution with epoxy self - leveling covering for kitchens and bathrooms; For the ground floor pavement will be applied the solution in parquet with insulation in XPS and the solution with insulation in XPS and epoxy self - leveling covering for kitchens and bathrooms, that proved to be more sustainable.



Legend:
1 – plaster (2 cm)
2 – stone masonry (45 cm)
3 – air space (3 cm)
4 – insulation XPS (6cm)
5 – plasterboard (1,5 cm)



Legend:
1 – plaster armed binders (1 cm)
2 – expanded polystyrene EPS (6 cm)
3 – stone masonry (20 cm)
4 – plaster (1,5cm)

Figure 3 – (A) Solution for the interior rehabilitation; (B) Solution for the external rehabilitation.

4.2 *Systems to be implemented*

4.2.1 *Passive 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*

For heating, cooling and hot water heating of the housing I a Heat pump connected to a solar thermal panel was chosen. For the housing II, for space heating and hot water heating a ventilation system with heat recovery connected to a solar thermal panel was selected. To complement both systems, it will be implemented an earth tube ventilation system associated with the 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.

To reduce the electricity costs, all the artificial illumination will be in LED, and the appliances will be of A energy efficiency class.

4.3 *Thermal Assessment of the Building*

Through the thermal evaluation of the building, it was verified that housing I had an annual consumption of 7.75 kWh/m^2 and housing II an annual consumption of 30.4 kWh/m^2. The consumption are higher for housing II than for housing I, even that housing I is bigger, 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 - SBTool^{pt} - H*

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

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+			

Table 3 – Values for the Environmental Dimension (continued).

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+	1,20	100	1,20
	P25 - Actual value of usage cost for m2 of area	A+			
	S= Performance in the Economic Dimension				**1,20**

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

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
$\sum$ = **Sustainability Level (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 more improved, 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 (Table 6), 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.

Table 6 – Implemented solutions – summary.

Summary of the implemented solutions
- Reorganization of the interior and exterior spaces (alteration of the existing levels of the terrain), to promote a better natural ventilation;
- Opening of new windows and implementation of a skylight to have more natural light into the interior spaces;
- Construction of a garage in the back garden, minimizing the impact of the structure with the implementation of a green roof;
- Rehabilitation of the front façade with the construction of interior wall in plasterboard and insulation in XPS;
- Rehabilitation of the back façade with the application of the Etics system with EPS insulation;
- Rehabilitation of the roof with the integration of a false interior ceiling in plasterboard with XPS insulation, and introduction of sub-tile;
- Replacement of the window frames for new windows with thermal cutting and double glass, similar to the existing ones;
- Rehabilitation of the ground floor through the recovering of the existing pavement and integration of XPS insulation, in the cases of bathrooms and kitchens the covering is in self-leveling;
- Rehabilitation of the pavements between floors through the recovering of the existing pavement and wood structure with the integration of a false ceiling in plasterboard with wool insulation, in the cases of bathrooms and kitchens the covering is in self-leveling;
- Integration of exterior blinds, like the existing ones;
- Integration of a heat pump with a solar panel in the housing I for heating and cooling and heating of the waters;
- Integration of a solar panel supported by a heat recovery system in the housing II for heating and water heating;
- Integration of a system of collection and treatment of rain and bath water, that is common to both housings;
- The artificial illumination will be in LED bulbs adapted to the dimension of the spaces, and all the electrical equipment will be the most efficient as possible.

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, 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 have a 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 7).

Table 7 – 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.

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

5 CONCLUSIONS

In this work it was presented the importance of the planning phase in order to evaluate all the components that make part of the building, and the steps to integrate sustainable criteria's (environmental, social and economic) since the early stages of the refurbishment project, in order to have more sustainable buildings.

The option for more sustainable constructive solutions and for systems that took in consideration the reduction of consumption and costs led, in terms of a global evaluation of the sustainability of the building, to obtain a good sustainable score.

In order to increase the number of sustainable refurbishment projects, 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. Because it takes time to apply all the methodologies that were presented and probably some technicians won't be available to apply them.

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