LOW COST SUSTAINABLE BUILDING REHABILITATION

SOLUTIONS SEEKING SUPPORT INSTRUMENTS

Alexandre Miguel Nunes da Silva Ramos

Extended Abstract

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1. INTRODUCTION

The rehabilitation of the existing housing represents a high potential area of intervention in urban areas, as a privileged path to achieve the goals of the strategies outlined in European directives and National legislation, to a more harmonious and sustainable operation of cities and the assurance of adequate housing.

For there to be an effective practice of sustainability in rehabilitation / construction there is a requirement that the building and the intervention processes respond positively to sustainability indicators. Thus, reducing costs and environmental impacts associated with traditional construction, by increasing efficiency in resource consumption during the life cycle of buildings (Pinheiro, 2006).

One of the issues which is verified in practice is how it is possible to integrate sustainability standards in low-cost rehabilitation solutions, especially in specific cases. This work intends to test the hypotheses' validity of integrating sustainability standards, according to LiderA. Thus, in low-cost rehabilitation solutions and in any scale of intervention, particularly in the case study of a Cartaxo's Kindergarten building as a small services building.

Therefore, tools are generated to identify and evaluate solutions in order to support decisions within the rehabilitation of the surrounding of a small services building, from a list of potential measures which increase the buildings lifespan on usage parameters, comfort and present habitability, at the lowest cost from a sustainability perspective.

Particularly, it is intended to:

» Validate that the definition of sustained intervention methodologies prevents unnecessary demolitions, ensuring an efficient management of resources, through a detail-oriented analysis of the existing building's quality and the purposes to be achieved.

» Test hypotheses of improving energy performance, associated with repair actions of detected anomalies, considering the passive design.

» Demonstrate through a life cycle approach, that the best solutions will reduce overall costs with economic return during the use phase, although they may represent an increase in initial costs, compared to conventional solutions.

The conservation status and the characterization of the identified anomalies are assessed through the survey and inspection of the building, Thereafter, solutions are presented regarding the diagnosis of anomalies, with quantification of the actions required for the re-establishment of requirements to the elements, which provide habitability conditions to the building. Then, intervention measures under evaluation are proposed, framing the solutions and considering improvement hypotheses of the passive design in regulatory use patterns. The decisions taken are based on the guidelines of LiderA's methodologies for assessing the sustainability and the REH of energy performance evaluation (DL No. 118/2013).

The cost-benefit calculation model of the measures proposed is based on a cost analysis methodology in the life cycle through the *net present value* (NPV) with updated values. This way, it allows the comparison of proposed measures with the current practice of reference in the study and the quantification of improvements by using the ratio lifetime / payback of investments.

Construction costs (CC), maintenance costs (MC) and energy costs (EC) for air conditioning are considered. The structure of costs related to intervention measures proposed is built, through market's research and use of CYPE program prices generator, following the assumptions and intervention strategies during the lifetime. According to the thermal behaviour characteristics of the constructive solutions considered in the intervention measures, the energy performance of the building is evaluated regarding the REH by estimating energy costs in each situation and using 0,1602 €/kWh as electricity price which refers to the simple rate published by the regulatory authority (ERSE, 2015).

Thereafter, will follow the systematization of cost functions and the performance evaluation, LCA and sustainability by the measures presented by LiderA.

2. CONSERVATION ASSESSMENT AND DEFINITION OF INTERVENTION MEASURES

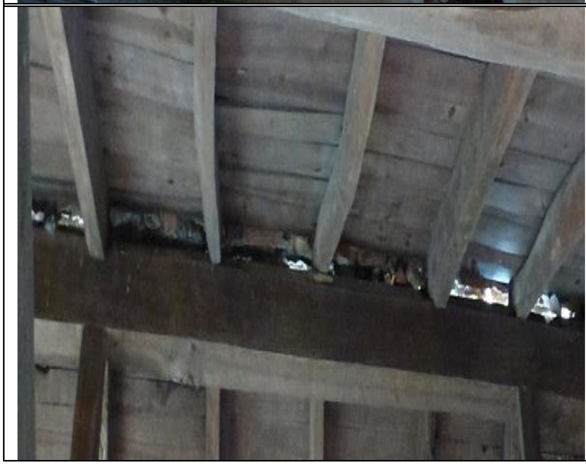
The main features of the building under study, located at Av. Mestre Cid, 2070 in the Cartaxo municipality, are described in Table 1.

Table 1 - General description of the building.

Element	Description	Areas
Plot	Urban area. It includes the building, outbuildings, streets and terraces.	1672 m²
Building	Services building composed of 3 floors with isolated construction and regular rectangular geometry.	Implantation: 225 m²; Construction area: 675 m²
Exterior walls	Massive limestone masonry, plastered and painted (t=0,60m). Stonework at the threshold of the doors and windows and ornaments.	372 m²
Interior walls	Masonry partition walls, plastered and painted (t=0,15m).	993 m²
Windows and door openings	Wooden window frames with single glazing (t=4mm).	91,6 m²
Roof	Sloping roof (i=40º) with two slopes in a wooden structure and lusa ceramic tile cover.	280 m²
Ground Floor	Concrete slab.	Useful area: 165 m²
First Floor	Slab in steel structure and masonry solution, reinforced with concrete beam.	Useful area: 174 m²
Attic Floor	Slab in wood structure solution.	Useful area: 180 m²

The survey of anomalies is accomplished by an inspection in the place by direct observation of the surrounding elements, following the guidance of the technical evaluation sheets. In table 2 some of the detected anomalies are presented.

Table 2- Examples of anomalies found

Anomalies: Leaching and debark of liners; cracks; disaggregation; efflorescence and subflorescence; broken and cracked glazes; corrosion; opening joints; wood warping.		**Inspection date:** 15.3.15
	 	
		

The classification of conservation status provides an estimation of the degree of intervention needed by the element and is based on the general criteria presented in Table 3. It takes into consideration the compliance of requirements, the quantification of degradation and the type of constructive solution.

Table 3 – General criteria for classification of conservation state.

Classification	State	Degree of intervention
1	Serious degradation, replacement> = 50%	Profound
2	Important, exceptional and localized degradation	Moderate
3	Exceptional and localized degradation <= 10%	Light
4	Good state	None

After the survey and analysis of anomalies in every aspect of the technical data sheets, the repair solutions are defined following the technical and scientific documentation guidelines, namely the study material of the course “Pathology and Rehabilitation of Construction” – IST. Conservation and rehabilitation interventions must comply with appropriate requirements to the historic character of the architectural heritage, namely authenticity, durability, affordability, compatibility and reversibility (Brito and Flores, 2004).

From the analysis of the anomalies (Table 4) it is possible to state that the major degradation mechanisms are infiltrations and aging by natural depreciation or lack of maintenance, with water as the main degradation agent. The roof area has the biggest impact on the origin of anomalies. The classification of the conservation state of envelope of the building by average weighting of checked parameters (2.06) indicates that, in general, the building has important, exceptional and localized degradation and needs a moderate degree of intervention. The most degraded areas are the balconies (A.1.3), the glass (A.2.8), the roof structure (B.1.11) and the gutters (B.3.15).

Proposed intervention measures, characterized in Table 5, are defined according to the anomalies or deficiencies identified in assessing the state of conservation. The time span of 40 years considered for LCA is related to the life expectancy of reference (LER) of the elements and the constructive solutions recommended. The maintenance plans selected follow the principles of a preventive strategy, defining the interventions and their frequency. It is based on performance indicators, such as the anomalies' forecast in the life cycle, allowing the comparison of estimated future costs.

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Table 4 - Requirements of the elements and conservation status evaluate.

Envelope element	Zone	Requirements	Aspects to be reviewed	Reference	Conservation state	interventions	Quantity
A. Vertical elements	A.1. Opaque wall portion	Stability and robustness; Thermal and acoustic insulation; Watertight; durability	Topcoats	A.1.1	2	Cleaning the facade of stone masonry with precision micro-jet abrasive particles or cleaning with biocides and brushing.	Total area: 270 m²; needing repair intervention: 50%
			Wall liners	A.1.2	3	Extract disaggregated material. Stabilizing the source of cracks in the support. Redo the liner using compatible materials with the existing ones.	Total area: 372 m²; needing repair intervention: 10%
			Balcony	A.1.3	1	Extract disaggregated material. Cleaning, treatment and replacement of reinforcement affected by corrosion with section loss. Redo the liner using compatible materials with the existing ones.	Total area: 160 m²; needing repair intervention: 50%
			Infiltration	A.1.4	2	(A.1.1; A.1.2; A.1.3.)	-
			Wall type	A.1.5	2	-	-
			Condensation on the inner vestments	A.1.6	3	Increase the thermal insulation.	-
	A.2. Frames / Glazing	Water tightness; Thermal and acoustic insulation; Control of permeability to air; Wind resistance.	Window frames	A.2.7	3	Repair / Replacement	Total area: 91.6 m²; needing repair intervention: 100%
			Glazes	A.2.8	1	Repair / Replacement	Total area: 51 m²; needing repair intervention: 100%
			Infiltrations	A.2.9	2	(A.2.7; A.2.8.)	-

Table 4 - Requirements of the elements and conservation status evaluate.

Envelope element	Zone	Requirements	Aspects to be reviewed	Reference	Conservation state	interventions	Quantity
B. Roof	B.1. Common area	Stability and robustness; Thermal and acoustic insulation; Watertight; durability	Liners	B.1.10	3	Cleaning and replacement of broken tiles. Removal of broken down equipment and redo the joints ridge and perimeter (10%).	Total area: 280 m²; needing repair intervention: 10%
			Roof type	B.1.11	1	Repair and protection with possible replacement of damaged elements of the support structure and the liner.	Total area: 280 m²; needing repair intervention: 15%
			Infiltration	B.1.12	2	(B.1.10; B.2.13; B.2.14; B.2.15.)	-
	B.2. Protruding elements	Watertight	Connections with protruding elements	B.2.13	3	Fill joint of chimney.	Total length: 5m; needing repair intervention: 10%
			Capstone	B.2.14	2	Replace damaged copings	Total area: 136 m²; needing repair intervention: 50%
	B.3. Drainage of rainwater	Effective flow	Gutters	B.3.15	1	Cleaning out the existing vegetation	Guttering length: 40 needing repair intervention: (100%)
			Downpipes	B.3.16	2	Replacing links (interior) between the gutters and cleaning of exterior downpipes.	Total length: 36 m²; needing repair intervention: 100%
			Mains rainwater	B.3.17	2	Close the meeting of water boxes.	4 water boxes.1 m²

Table 5 – Characterization of intervention measures.

<table>
<tr><th colspan="3">Element and intervention measures</th><th>LER and maintenance plan</th><th colspan="2">U solution (W/m².°C)</th></tr>
<tr><td rowspan="3">A.1. Opaque wall portion</td><td>Repair the existing constructive solution.</td><td>Out.L.s1 + Int.L.s1</td><td>Outside: (LER: 30 years): cleaning, painting every 5 years. Replace the liner in the 10th year of the time span. Repair of 10% every 10 years.
Inside: (LER: 40 years): Cleaning every 5 years, 10% repair of plaster and painting every 10 years.</td><td colspan="2">1,60</td></tr>
<tr><td>Substitution of the outer liner and repair of the existing inner constructive solution, applying insulation on the outside (1)</td><td>Out.L.s2 + Int.L.s1</td><td>Exterior (LER: 40 years): Cleaning and painting every 5 years and repair of 10% every 10 years.
Inside: (LER: 40 years): Cleaning every 5 years, 10% repair of plaster and painting every 10 years.</td><td colspan="2">0,53</td></tr>
<tr><td>Repair constructive solution existing outside and replace the liner with insulation applied on the inside (2).</td><td>Out.L.s1 + In.L.s2</td><td>Exterior (LER: 30 years): cleaning, painting every 5 years. Replacing the liner to 10 years. Repair of 10% every 10 years.
Inside: (LER: 40 years): Cleaning every 5 years, repair 5% of plaster and painting every 10 years.</td><td colspan="2">0,52</td></tr>
<tr><td rowspan="2">A.2. Frames / Glazing</td><td>Repair the existing constructive solution.</td><td>WF.s1</td><td>(LER: 40 years) Lubrication of fittings and annual cleaning. Painting window frames every 5 years. Replacement of the seals 10 years</td><td colspan="2">4,30</td></tr>
<tr><td>Replacement for aluminium window frames with thermal protection and double glazing 4-16-5</td><td>WF.s2</td><td>(LER: 40 years) Lubrication of fittings and annual cleaning. Replacement of the seals every 10 years</td><td colspan="2">2,70</td></tr>
<tr><td rowspan="4">B.1. Common area</td><td rowspan="2">Repair the existing constructive solution.</td><td rowspan="2">R.s1</td><td rowspan="2">(LER: 40 years)</td><td>Asc.</td><td>Desc.</td></tr>
<tr><td>3,80</td><td>2,50</td></tr>
<tr><td>Repair the existing constructive solution. Application of thermal insulation in the interior area (3).</td><td>R.s2</td><td>(LER: 40 years)</td><td>0,44</td><td>0,42</td></tr>
<tr><td>Installation of windows on the roof.</td><td>R.s3</td><td>(LER: 40 years) Lubrication of fittings and annual cleaning. Replacement of the seals every 10 years</td><td colspan="2">2,80</td></tr>
</table>

(1) Solution with exterior wall insulation: continuous thermal insulating liner mineral-based "mechanic weber.therm" λ = 0.042 W / m.ºC. The insulating layer thickness: 60mm (Saint-Gobain, 2014).

(2) Solution with indoor wall insulation: EPS boards, λ = 0.040 W / m.ºC. The insulation layer thickness: 60 mm.

(3) Solution insulated interior of coverage areas: XPS boards, λ = 0.037 W / m.ºC. The insulation layer thickness: 100 mm.

3. PERFORMANCE EVALUATION

Table 6 summarizes the performance evaluation results of the situations constituted by the proposed intervention measures. Data on LCA cover the costs during the life cycle updated in year 0 and the indicators of cost-benefit analysis. Sustainability was assessed considering the four criteria mentioned of the LiderA system.

Table 6 – Performance evaluation by LCA methodology and sustainability evaluation by LiderA of the proposed situations

SITUATIONS		LCA					LiderA					
		CC (€)	**MC (€)**	**EC (€)**	**NPV (€)**	**Payback**	**C6** Heritage protection and valuing	**C7** Efficiency in consumption - Energy certification	**C8** Passive design	**C40** Costs in the life cycle	**Global (%improvement)**	
SITUATION 1	Out.L.s1+In.L.s1 WF.s1 R.s1	17 545	49 433	230 879	0	40	A+	D	B	E	D	10,7%
SITUATION 2	Out.L.s2+In.L.s1 WF.s1 R.s1	38 898	40 674	183 158	35 126	10	A+	D	B	A+	D	11,3%
SITUATION 3	Out.L.s1+In.L.s2 WF.s1 R.s1	41 204	48 215	186 592	21 846	17	A+	D	B	E	D	10,7%
SITUATION 4	Out.L.s1+In.L.s1 WF.s1 R.s2	21 465	49 433	140 147	86 812	1	A+	C	B	A+	D	11,4%
SITUATION 5	Out.L.s1+In.L.s1 WF.s2 R.s1	39 170	46 779	221 019	-9 111	(77) No payback	A	D	A	G	D	10,7%
SITUATION 6	Out.L.s1+In.L.s1 WF.s1 R.s1+R.s3	24 145	50 879	220 045	2 788	24	A+	D	A	B	D	11,1%
SITUATION 7	Out.L.s2+In.L.s1 WF.s1 R.s2	42 818	40 674	99 873	114 492	5	A+	B	A	A+	D	11,8%
SITUATION 8	Out.L.s2+In.L.s1 WF.s1 R.s2+R.s3	49 418	42 120	96 695	109 624	7	A+	B	A+	A+	C	12,9%
SITUATION 9	Out.L.s2+In.L.s1 WF.s2 R.s2+R.s3	71 043	39 466	88 482	98 865	10	A	B	A+	A+	C	12,7%

Situation 1 of reference is the current practice which features primary energy supply, about 54% higher than the reference values in REH. The estimated electricity consumption performance in the current situation of reference represents the standard average consumption in buildings in Portugal of 100kWh / m^2.year (EnerOne, 2012).

The high thermal inertia of the outer walls is a positive factor of the current features of the building that contributes to a good energy performance, mainly in the cooling period.

The assessment of the energy performance of the several solutions demonstrates an improvement energy consumption for air conditioning, as expected. The situation, which implies the application of the greatest number of measures that change the surrounding elements (Situation 9), allows the reduction of 62% in consumption in the current practice and it corresponds to a B rating by REH.

There is an improvement made by the application of insulation to the roof, which reduces the consumptions in about 40% and it is, indeed, the main factor for the improvement of energy performance. The application of exterior insulation of walls has outperformed insulation from the inside, mainly due to reduction of thermal bridges.

The situations evaluated creates economic benefits after the payback period, represented in the year of the study period which the NPV becomes positive. Situation 5 is the only solution that provides a NPV <0, which does not allow a payback within the study period. Therefore, it is more advantageous to repair and maintain the existing window frames.

The placement of windows on the roof leads to a reduced impact for the performance factors under consideration. NPV> 0, with payback within the study period (Situation 6). However, when combined with other measures such as the application of thermal insulation on the outside walls and on the roof (Situation 8) it reduces the benefits compared to an identical situation, ever without the placement of these windows (Situation 7). This result is due to the fact that these windows have a better thermal performance than the current roof but not as good as the solution with the application of insulation on the roof.

The assessed situation with better energy performance (Situation 9) has a payback in the 10th year of the project, assuming an updated rate of 2% and a constant energy cost. For the same assumptions, the solution with the replacement of an external liner with the application of insulation, repair of the internal liner and the insulation application in the roof area (Situation 7) has the highest NPV, thus generating greater economic benefits with payback of investment in the 5th year of the project. This situation reduces electricity consumption by about 57%.

The recovery solution of the existing window frames is considered not only an economic benefit by LCA, but also a valorisation of existing materials that constitute heritage of historical and cultural value. Moreover, it has the benefits stated in the methodology of LiderA. Particularly, in the "heritage protection and valuing" criterion (C6) it was considered that the repair of the existing window frames (WF.s1) preserves a greater amount of existing elements, which is reflected in the ratings attributed in this criterion.

4. CONCLUSIONS

The approach used for searching low-cost solutions in the case of Cartaxo's Kindergarten allowed the attainment concrete conclusions, comparing the performance of solutions, namely energy performance, costs in the life cycle and sustainability.

The problem addressed was the study of possible rehabilitation interventions with the integration of sustainability standards. In this way, it contributes with a guideline with indicators to support intervention decisions within the framework to low-cost rehabilitation of a service building.

The surrounding area of the building was analysed, because it is the area with the greatest impact on energy performance. For defining intervention requirements applied a methodology for the evaluation of the conservation status of the elements based on the compliance of the requirements to the elements (walls, glazed areas and roof) and quantification of the degradation. This approach has allowed the definition of existing anomalies and necessary interventions for the restitution of habitability requirements, from a low-cost and intervention reduction perspective.

After outlining the repair solutions on the anomalies, the measures of intervention were analysed. These measures had to respond directly and exclusively to the needs raised. Additionally, alternative measures to promote sustainability and passive design were analysed, considering the guidelines of LiderA and REH.

The exploitation of the passive design allows the improvement of energy performance, reducing energy needs for air conditioning by more than 60%, through the measures considered. The performance evaluation of the measures was obtained by LCA methodology using the NPV, the payback and sustainability of the solutions, measured by LiderA evaluation criteria.

The results show that it is possible to promote the sustainability of the building through rehabilitation, implementing measures which ensure or return habitability conditions to standards of comfort, health and safety. Thus, it is adjusted to current requirements, while avoiding unnecessary demolitions and at the same time generating economic and environmental benefits, compared to current action practices.

Although this evaluation only covers 4 of the 43 criteria of LiderA methodology, areas relating to local integration, resources and socio-economic conditions are considered. It can be stated that the results are representative of an effective increase in the sustainability of the building through rehabilitation, reflected in the global rankings obtained.

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