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MEASURES FOR RESOURCE AND SUSTAINABLE PRACTICES MANAGEMENT IN BUILDING REHABILITATION

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Abstract. *The rehabilitation of buildings is a kind of practice that involves an improvement of the comfort and building habitability conditions through the reuse of existing resources. However the rehabilitation process requires ingenious solutions and specific knowledge by designers and builders. The reuse of material resources existing in buildings that align with the adoption of environment concerns could balance the embodied energy and water and emission reduction. Furthermore, the construction procurement could facilitate the rehabilitation process and also adopt a management contracting process which requires a specialized contractor to support the design and work's needs.*
This article describes a set of measures from a management system to support the project management process of a building rehabilitation works. The set of proposed measures could facilitate the skilled labour and material resources management, which are focused on the principles and assumptions of sustainability. In addition, it could also give a contribution to devising different ways to organize and manage works in buildings with rehabilitation needs and in a way to have more sustainability benefits.

1 INTRODUCTION

The rehabilitation of buildings can be nowadays considered a usual practice. However, in older buildings, a set of precautionary measures should be considered in light of the innumerable specific features of each intervention. Some rehabilitation works involve the demolition of existing building materials and structural elements in buildings that can be reused. In many cases those materials perform their functions efficiently and even better than new ones [1].

The reuse of existing materials in a good status of conservation can reduce the extraction of natural resources as well as atmospheric emissions and embodied energy and water, which, in turn, contributes to Reduce Global Warming, Ozone Depletion, Acidification, Eutrophication, among others [2]. The rehabilitation practices and consequent reuse of existing materials contribute to a great extent to promote sustainability and, to some extent, preserve the authenticity and uniqueness of the property. However, there are solutions that, even if they are not original, can bring benefits in the context of sustainability. These solutions can also guarantee a more effective response to the specific problems and constraints of each work, related to planning, deadlines, cost increases, changes, non-contractual works, among others [3]. Some of the problems described can be solved using some specific procurement practices [4].

The paper describes the application of some parameters of a toolkit in a building rehabilitation design. This toolkit to support the rehabilitation of old buildings is denominated "*Retrofitting management system for buildings located in consolidated urban areas*", referred to as management system [3]. The system is structured with 50 parameters linked to the building envelope and the environment, project design, works and site works and also costs, presenting a set of practices in each parameter classified from less sustainable to more sustainable. Therefore, the management system is an aid in the management of the project, seeking to preserve the authenticity of buildings, as well as contributing to the decision-making of the stakeholders involved in the rehabilitation process. The paper presents also a study of possible structural options to be applied in a building rehabilitation works according to their own constraints and possible solutions based on the scope of the management system. These structural options have been analyzed on the basis of environmental impact categories. [2]. In turn, all the options were weighted and the chosen solution was for the one that best serves a set of assumptions analyzed, namely the benefits for sustainability, advantages for the intervention and that better respond to the contents of the management system against the work constraints and specificities.

2 METHODOLOGY

In this article the authors intend to analyze some parameters of the management system with applicability in a practical case of an old building rehabilitation process. Some of these parameters are analyzed according to the specificities and constraints of the works to be rehabilitated. In addition, the opinion of a building contractor with expertise in this type of interventions is elicited [4], which contributes to a more careful and a precise reflection of the building process in the design phase.

Based on this analysis, a set of feasible proposals / options for structural solutions are considered and compared with each other in the light of the results of the quantification of environmental impact categories [5], as well as other aspects under analysis. The structural options studied involve a wooden structure (similar to the original structure), a concrete reinforced structure (conventional use in new buildings) and steel structure with metallic elements. The advantages and disadvantages of each option also allow us to reflect on its framework and interest for the intervention context. Thus, the quantities of materials of each option for structural solutions were calculated, following by the quantification of each categories of environmental impact [5].

Some different phases are, such as: Global Warning Potential (GWP); Destruction of Atmospheric Ozone (ODP); Acidification Potential (AP); Photochemical Ozone Creation, smog (POCP); Eutrophication Potential (EP); Non-renewable Primary Energy (FFDP).

Based on these weighted results, it is possible to ascertain which solution has most benefits for the sustainability context, as well as those that meet the technical constraints of the intervention based on the assumptions of the management system parameters. The figure 1 outlines the methodology used in the paper.

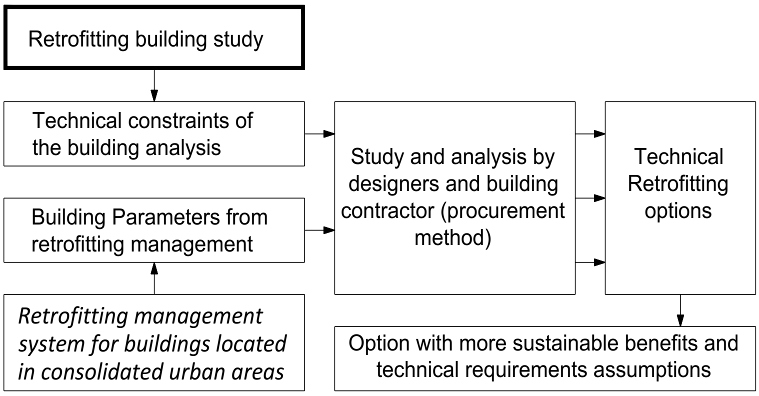

Figure 1: Framework scheme of management system uses for building retrofitting works

This study is based on the observation *in situ* of the technical constraints of the building under study. This method of analysis has as strengths real and contextual events but may require more time and even costs [6] [7]. The analysis of the adequacy of the existing constraints with the proposals of the management system parameters, adapted to the context by the designers and a contractor in the project design phase, result in some technical options that are studied from the point of view of their possible adaptation and benefits for the sustainability context. However, the option selected is based on a weighting with percentages assigned according to the results obtained in the categories of environmental impact, technical constraints, solutions guaranteed by the management system parameters, and also based on the analysis of the advantages and disadvantages of each structural option.

3 BUILDINGS REHABILITATION AND SUSTAINABILITY PRACTICES

Building rehabilitation is directly connected to sustainable practices which involve existing material reuses, natural resources extraction and emissions reducing, besides embodied water and energy contents [2]. Some kinds of rehabilitation practices are designated rehabilitation works but they are more similar to new construction. So, there are rehabilitation works more beneficial to the sustainable context when compared with other ones.

The building rehabilitation is defined as "*the set of interventions focus in conservation and restoration of significant parts in historic and esthetic terms of an architecture, including their general beneficiation, in form to allow them to satisfy a performance and actualized functional exigencies levels*"[1]. Existing buildings, even old ones, in good conservation status could be adapted attending the improvement of their comfort and performance conditions, adapting the existing elements to new functional exigencies and preserving their original identity, figure 2.

Figure 2: Examples of building rehabilitation practices reusing some existing materials

3.1 Buildings rehabilitation context

According to the National Statistics Institute there are 206343 buildings built before 1919 and 305696 are dated between 1919 and 1945 [8]. Total building in Portugal in 2016 is estimated at 3592580 corresponding to 5932990 housing units. However, 45% of the buildings built before 1919 needs reparation works and 12% of this percentage is in a much degraded status.

About 4,3% of buildings concluded between 2006 and 2011 needs repair works despite their recentness. In 2016, the number of completed buildings was 10251 units (10972 in 2015). Of this, 68% corresponds to the new construction typology and 32% represents building works other than new building construction [9]. And 63% of buildings concluded in 2016 were built for family residences. This analysis allows to conclude that the number of residential building are still increasing, but the number of rehabilitation projects does not still mach the number of the new building construction.

3.2 Constraints to old buildings rehabilitation works

As stated above, the building rehabilitation process faces a number of constraints that are specific to each rehabilitation project, especially in the case of old buildings. These projects must be studied in detail and managed in a way to solve existing problems. On the other hand, the omitted recommendations for problems resolution in the design phase resolution can cause risk occurrences and unexpected situations and, consequently, may result in increased costs, delays and other contingencies, table 1.

Table 1: Example of possible constraints in rehabilitation works [1] [10]

Type	Description
Low interest	- The consumer searches generally for recent buildings with better comfort, sanity and safety conditions, near to big cities and so far possible from villages. - Low air renewal, causing characteristic smells and humidity.
Traditional trade	- The lack of parking spaces contributes to the closure of shops. - High rents for shopping spaces opening, and the existing ones are old and traditional.
Morphology	- Many old building are located in a local topography that is often uneven and steep, with narrow streets and no car accessibilities or parking and without access by people with low mobility.
Degradation	- Places associated with rundown and dangerous areas, some of them are inhabited.
Public spaces	- Frequent use of the public space for the residents use.
Unsanitary conditions	- Dirty and inappropriately used alleyways, common areas and other public spaces. - Proximity of opposite buildings (shadings, low sun exposure, low natural lighting and easy fire propagation).
Fire safety	- Lack of hydrants and of emergency and evacuation plans. - Places with potential larger damage and higher difficulty of control in case of fire.
Faulty infrastructures	- Faulty volume of containers for urban solid waste (USW) and of recycling bins. - Inexistent, degraded or outdated infrastructure networks.
Urban space quality	- Frequent aspect of degraded surroundings and inexistent maintenance operations. - Unsuccessful refurbishment operations which spoil the surrounding area.

3.3 Recommendations to support old buildings retrofitting practices

In this section, some recommendations about old buildings rehabilitation works are put forward, considering a conjugation of the following thematic areas: management system; environmental impact categories quantification; procurement practices.

3.3.1 Retrofitting management system for buildings located in consolidated urban areas

The management system is a toolkit to support retrofitting old buildings, structured in 4 areas, 15 indicators and 50 thematic parameters [3], Table 2.

Each thematic parameter is a result of the study of possible constraints about that kind of problems in a building rehabilitation project. And the parameters also promote some technical solutions and recommendations attending to law, regulations and sustainable practices with better benefits. Each parameter is classified in 5 possible options, from less sustainable (level 1 valorisation) to most sustainable (level 5 valorisation). The valorisation with level 2 is considered as a frequent or conventional option without any increased sustainable benefits.

Table 2: Management system thematic areas, indicators and parameters [10]

Area	Indicators	Parameters description
A1. Surroundings and location	I1. Mobility and amenities	P01. Public transport P02. Car parking P03. Local amenities
	I2. Local infrastructures	P04. Outward firefighting means P05. Technical networks in public space P06. Urban space quality
	I3. Land use occupation	P07. Land occupation P08. Total area and deployment area P09. Gardens and leisure places
	I4. Solar orientation and exposure	P10. Solar exposure P11. Solar orientation
A2. Project design	I5. Characterization of building conditions	P12. Request for technical studies P13. Characterization diagnoses of building conservation status P14. Project Design specificities
	I6. Architectonic organization and salubrity	P15. Conceptual architecture configuration and adaptability P16. Ratio useful floor area/Gross lettable area (GLA) P17. Acoustic insulation and indoor air quality
	I7. Infrastructures, foundations and structural elements conditions	P18. Building technical networks P19. Peripheral retaining structures P20. Foundations P21. Structural elements
	I8. Materials	P22. Materials reuse P23. New materials P24. Fire safety
	I9. Sustainability promotion	P25. Water recovery and reuse P26. Solar collectors for hot water production P27. Electrical energy production P28. Energetic efficiency in thermal comfort P29. Other solutions for energetic efficiency P30. Bioclimatic solutions P31. Other sustainable solutions
A3. Construction works and site works	I10. Initial works constraints	P32. Site works and surrounding space P33. Adjoining building conservation state P34. Stabilization and consolidation of building works and adjoining buildings P35. Adjoining buildings waterproofing
	I11. Industrialization/ execution of works	P36. Workforce P37. Specialized workforce and company's technical capacities P38. Specialized subcontracts P39. Technical requirements monitoring
	I12. Risk and constraints potential	P40. Propensity to project design changes P41. Propensity to the occurrence of unexpected works P42. Propensity to time overruns P43. Propensity to other work constraints
	I13. Other features resulting from works	P44. Archaeological Works prospection P45. Construction and demolition waste management P46. Needs of occupant's relocation
A4. Costs	I14. Work costs	P47. Costs of urban space works P48. Costs of general building works
	I15. Tax incentives and other costs	P49. Possibility to apply for benefits and tax incentives P50. Maintenance and conservation strategies

3.3.2 Sustainability benefits in existing resources uses

There are some building environment sustainability assessment methods that consider the environmental, social and economic dimensions according to the Life Cycle Assessment (LCA) building context [11]. However the LCA methodology is very complex, lengthy and connected to many uncertainties about the building context. Buildings use hundreds or thousands of different products and involve the works from several enterprises during their life cycle that generally spans 50 years or longer [5]. In many cases, the LCA tools are not used by the construction stakeholders, which make it more usual the approaches that use a simplified LCA methodology. This simplification does not allow a comparison of the results between different LCA methods, consequence of their differences and lack of standard rules in some of them. Table 3 describes thirteen different environment indicators considered by CEN (European Committee for Standardization) in a building environmental assessment performance.

Table 3: Indicators for assessing environmental performance (source EN 15978:2011) [5]

Environmental impacts expressed in LCA categories	Environmental impacts based on life-cycle inventory (LCI) data, but not expressed in LCA categories
- Depletion of abiotic resources; - Climate changes expressed as Global Warning Potential; - Destruction of the stratospheric ozone layer; - Acidification of soil and water resources; - Eutrophication; - Formation of tropospheric ozone, expressed as photochemical oxidants.	- Use of non-renewable resources, in addition to the primary energy; - Reuse and use of recycled products; - Use of non-renewable primary energy; - Consumption of drinking water; - Storage of non-hazardous waste; - Storage of hazardous waste; - Nuclear waste (hazardous waste separated);

These indicators values are described in EPD (Environment Product Declaration) of each product published after studies and different approaches. There are many sustainable assessment systems for buildings, such as: BREAM, LEED, SBTool, BEPAC, HQE, CASBEE methods, among others [12]. Some different phases are presented in the building life cycle, such as: material acquisition (extraction of raw materials, transportation to the processing site, processing, transportation to the construction site), construction (operation in the construction site), Operation (use, reuse, maintenance), demolition/treatment (demolition/deconstruction, reuse and recycling of products, waste management, transportation) [2].

On the other hand, the materials/construction products reused from other building deconstruction or the rehabilitated building do not cause environmental impacts related with in new materials acquisition and also delay their demolition/treatment guiding. The building rehabilitation is a kind of sustainable practice when compared to new building construction [1]. However, the building renovations must be seen in the context of the building entire life cycle. An efficient rehabilitation process must aspire to reach good performance and comfort levels as well as to increase the sustainability benefits in the occupancy phase of the building, such as [1] [13]: energy and water consumption reduction, thermal and acoustic comfort levels, public transport proximity, wheelchair access, amenities, among others.

3.3.3 Management contracting as procurement method in rehabilitation works

In cases where the projects dimmed technically complex and with unpredicted risks and uncertainties, it is recommended to adopt management contracting as the most suitable procurement method. According to Ciria (1984) "*The characteristics of a management contract are that the client engages the management contractor to participate in the project at an early stage, contribute construction expertise to the design and manage the construction*" [14]. "*Because of these requirements, it is normal for the management contractor to be an experienced builder or construction company, but this is not a pre-requisite*" [4]. The management contracting is a procurement method where 100% of construction works are sub-contracted. The management contractor is contracted for managing the process and it is not a sub-contractor but a manager. This kind of procurement method could be required for several situations in specific retrofitting projects [4]: the project requirements are complex; the project entails, or might entail, changing the employer's requirements during the building period.

4 RETROFITTING BUILDING STUDY

The study deals with the rehabilitation project of a building constructed in the 2nd half of the 18 century, localized in a village near the town of Viseu (Portugal). This building was recognized as immovable cultural heritage and listed as bearing municipal interest without general protection zone [15]. The exterior walls are in granite stone, the floors and roof in wooden structure, figure 3a). The building was abandoned in 1970s and it had since been without conservation practices. This situation has caused many damages and ruins in the roof that consequently extended to all internal wooden structure, figure 3b). These damages were so extended that there was no room (both technically and economically) for the recovery of the structure and building components (roofs, interior walls and floors). The actual owner had some financial constraints and he decided to rebuild the building in 2 phases [16]: Structure and roof in 2012; infrastructures and finishing in 2025. His goals are preserving the original façade and organize the interior with solutions to promote comfort and performance levels.

a) b)

Figure 3: a) Building exterior walls; b) Interior building degradation and ruins

4.1 Technical constraints and retrofitting goals

The owner priority is to rebuild the structure and roof to protect the building from rain water of external walls inside. Table 4 describes the technical constraints about that structure rebuild.

Table 4: Technical constraints about building structure build

Code and Group	Description:
(X) Existent and design project aspects	- (X1) Wood structure in ruins with waste cleaning, figure 3b; - (X2) The building has 3 storage floors (middle one was 1.8 m high). The slabs may have less than 20cm thickness, figure 4a; - (X3) Right façade partially leaning against an adjoining building; - (X4) Internal stairs steps are 25cm to 28cm high - (X5) Posterior façade wall have not reinforcement and strengthened locking, figure 4b; - (X6) Principal façade has some sculpture stone elements and a staircase in the street; - (X7) Needs of lateral water proofing for adjoining building roof.
(Y) Economical, financial and sustainability	- (Y1) Priority to protect external walls from rain waters so soon as possible; - (Y2) Financial resources with a maximum limit (without margin); - (Y3) Some materials have environmental concern;
(Z) Site works and rehabilitation works	- (Z1) Site works with limited access entrance (figure 4c); - (Z2) Overhead electrical power lines on the street at 3m distance from the building; - (Z3) Narrow street which is the only connecting access within the village.

4.2 Management system thematic parameters used

According to Kerzner (2013), the success of a project is related a minimum of changes in the goals and that does not disturb the normal workflow and corporate culture of the company [17]. Against the constraints described in section 4.1 related to structural and roof works, some recommendations [18] and parameters of the management system were utilized [3], table 5.

a b c

Figure 4: a) Building floors constraints; b) Lack of posterior façade without reinforcement and strengthened; c) Site works with limited access entrance.

Table 5: Management system thematic parameters used

Parameters (table 2)	Constraints (table 4)	Recommendations and solutions adoption and constraints resolution
P15	X2, X4, X6	The new slab of the intermediate floor was built 20cm below that existing one. This solution reduces the height of the lower floor to 2.40m but increase the intermediate floor to 2.20m. Replacement of the existing interior staircase by a new one designed according to steps height regulation. Preservation of sculptural elements on façades.
P22	Y3	Reutilization of existent materials (stones, exterior walls, woods).
P23	Y3	Pre-fabricated options promote reversibility principle.
P32	Z1, Z3	Demolition of the entrance portal permit to assembly a fixed crane which it will be rebuild in the works end. Limit the works in the street and after a planning schedule. Example, there was a traffic stop during 1 hour in each slab for concrete application.
P33	X3	Adjoining building has good conservation state without any work's needs.
P34	X3, X5	The adjoining building has not need any reinforcement or consolidation works. Reinforcement needs in posterior façade had a concrete pillar integrated in the design.
P35	X7	Construction of the lateral roof wall was lacking in the adjoining building.
P36, P37	Y1	Structure with prefabricated elements, manufactured by a specialized enterprise with quality control, promoting fast work during assembly, without skilled work force.
P38	X4, X6	The new staircase was made by a specialized company (same original design form with legal height). The conservation façades does not require specialized companies.
P39	X6	The project design is very detailed without the need of permanent technical monitoring. It also allows the clarification of specific questions not frequent in design.
P41, P42	Y2	The project design has a detailed survey of all constraints as well as their resolution measures and guidelines for real planning. As an example, the structure rehabilitation works had a duration of 120 workers- days for demolitions, structure and coverage (3 daily workers x 40 working days), thus reducing the exposure to occupational hazards.
P43	Z2	The electrical networks of public lighting were distanced 3 meters from the building principal façade, which makes the option of a mobile crane unviable.
P45	X1	The building rehabilitation works reutilize the existing façades, uses some wood elements and also some building deconstruction/demolition waste reuses. The option for a prefabricated structure contributes to the minimization of construction waste.

4.3 Structural technologies options and sustainability analysis

The design project design of the building rehabilitation attended to the constraint (table 4), as well as the solutions and recommendation analyzed in management system parameters (Table 5). The study devised 3 different structural options for the building:

- Option A – Foundation in concrete. Wood flooring on wooden structure (similar to existent ones) with some metallic elements for reinforcement, figure 5a);

- Option B – T beam and block system slabs. Pillars, beams and foundations are in concrete (similar to new construction), figure 5b).

- Option C – Foundation in concrete, beams and pillars in steel structure and steel decking for concrete floors slabs, figure 5c).

a) b) c)

Figura 5: a) Wood flooring on wooden structure; b) T beam and block system slabs; c) Composite metal deck (steel decking for concrete floors slabs)

All of these different options were analyzed according to the advantages and disadvantages of each option (Table 6). This was followed by quantification of benefits to sustainability of the environmental impact categories (Tables 7 and 8).

Table 6: Advantages and disadvantages of each structural option

Option	Advantages	Disadvantages
A	- Similar weight to existent structure; - Similar structure existences and reversible.	- Specialized subcontracting is required; - The intermediate floor needs new holes drilling to support; - Expensive solution and quite difficult to protect from rain according to owner planning decisions. - The solution requires more beams or beams in steel elements and the internal walls need reinforcement; - The noise is difficult to control and also fire protection
B	- Solution does not require skilled workforce; - Current solution;	- It requires more space in site works; - More concrete volumes and the slabs require a minimum of 20cm thickness; - More weight and difficult reversibility; - More amount of workforce (more exposition to safety risks);
C	- Less amount of workforce (rapid assembly that reduces risks exposition); - Light structure with reversibility; - The slabs can be 14cm thick; - Few site works space; - Networks wires and pipes under slab.	- Expensive solution; - Possibility to higher steel corrosion and fragile in the case of fire occurrence. - It requires rigorous geometric and topographic surveys and technical knowledge in assembly; - More weight than original option and less than option B.

For this proposal, the building sustainable assessment method SBTool PT was utilized and, particularly, its methodology for calculating the Parameter P1 denominated "Construction materials' embodied environmental impact". This parameter encompasses the following environmental impact categories quantification [5]: GWP (Global Warning Potential) - KgCO2equiv.); ODP (Ozone Depletion Potential - KgCFC-11equiv.); AP (Acidification Potential - KgSO2equiv); POCP (Photochemical Ozone Creation Potential - KgC2H4equiv.); EP (Eutrophication Potential - KgPO4equiv); FFDP (Non-renewable Primary Energy - MJ equiv.). The unitary value from GWP, ODP, AP, POCP, EP e FFDP indicators are in a LCA Database. This covers a wide range of solutions concerning building elements and constructive materials. Table 7 shows the values of that LCA impact categories multiplied by the thickness of structural elements options.

Table 7: Quantification of the categories of environmental impact according to constructive solution types (per square metre)

Option	Constructive solution types	Quantification of the categories of environmental impact (per m²)					
		GWP	ODP	AP	POCP	EP	FFDP
A	Wooden structure 355m² (15cm)	1,30E+00	2,06E-07	9,09E-03	5,30E-04	2,94E-03	3,03E+01
	Weak fill concrete 1555,2kg	1,10E-01	3,55E-09	1,79E-04	6,49E-06	2,84E-05	5,56E-01
	Foundations concrete 14250kg	1,48E-01	3,55E-09	5,56E-04	5,28E-05	5,76E-05	1,24E+00
	Metallic structure 4500kg	5,71E-01	5,40E-08	3,04E-03	1,85E-04	4,86E-04	8,66E+00
B	T beam slabs 355m² (20cm)	1,76E+01	1,46E-06	5,32E-02	3,14E-03	9,80E-03	1,94E+02
	Weak fill concrete 1555,2kg	1,10E-01	3,55E-09	1,79E-04	6,49E-06	2,84E-05	5,56E-01
	Concrete structure 88000kg	1,48E-01	3,55E-09	5,56E-04	5,28E-05	5,76E-05	1,24E+00
C	Steel decking slab 230m² (14cm)	1,02E+01	6,29E-07	3,35E-02	3,63E-03	6,68E-03	1,32E+02
	Weak fill concrete 1555,2kg	1,10E-01	3,55E-09	1,79E-04	6,49E-06	2,84E-05	5,56E-01
	Foundations concrete 14250kg	1,48E-01	3,55E-09	5,56E-04	5,28E-05	5,76E-05	1,24E+00
	Metallic structure 15000kg	5,71E-01	5,40E-08	3,04E-03	1,85E-04	4,86E-04	8,66E+00

Table 8 presents the sum of the environmental impacts of the constructive solution parts in each structural option studied which results from the values presented in Table 7 multiplied by the quantities (square meter, kilogram) of each part described [5]. An analysis of Table 8 indicates that the option A (wooden structure) is the option with less environmental impacts in all studied environmental categories. The structural options B and C have more embodied energy concentration and emission during building life cycle and, consequently, more impact.

Table 8: Quantification of the categories of environmental impact (Total results by option)

Option	Quantification of the categories of environmental impact (Total results)					
	GWP	ODP	AP	POCP	EP	FFDP
A	5,31E+03	3,72E-04	2,51E+01	1,78E+00	4,10E+00	6,83E+04
B	1,94E+04	8,35E-04	6,81E+01	5,77E+00	8,59E+00	1,79E+05
C	1,32E+04	1,01E-03	6,15E+01	4,37E+00	9,69E+00	1,79E+05

4.4 Weighting of structural technologies options

A decision support was devised considering a scale of interest ranging from 1 (least interesting) to 3 (most interesting) and attributing percentage levels to the analyzed variables [6] [19]. The assignment of the percentage levels was the following: 30% for recommendations and solutions from management system parameters (Table 5) – Factor F1; 30% for advantages and disadvantages (Table 6) – Factor F2; and 40% for environmental impact categories quantification (Table 8) – Factor F3.

Table 9 presents the percentages, scale decisions choice and calculations results.

Table 9: Calculation results of structural options studied

Option	Factor F1 (30%)	Factor F2 (30%)	Factor F3 (40%)	Results
A	1	1	3	1,8
B	3	2	1	1,9
C	2	3	2	2,3

The results consider C as the more favourable option that attends to the constraints of the proposals of this construction phase. However this option does not contain the best results in several analyzed environmental impact categories but, in other point of view, it has more advantages and also attends to the management system thematic parameters. Furthermore, the option C encompasses a steel structure with easy and quick assembly, being light, reversible and could give some reutilization possibilities. The structural slabs option solves the floors thickness limitation (20cm) and it is more durable to rain exposition, which goes according to the planning defined by the owner to finish all building rehabilitation works in 2025.

5 CONCLUSIONS

The article presents the study of several structural options that can bring sustainability benefits in the rehabilitation of an eighteenth-century building. The survey of the existing constraints was exhaustively described and analysed in the project design phase and supported by a management system [3]. This management system adds to the management of old buildings rehabilitation works, compiling in 50 parameters various practices to support the management of building rehabilitation works. A set of 3 possible structural options were considered to meet the structural requirements and constraints of the building. These 3 options were analysed taking into account their advantages and disadvantages within the context of the specificity of this building, quantified in terms of categories of environmental impact and their representation based on the assumptions of the analyzed parameters of the management system. Subsequently, the structural options were weighted considering the set of analyzes already described.

The option C has better results and involves the use of a steel structure (beams and pillars in steel structure and steel decking for concrete floors slabs). O other hand, the option A is the one that has the lowest results in the quantification of environmental impact categories, but option C is the one that has the most advantages in relation to the specificities of the building. It allows reversibility, quick assembly and is the one that best responds to the existing constraints.

In addition to these facts, Option C allows greater durability and does not require large maintenance requirements during the time frame of the works (2012-2025). This weighting also allows us to understand that the reuse of existing materials makes the intervention more sustainable and with less impact on the environment. This paper presents in a simple way the analysis of several requirements that are expected to be considered in building rehabilitation projects. In this sense, it sheds more light on the importance of rehabilitation [2].

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