The Huge Importance of Inspecting and Diagnosing a Building for a Sustainable Rehabilitation Project

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***Abstract*—**The text presents the preparatory work carried out for the rehabilitation of a building in Sintra for housing and commerce, respecting the themes of Inspection and Diagnosis for a Sustainable Design. Following a correct methodology for the diagnosis and identification of anomalies in the building elements was fundamental to making decisions about the actions to be taken for each element of the construction: conservation, rehabilitation, reinforcement, or removal. The building in question requires intervention to meet current seismic requirements, with structural reinforcement, but also rehabilitation to meet current comfort and safety regulations.

The option of having a mixed structure in wood elements and metal profiles with stairs in metal profiles covered in wood, is aimed at having an economical and safe option, in order to guarantee the regulations in force as well as the execution standards, making the execution deadlines compatible and taking into account the ease of execution. Raising the foundations by increasing the contact surface of the soil footing, reinforcing the foundations by installing foundation lintels with connections to the stone masonry walls, in order to consolidate the building's foundations and reinforce them against seismic activity.

***Index Terms*—**Building, Inspection and diagnosis, Rehabilitation, Sustainability.

I. Introduction

The aim of this work was to carry out an inspection and diagnostic study with a view to rehabilitating a residential and commercial building, applying the principles of sustainability which are based on: i) keeping as many elements in the building as possible [1] - [3]; ii) using non-destructive techniques [4], and iii) laying the foundations for a rehabilitation project with maximum energy efficiency [5].

In fact, the act of rehabilitating old buildings is just as important [1] – [4] as doing so in a uniform and sustainable way, so that their maintenance and future energy efficiency is as good as possible [5], [6].

In this way, the anomalies of the building elements were diagnosed and identified and the actions to be taken in terms of conservation, rehabilitation, reinforcement or removal were decided. All rehabilitation actions require in-depth knowledge based on a diagnosis of the building's quality [6]-[9]. All the tests carried out were non-destructive (NDT). The main objective of the non-destructive methods currently being developed is to allow the assessment of characteristics other than strength in structural elements and structures [4], [5].

However, as mentioned in [7], maintenance models usually consider that maintenance actions are perfect, i.e. that these interventions can restore components to "as new" condition. However, in many situations, this assumption is too simplistic and, moreover, not true. In this study, imperfect maintenance actions are considered. The building in question requires intervention to meet current seismic requirements, with structural reinforcement, but also rehabilitation to meet current comfort and safety standards [8] – [13].

Consequently, the rehabilitation will take into account structural and non-structural intervention.

The pathology, its causes and effects were therefore identified to propose the best solution for each situation [13].

II. Characterization of the Building and its Surroundings

A. Actual situation

The building consists of two floors and an attic above the threshold level and one floor below the threshold level, with independent access through the patio, which in turn adjoins the public road. The morphological, volumetric, and architectural characteristics of the existing building fit in with the style of the surroundings, at the entrance to the historic area of the town of Sintra, Portugal (Fig. 1).

Fig. 1. The building (in the center) and its surroundings.

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The building was constructed at the beginning of the 20th century, using systems of the usual nature for its construction period. It is possible to distinguish interventions later, particularly on the roof and sanitary installations. A visual inspection revealed that the interior of the building is in a poor state of repair.

B. *Inspection Methodology*

Initially, the collected data from the building is approached, providing a geographical context, a brief history, and a description of the materials used in its construction. Next, the work will translate the adopted evaluation method for inspecting the building, reflecting on the method's essence, its application, and the chosen criteria and weightings for its implementation.

After conducting the building inspection, a rehabilitation plan is then formulated, primarily supported by documents provided by the professors of the postgraduate program's courses. A maintenance plan is developed too, to ensure that the conservation state of the building is not compromised again, Table I. [9], [10].

TABLE I: INSPECTION METHODOLOGY

Sequence of actions	List of anomalies
Architectural survey;	Type of anomaly;
Structural survey;	Description of the anomaly;
Dimensional survey;	Degree of degradation;
Characterization of the cross-section of structural elements;	Minimum intervention;
Characterization of mechanical properties;	Severity;
Reconnaissance of the buried structure and the foundation soil;	Photo Ref;
Survey of visible anomalies:	Possible causes;
Structural anomalies;	Corrective Measures \ Repair;
Non-structural anomalies;	Remarks
Conclusion.	Type of anomaly;

C. *Initial conclusions from the inspection*

According to the state of conservation found and seen rigorously through the methodical inspection, the initial intention was to: i) preserve the old cladding through maintenance and occasional repairs; ii) consolidate the existing cladding; iii) partially or totally replace some walls, using cladding similar to the old one [6].

III. CONSTRAINTS

A. *Main constraints*

The main constraints are not knowing the state of the structure, the architectural solutions do not fit in with the structure initially proposed, and the solution is to design a structure that meets the architectural requirements without jeopardizing its functionality.

As the foundation slab is in a basement, it may be subject to a high-water table, which causes it to receive vertical loads in an upward direction due to hydrostatic thrust. The method used to lower the water table was to waterproof the façade with two handfuls of bituminous emulsion, then lay a bituminous membrane followed by a piton mesh with geotextile next to the façade, and to capture groundwater by laying a geodrain pipe wrapped in a geotextile sleeve wrapped in a rockfill next to the building's walls [11].

The thickness of the attic slab is 10cm, which makes it difficult to decide on its design. The construction of two 1.10 m x 1.30m mansards on the roof, given their proximity to each other (approx. 0.60 m) could lead to a solution using metal profiles and not wood as initially thought, to withstand the stresses caused by wind and weather. water table, which causes it to receive vertical loads in an upward direction due to hydrostatic thrust (Fig. 2) [12], [17].

B. *Other constraints*

The plaster on the walls has anomalies, with occasional detachments. One of the possible causes could be infiltration and the cycles of air humidity in the winter and drying in the summer, stiffening the base of the plaster and causing it to detach (Fig 2).

The floor is in poor condition and the wood is not mechanically resistant enough for its intended use. The wood has degraded as a result of use, with signs of humidity that have reduced its mechanical resistance [12], [18].

Although the trusses are in good condition, the architecture contemplates the construction of two massardas on the roof, which is why it will be completely replaced, regardless of the assessment of its state of conservation.

Reusing the roof tiles could be considered a good solution once the new roof has been built.

Fig. 2. The building (in the center) and its surroundings.

IV. INTERVENTION PROPOSAL

A. *General*

In view of the need to create new ceiling heights, the first floor and attic will be fitted with new slabs consisting of wooden beams with metal profiles embedded beneath the wooden beams, connected in such a way as to brace and lock the master walls.

The exterior façades will be maintained, with occasional new openings, as indicated in the attached details.

The existing wooden roof will be removed and replaced with a metal structure, where two mansards will be created, similar to those existing on the same frontage of the built-up street.

The wooden stairs will be demolished and replaced by a metal structure with a wooden floor. The existing stonework and wooden frames will be maintained.

Rainwater from the roof, balcony and patio will be properly collected and directed to prevent it from flowing into the neighboring yard [19 - 22].

B. *Structural analysis*

The structural analysis arises within the scope of the work and syllabus acquired and developed during the Postgraduate course, more specifically in the Rehabilitation and Reinforcement of Masonry and Wood Structures (RREAM) curricular unit [23]

The aim was to analyze the mixed masonry and timber building in terms of its safety from seismic action.

To carry out the linear dynamic analysis, we used the structural calculation program SAP2000v16 (Structural Analysis Program), which works with four-node finite elements and assigns simulated real dynamic conditions.

The linear dynamic analysis is used to determine the forces and actions in shear, traction and the main compressions, in order to ascertain the weakest areas of the building.

The structural reinforcement proposals will be the result of the results obtained from the linear dynamic analysis, in order to be technically feasible from a construction point of view and to keep the building as original as possible, in order to prevent possible structural damage that could occur during seismic actions.

To model the stone and wood masonry building in (SAP2000v16), the following data was taken into account:

- Geometric characteristics of the building's structural elements;
- Mechanical properties of the materials that make up the building;
- Characteristics of the mechanical actions exerting stress on the structure;
- Dynamic stresses to which the structure is subjected and its response to these actions.

C *Structural reinforcement proposal*

The structure of the building was modeled from floor -1 to the roof using a structural modeling program. For this purpose, SAP2000v16 was used, which is a finite element program that performs static and dynamic, linear or non-linear analysis of structural systems.

The SAP2000v16 modeling of the masonry and timber building included the following data:

- The geometry of the structure and its constituent elements;
- The mechanical characteristics of the materials that make up the different structural elements and their connections;
- The mechanical characteristics of the foundation soil.

The first step was to survey the dimensions of the plan provided in CAD for the X, Y and Z axes. Data was entered for the reference lines of the walls, beams, door and window boundaries, as well as those of the roof. With regard to the stairs, only their openings on the 1st floor and the loft were considered.

A Cartesian mesh called the "Grid" was formed, defined by the width and height coordinates of the building. The three-dimensional model was further divided into a 50 cm x 100 cm square grid, according to the connecting elements - walls, floors, ceilings, wooden beams, window and door openings, except for the roof, where triangular and trapezoidal shapes appeared at the transition of the grid.

After surveying the X, Y and Z coordinates, it was possible to create the geometric model to start developing the base grid in the SAP2000v16 program (Fig. 3)

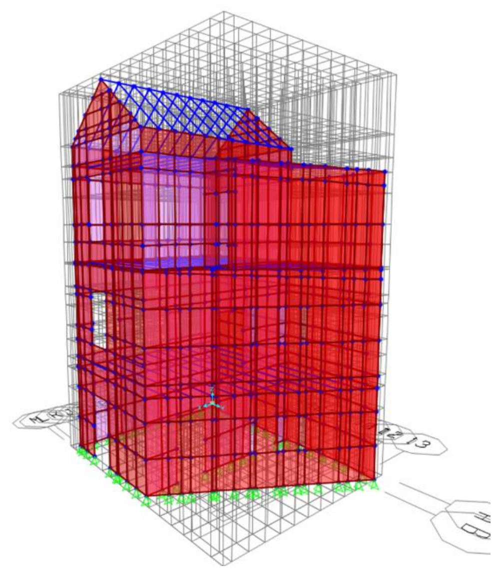

Fig. 3. structural model in the SAP2000v16 program.

The strategies adopted for this structural reinforcement study to promote better overall behavior in the face of seismic action are based on the least intrusive intervention techniques possible (in order to preserve the building as it was originally):

- Reduction of stiffness discontinuities, by correcting the modifications that caused the discontinuities (introduction of connections between wooden floors and interior walls);
- Overall increase in rigidity due to bracing with metal elements;
- Global increase in localized or global resistance, by reinforcing existing structural elements with the inclusion of new elements with resistant characteristics.

The recommended interventions concern the masonry structural components, the timber structural components and the structure of the building as a whole. Thus, considering the

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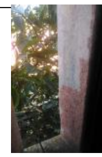
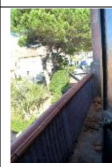
possibility of earthquakes of greater intensity and different directions, three active reinforcements of the structure were considered which aim to improve the overall behavior of the structure in the face of seismic action [24 – 26]

Waterproofing the façades at ground level by consolidating the foundations and stabilizing the slopes (widening the foundations and reinforcing the connections between masonry walls and due to the water table making a ground floor slab on floor -1 with widening of the foundations through foundation lintels.

Covering up the existing openings in the masonry wall on floor -1, with the execution of support walls connected to the foundation lintels, up to the HEB 300 strapped metal profiles, placed under the existing wooden slab, so that they act as reinforcement for the existing wooden slab, and unload the structure's stresses on the foundation reinforcement lintels.

Reinforcement of the interior of the wooden floor with metal profiles for better resistance to seismic action and to prevent the wood from ageing due to excessive loads [17 – 29].

Pathology of the building's exterior									
Ref	Type of Anomaly	Description	Level of degradation	Minimum intervene	Severity	Photo	Possible causes	Corrective Measure/Repair	Observations
1	Efflorescence / Cryptoflorescence	Whitish stains on the walls. Mould and fungus growth.	Medium	Superficial reparation	I		Crystallization on the surface of the parameters of soluble salts, usually sodium, potassium or magnesium sulphates contained in the materials supporting the cladding. Infiltration from the ground, humidity.	Eliminate the causes of water infiltration. Creating an efficient capillary cut between the foundations and the wall or support. Drying the coating and removing the salts formed by dry brushing.	Non-Structural
4	Efflorescence / Cryptoflorescence	Whitish stains on the walls. Mould and fungus growth.	Medium	Local reparation	II		Crystallization on the surface of the parameters of soluble salts, usually sodium, potassium or magnesium sulphates contained in the materials supporting the cladding. Infiltration from the ground, humidity.	Eliminate the causes of water infiltration. Creating an efficient capillary cut between the foundations and the wall or support. Drying the coating and removing the salts formed by dry brushing.	Non-Structural
5	Support cracking	Large, deep cracks, usually with relative displacement of the edges, forming a wide mesh.	High	Integral reparation	III		It can occur on substrates with low mechanical resistance, application of a coating with too high a tensile strength, stiffness and shrinkage, unsuitable for this type of substrate.	Replacing damaged elements and applying a coating with suitable characteristics. Application of a coating that is independent of the substrate and capable of ensuring the overall watertightness of the wall, if the wall does not perform.	Structural
Patology of the Building interior									
6	Biodeterioration Profile corrosion	Algae, Mosses, Lichens, Fungi, Plants, Rust	Medium-High	Integral reparation	IV		Prolonged presence of humidity Lack of ventilation Bacteria causing metal corrosion, reduced cross-section and loss of structural strength	Total replacement of the metal profiles due to their state of degradation and loss of resistance	Structural
7	Cracks	Large and deep cracks, with deformation in the opening of the slab, for access to interior stairs.	Medium	Local reparation	II		Cracking of the support or deformation of structural elements (usually beams or slabs) transmitted to the masonry.	Extraction of the element up to the support of an area of coating that surrounds the degraded area, then new application of the same product, but reinforced with a fiberglass mesh or galvanized metal mesh.	Structural
12	Support cracking	Extraction of the element up to the support of an area of coating that surrounds the degraded area, then new application of the same product, but reinforced with a fiberglass mesh or galvanized metal mesh.	High	Integral reparation	III		It can occur in substrates with low mechanical resistance, the application of a coating with too high a tensile strength, stiffness and shrinkage, unsuitable for this type of substrate.	Replacing the damaged elements and applying a coating with suitable characteristics. Application of a coating that is independent of the support and capable of ensuring the overall watertightness of the wall, if the wall does not perform.	Structural

V. Conclusion

Based on the exhaustive survey of anomalies, a qualitative assessment of the structure was carried out, based on the classification of levels of degradation according to the cause. These levels are defined in a semi-empirical way, without having numerically defined boundaries, and it is sometimes difficult to distinguish between the different levels.

The grading of construction anomalies is based on on-site expert observation, so there is a subjective factor that should be minimized whenever possible through inspection tests using the appropriate instruments and, if necessary, accredited laboratories. As a result of this work and the structural analysis carried out, it can be concluded that the building can withstand bending and compression. With regard to seismic actions, structural and non-structural reinforcement will have to be carried out to resist tensile and shear forces.

In short, the work reflects the entire learning process that was transmitted and applied during the postgraduate course, based on consultation of the bibliography provided and recommended, dissertations, technical articles and using a structural calculation program SAP 2000 v.16 to carry out the structural modeling of the building and verify that the interventions to be carried out are compatible with the existing structure. It turned out that it was possible to opt for much more sustainable and economical solutions, while retaining many of the original materials.

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