Visual assessment and diagnosis of a timber railway station warehouse in Foz do Tua

Hélder S. **Sousa** [1] [*]; Jorge M. **Branco** [1]; Catarina V. **Silva**[1]
[1] Department of Civil Engineering, ISISE, University of Minho, Portugal

[*] corresponding author: ISISE, University of Minho; Dept. Civil Engineering, Azurém, 4800-058 Guimarães, Portugal; e-mail: sousa.hms@gmail.com

ABSTRACT

Aiming at the rehabilitation of a timber warehouse in the Tua train station for a new use, it was necessary to assess the level of conservation of the building's elements and determine if intervention measures were required. This work sums the assessment made to the timber elements obtained by visual inspection and non-destructive testing. The main results, obtained in the diagnostic survey, were the conservation level of the timber warehouse, the visual strength grading of the timber elements and damage maps indicating the main pathologies and its probable causes.

KEYWORDS:
timber warehouse, train station, visual inspection, non-destructive tests

1. INTRODUCTION

In the beginning of the railway, main buildings and bridges were built of wood as construction had to be achieved at low costs and in a short time. Nowadays, a significant legacy of the railway expansion through Europe are timber constructions that subsisted through the 19th and 20th centuries, some still operational. In this work, a diagnostic survey was done to the timber elements of a train station warehouse), to assess its conservation state and need of intervention regarding a new use, namely the construction of a museum. The objective is to catalogue damages found in the timber elements and its source as to define if they may be reused, have to be repaired or even replaced.

Visual grading is the first step for timber on-site assessment and non-destructive tests (NDT) are considered as a means to decrease its subjectivity and to obtain a more reliable prediction

of the level of conservation and mechanical performance of the structural members (Cavalli and Togni, 2013; Cruz, *et al.* 2015; Feio and Machado, 2015). Depending on the scope of the analysis diverse NDT can be used with different capabilities and limitations (Riggio et al. 2016; Tannert et al. 2014). In this work, visual inspection complemented by moisture content measurements and impact penetration tests were considered. In this phase, only a surface analysis was required as it was only intended to identify damaged and decayed elements, where intervention could be needed. In a future analysis, regarding the structural analysis of the building and choice of intervention, other NDT may be considered as to assess the residual cross-section of the elements, as well as its correlations to timber's mechanical properties (Calderoni et al. 2010).

2. BUILDING'S CHARACTERIZATION

The timber warehouse is located at Tua train station (Portugal) built in late 18th century. The warehouse was used as a deposit for train cargo and machinery and it is almost completely made of timber (Figure 1), with the exception of the granite masonry foundation and of the roof cover.

Figure 1: Timber warehouse: a) main façade and lateral façade oriented to the railways; b) view of the roof by the interior.

The roof is covered by ceramic tiles and supported by seven timber trusses distanced 3.80 m from each other. The trusses have a double tie beam, a single post and diagonals that are connected to the timber columns. The diagonals coming from the interior of the building connect the rafters to the column at a distance of 1.15 m below the level of the tie beam, whereas the diagonals coming from outside of the walls of the building connect the rafters to the column at a distance of 1.95 m below the tie beam. The distance between connections of the rafters to the column is 80 cm (Figure 1.b). The walls are made of timber vertical cladding with 3 cm thickness.

The different timber elements are made of pine (*Pinus pinaster* Ait.) and were treated with creosote. The elements have constant rectangular cross-section and repetition of structural modules is noticeable. The main connections between elements are made by metal dowels and carpentry joints.

3. METHODS

3.1. Visual inspection

During visual inspection to a timber structure, natural defects and deterioration are detected and inventoried. After, a visual grading is made based in the size, number and location of defects related to the timber member's size and structural use. In this work, UNI 11119 (UNI, 2004) was used taking into account its applicability for visual grading of structural wood elements in cultural heritage buildings. For visual strength grading of an element, this standard considers three classes (I, II, III) and provides indicative values for strength and stiffness properties. The element is from a given class if it fulfils all imposed requirements. The strength values are to be used within a deterministic permissible stress design, thus are not the characteristic values commonly used for a semi-deterministic partial safety method. However, for similar visual grades provided in UNI 11035-2 (UNI, 2010), and considering other species of conifers, the visual grades are roughly comparable to strength classes between C22 and C30 (CEN, 2009).

3.2. Columns' deformation

Columns' deformation was measured by the distance between columns of the same truss (sections 1 to 4) and by the measurement of the inclination with the vertical axis (points 2 and 4) (Figure 2).
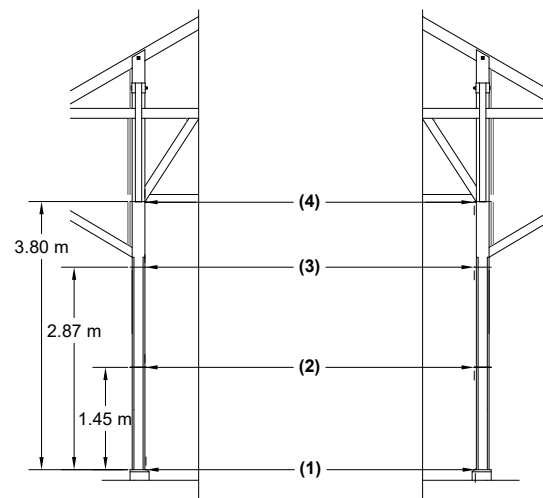

Figure 2: Location for measurement of the columns' deformation.

3.3. Non-destructive tests

3.3.1. Moisture content

Moisture content was measured by an electrical resistance hygrometer. Measurements were made at all columns at a height of 1.45 m, as to assess different levels of climate exposure between façades, either facing the railway or the river, without influence of rising damp. Moreover, critical zones where rising damp and water accumulation could be expected (e.g. elements on ground contact, connections, elements near the roof cover) were also assessed, as to verify if there were any favorable conditions to the presence of biological decay.

3.3.2. Pin penetration tests

Pin penetration tests consist of releasing a steel pin of a fixed diameter into the material by a dynamic force. The penetration depth is inversely proportional to wood's density (Görlacher, 1987) and is also used as a measure to detect different levels of degradation (Hasnikova and Kuklík, 2013; Sousa *et al.*, 2014). In the case of *Pinus pinaster*, Notivol *et al.* (1992) found a strong correlation (-0.73) between pin penetration depth and wood density for 34 years old specimens. However, as stated by Bouffier *et al.* (2008), these tests may not be a reliable for wood density assessment of young *Pinus pinaster* trees.

In this work, a Pilodyn 6J was used and measurements were made on all columns near the granite blocks foundations and at 1.45 m height. To each section, five measurements were made from which the maximum and minimum values were disregarded and an average value was taken from the remaining three, as to minimize the effect of local defects. Measurements were also made to one section of each rafter and tie beam (near the bottom end of the elements).

4. RESULTS

4.1. Visual inspection and grading

4.1.1. Timber columns

The columns presented similar state of conservation. The columns did not present signs of decay, however they evidenced humidity stains in the lower sections near the foundation. The cross section was regular and without wane, however, localized crushing of the wood fibers was visible near the foundation blocks, due to the inclination of the columns. Small diameter knots were found along the extent of the element with diameters lower than 45 mm. The orientation of fibers regarding was 14.0%. According to the visual inspection, the timber columns were graded as class III.

4.1.2. Timber trusses

The timber elements that compose the trusses presented mostly small size isolated knots Small cracks were detected near the connection to the columns due to stress concentration, as well as cracks in the diagonals resulting from restrained shrinkage. The cracks extension and depth were minor and the edges of the cracks were not sharp or clean evidencing that they corresponded to old cracks that had already stabilized. The state of conservation is comparable to the columns and visual grade III was attributed.

4.1.3. Timber cladding

The timber cladding elements were more deteriorated than the other timber elements, due to its direct exposure to the climate agents. With exception of localized damage on the cladding planks in ground contact, they were still providing an adequate performance for isolation and wind load distribution. Damage mainly consisted in humidity stains, surface decay by fungi and biological colonization, as well as broken elements. The timber cladding presented larger knots and higher slope of grain compared to the timber columns and roof elements. Visual grading based on UNI 11119 (UNI, 2004) was not considered as they are not load-bearing structural elements.

4.1.4. Damage mapping

Damage maps were made for each façade (exterior and interior) with indication of location, severity and possible source of each damage, complemented with a photographs.

The damage map for the front façade (Figure 3), evidences the presence of humidity in the roof elements and in the ground walls, as well as broken elements. High level of decay was found on a purlin connected to the façade truss, due to water accumulation resultant caused by incorrect position of the roof tiles. It was also observed that the cladding was decayed at the base of the building, due to rising damp, also evidencing warping and splitting due to the water content variation.
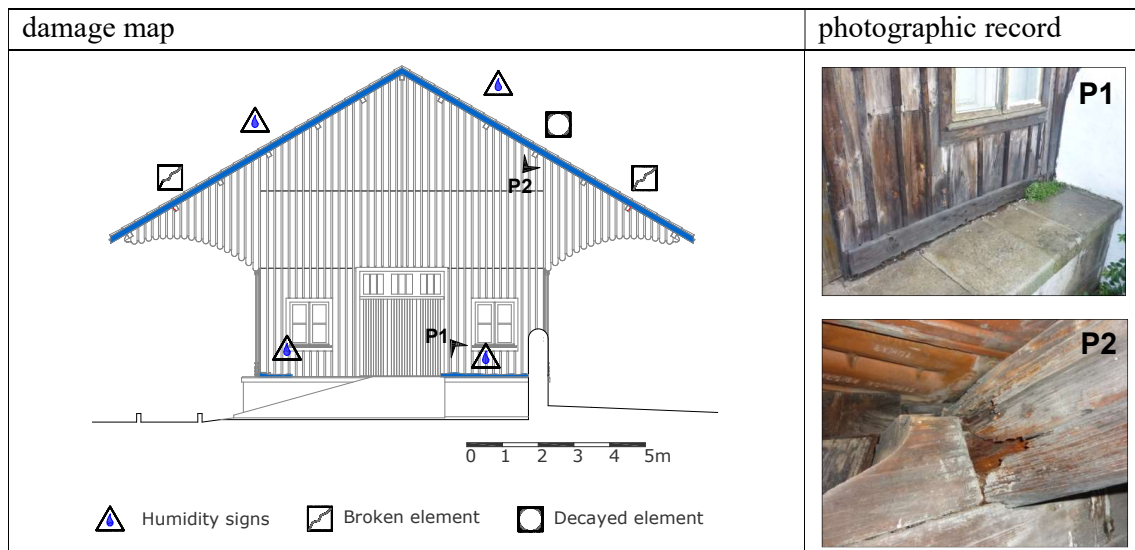

Figure 3: Damage maps for the front façade (exterior).

The damage map for the lateral façade facing the river is presented in Figure 4. Localized crushing of the wood fibers on the base section of the columns was visible. This damage resulted from the deformation of the timber columns, leading also to end splits associated to perpendicular to the grain stresses. More detail on the type of cracks can be obtained in Franke *et al*. (2015).

Drying cracks were detected in the diagonals, as well as cracks in elements with pit misaligned with the longitudinal axis. Drying cracks were not considered structurally significant as their depth was minor. However, the presence of pit in a structural element is a parameter that often leads to downgrading in a visual grade.

The cracks found in the lintels of the lateral doors were caused due to stress concentration in the segment where a metallic dowel was introduced (used for supporting the door). These used based cracks occurred by bending failure evidencing rupture of the fibers in the tensioned zone and kink bands on the compression zone (Franke *et al*., 2015).

Evidences of damaged cladding and signs of humidity (discoloration) in both cladding and columns were visible at the base section of the building.
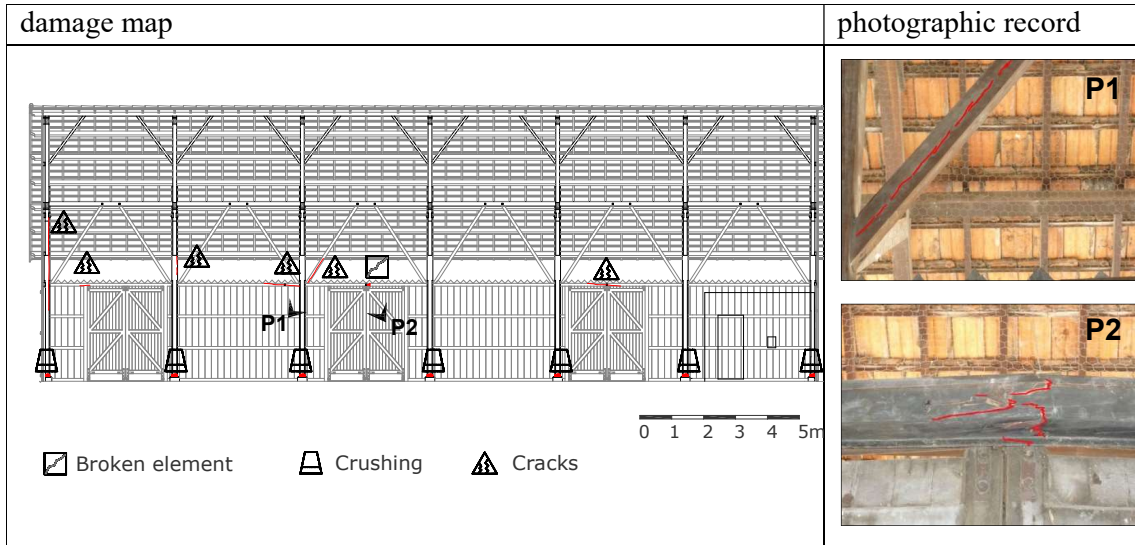
damage map	photographic record

☑ Broken element   ⊓ Crushing   ⚠ Cracks

Figure 4: Damage map for the lateral façade (facing the river, interior).

4.2. Columns' deformation

Regarding the distance between columns supporting the same truss (Figure 2), it was found that an average value of 7.60 m is found at level 1. However, columns are inclined to the interior of the building, being distanced in average less 9 cm at level 2 and less 15 cm at levels 3 and 4. Inclination of the columns was more significant on the railway line façade. Also on that façade, the columns had the same inclination direction along its height with a small decrease in inclination from the bottom ($\alpha1$) to the top measurements ($\alpha2$) with mean values of 2.4º and 0.5º, respectively (Figure 5.a). Meanwhile, for the façade facing the river, the columns had two inclination directions, with mean values of 1.0º and 0.7º, respectively for $\alpha1$ and $\alpha2$ (Figure 5.b). In both cases, the inflection point is located at the connection of the exterior diagonal with the column. On the longitudinal direction of the warehouse, measurements were made to assess the deformation of the columns and no significant inclination was found in that direction.
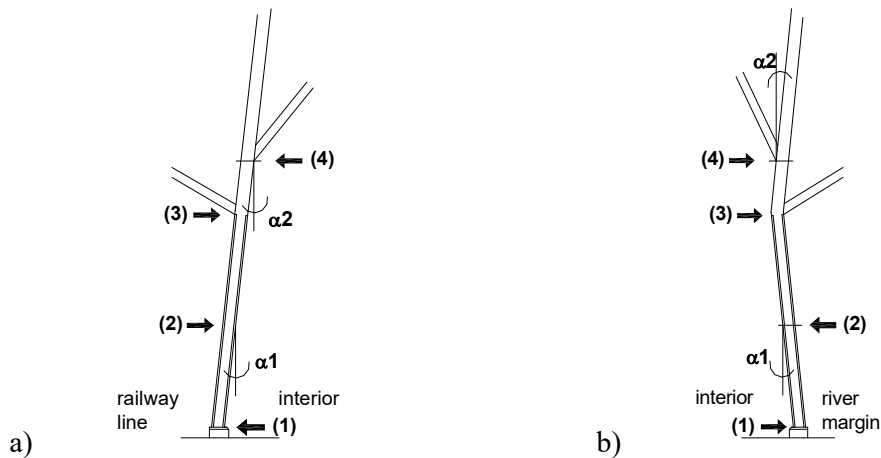

Figure 5: Representation of columns' deformation, facing: a) railway line; b) river margin.

4.3. Non-destructive tests

4.3.1. Moisture content
Moisture content measurements made on all columns ranged between 13% to 17% with mean value of 14.7% and coefficient of variation of 6.7% (14 measurements). The moisture content results obtained for the columns in the façade facing the river had a 0.7% higher value than those facing the railway line. Measurements made to the bottom of the columns and to elements on ground contact obtained values up to 21%, whereas values up to 24% were found for critical sections of the roof, namely the connection between purlins and the front and back façades. As moisture content values above 20% present favorable conditions for decay progress, these sections were identified in the damage maps.

4.3.2. Pin penetration tests
The pin penetration tests, made at a height of 1. 45 m, were made in sections of the columns where decay was not found as to obtain reference value for qualitative assessment of the level of decay in critical decayed sections. A mean penetration depth of 8.6 mm was found for that height with an average increase of 1.1 mm at the ground level, indicating a lower superficial resistance on those sections resultant from moisture induced damage.

Different elements of the timber roof trusses were also tested with mean penetration depth values ranging from 7 mm to 8 mm, thus consistent with the same state of conservation as the columns. In this work, pin penetration tests were made to qualitatively complement the visual grading, and there was no correlation made with density of the element or other mechanical property.

5. DISCUSSION OF RESULTS
Although the overall good state of conservation of the timber elements, visual inspection and pin penetration tests allowed to find localized decayed sections. Both methods are limited to the evaluation of the surface of the elements but allowed to qualitatively identify different levels of conservation within and between the timber elements. The roof trusses did not present deformations and were in a good state of conservation with exception of the trusses in contact with the façade walls which presented local deterioration due to higher exposure to the climate conditions

The timber columns presented a slight inclination towards the interior of the building. This inclination led to crushing of the timber fibers on the columns supports and end splits induced by perpendicular to the grain stresses. Inclination of the columns was caused by an eccentricity between connection points of the diagonals and the column, which introduced significant localized bending stresses. Cracks found along the timber elements were mainly due to moisture induced effects (drying and shrinkage). However, were considered not relevant for the global structural behaviour of the analyzed structure. Significant cracks were found in the door frames due to bending failure caused by the presence of a metallic dowel that supported the doors' locking system.

The timber cladding, due to its larger exposure, presented higher levels of decay specially at the base level, where moisture induced damages were visible. The bottom of the columns also presented humidity stains due to rising damp and due to the contact with the lower boards of

the cladding. Decay was found in roof elements (purlins) in zones where water accumulation occurred due to poor maintenance of the roof (misplaced or broken tiles). Taking into account the results from the visual inspection and diagnosis made to the warehouse, it is found that the structure may be maintained if no modifications are made to the use of the building or no significant loading is introduced. Regarding localized damages, elements from the timber cladding in contact with the ground must be replaced, whereas repair of the doors lintel from the lateral façades must be considered. Furthermore, there is need to consider a timber prosthesis for the end section of a purlin, which had loss of cross-section due to severe decay. Due to the state of conservation of the columns, it is recommended to determine if it is necessary to strengthen or replace those elements, due to its deformation and damage at the base sections. This analysis should comprise the numerical modeling of the structure regarding its current level of deformation and assuming the increment of load expected for the intended new use. In any case, the connection between columns and the granite foundation blocks should allow for an impermeability solution and the broken tiles should be replaced in order to avoid further local moisture induced damages.

Due to the subjectivity inherent to a visual inspection, pin penetration tests were made to qualitatively define different levels of decay allowing to signalize those critical sections in damage maps. In this phase, only a surface analysis to the elements was required as it was intended to identify critical damaged and decayed elements. In order to obtain a safety level for the structure and verify its suitability for a new use, the results of the diagnosis described in this work may be complemented with information from other non-destructive methods, such as drilling resistance tests, to better assess the residual cross-section and with removal of small size specimens for mechanical properties determination.

6. CONCLUSIONS

In this work, a diagnostic survey based on visual grading and on impact penetration tests was made to a timber warehouse located in the Tua train station, aiming at the definition of possible reuse of the existing timber elements and structure. Based on the visual inspection results, damage maps were made with indication of the location, severity and possible source of each different damage, proposing recommendations for intervention where needed.

From the inspection and diagnosis made to the Tua railway warehouse it is noted its overall good state of conservation both in terms of the individual timber elements as well as the global structure.

In this work, it was found that visual inspection should be complemented with other NDT as to qualitatively assess the level of conservation within and between elements, thus enabling to identify and characterize different critical sections in a damage map. This method may be extended to other historical structures made in timber or other materials.

ACKNOWLEDGEMENTS

REFERENCES

artmetro, arquitetos associados (2011) Centro Interpretativo da Memória do Vale do Tua drawings, Architecture School Study Centre of University of Minho, Guimarães.

Bouffier, L., Charlot, C., Raffin, A., Rozenberg, P., Kremer, A. (2008). Can wood density be efficiently selected at early stage in maritime pine (Pinus pinaster Ait.)?. Annals of Forest Science, 65(1).

Calderoni, C., De Matteis, G., Giubileo, C., Mazzolani, F.M. (2010). Experimental correlations between destructive and non-destructive tests on ancient timber elements. Engineering Structures, 32(2), 442-448.

Cavalli, A., Togni, M. (2013). How to improve the on-site MOE assessment of old timber beams combining NDT and visual strength grading. Nondestructive testing and evaluation, 28(3), 252-262.

CEN (2009) EN 338:2009. Structural timber – strength classes. CEN European Committee for Standardization.

Cruz, H., Yeomans, D., Tsakanika, E., Macchioni, N., Jorissen, A., Touza, M., Mannucci, M., Lourenço, P.B. (2015). Guidelines for the on-site assessment of historic timber structures. International Journal of Architectural Heritage, 9(3), 277-289.

Feio, A., Machado, J.S. (2015). In-situ assessment of timber structural members: Combining information from visual strength grading and NDT/SDT methods–A review. Construction and Building Materials, 101, 1157-1165.

Franke, S., Franke, B., Harte, A.M. (2015). Failure modes and reinforcement techniques for timber beams–State of the art. Construction and Building Materials, 97, 2-13.

Görlacher, R. (1987). Non destructive testing of wood: an in-situ method for determination of density, Holz as Roh-und Werkstoff, 45, pp. 273-278.

Hasnikova, H., Kuklík, P. (2013). Investigation of Timber Members at the Marasyk Station in Prague by Non-Destructive Methods. Advanced Materials Research, 778, 243-249.

Notivol, E., Gil, L. A., Pardos, J.A. (1992). Wood specific gravity and variability estimation in Pinus pinaster Ait. trees. Forest Systems, 1(1), 41-47.

Riggio, M., Macchioni, N., Riminesi, C. (2016). Structural health assessment of historical timber structures combining non-destructive techniques: The roof of Giotto's bell tower in Florence. Structural Control and Health Monitoring, doi:10.1002/stc.1935.

Sousa, H.S., Branco, J.M., Lourenço, P.B. (2014). Characterization of Cross-Sections from Old Chestnut Beams Weakened by Decay. International Journal of Architectural Heritage, 8(3), 436-451.

Tannert, T., Anthony, R.W., Kasal, B., Kloiber, M., Piazza, M., Riggio, M., Rinn, F., Widmann, R. Yamaguchi, N. (2014). In situ assessment of structural timber using semi-destructive techniques. Materials and structures, 47(5), 767-785.

UNI (2004). UNI 11119:2004 Cultural Heritage - Wooden artifacts - Load-bearing structures - On site inspections for the diagnosis of timber members. UNI Milano.

UNI (2010). UNI 11035-2 Structural timber. Visual strength grading rules and characteristic values for Italian structural timber population. UNI Milano.