An experimental approach to the treatment and consolidation of degraded timber elements from a XIX century building

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Abstract This paper presents the *in situ* experimental conservation work performed on three timber structural elements from a XIX century building: two floor beams and one roof beam. This palace was built in 1877 in the centre of Lisbon initially with residential purposes. It has four floors, with timber structural horizontal elements, stairs and roof beams (generally of *Pinus sylvestris*). The exterior walls are made of irregular stone masonry bedded on mortar, rendered and painted.

Keywords wood, buildings, degradation, consolidation

1. INTRODUCTION

1.1. General information

This paper presents the *in situ* experimental conservation work performed on three timber structural elements from a XIX century building: two floor beams and one roof beam.
This palace was built in 1877 n the centre of Lisbon initially with residential purposes. It has four floors, with timber structural horizontal elements, stairs and roof beams (generally of *Pinus sylvestris*). The exterior walls are made of irregular stone masonry bedded on mortar, rendered and painted.

Figure 1 – Palace Ribeiro da Cunha, Lisbon, Portugal

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The building has been vacant since 2003 but remains in a reasonable conservation state. In terms of the timber elements condition some disperse and superficial degradation by wood-worm can be found as well as some fungal degradation in specific areas. This particular degradation results mainly from water leakage points in the roof and façades and also from the rupture of a pipe from the domestic water system.

Figure 2 – Details of rotted timber *in situ*.

Three sections of timber structural elements (*Pinus sylvestris*) moderately degraded by fungi and thought to be recovery-prone were subjected to consolidation by impregnation with an epoxy-based product, combined with the previous application of a biocide. In every case the degradation was located in a small part of the element with an extent generally lower than 80 cm.
Indeed when timber elements are moderately degraded by fungi, assuming underlying moisture problems are solved and the wood is treated with adequate preservatives, the degraded elements need to be consolidated so that the timber keeps on fulfilling its structural and decorative functions.
As a preservative a boron water-based commercially available biocide product was used. The consolidation product was also a commercially available epoxy-based bi-component with low viscosity, specific for impregnation of rotten timber. The compatibility between these products when applied sequentially in timber had previously been evaluated by the authors, both for new and artificially aged timber (Henriques *et al,* 2010b). In that study it was found that the performance of the epoxy product as consolidant remains practically unchanged in timber previously treated with boron.
The evaluation of the performance of the consolidant was made *in situ*, given the fact that it is neither possible nor desirable to move the elements to laboratory premises. The consolidation efficacy was checked using non-destructive tests performed with the *Pilodyn*® and *Resistograph*® apparatus, before and after the application of the products. The ability of these equipments for the estimation of timber properies was previously cheked (Henriques *et al*, 2011).
The performance of the biocide itself was not evaluated since the efficacy of boron as a wood preservative is well established. Through non-destructive tests an increase of the consolidation effect on the degraded timber elements, promoted by the consolidation product used, was detected.

2. WORK PLAN

2.1. Selection of sites

Within the building three replicate test sites (Pavement 1, Pavement 2 and Roof – Figure 3) were selected each with three elements that would be tested: (A) one showing early rot symptoms (B) one heavily rotten, for comparison, and (C) one apparently sound as control. In Pavement2 only two elements were tested as no sound wood was available.

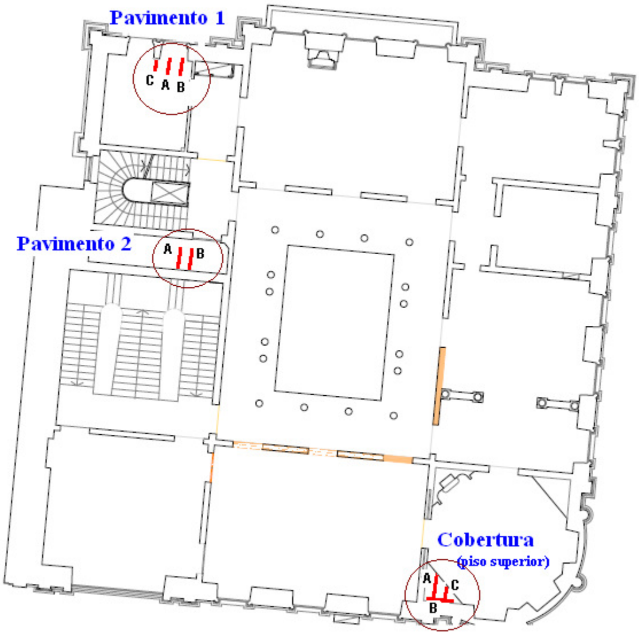

Figure 3 – Test areas where treatment and consolidation was conducted (plan: East Banc).

2.2. Pavement 1

Area located near one of the many exterior windows (Figure 4). The probable cause of degradation (cubic rot) was the deficient performance of the window and consequent water entry. These anomalies have been repaired and the moisture content of the timber seems to be stable again. To gain access to the three tested beams some floor boards had to be removed.

Figure 4 – Pavement1 – Location of the floor beams where treatment and consolidation was conducted.

2.3. Pavement 2

Interior area of the building used for sometime as bathroom but lately adapted to storage room. The wooden floor had a vinyl cover. Due to the use as bathroom and the vinyl layer that kept moisture in the wood, the floor beams were either degraded or severely degraded (cubic rot). Only two beams were tested as it was not possible to identify an element that could be considered as sound (Figure 5).

Figure 5 – Pavement2 - Location of the floor beams where treatment and consolidation was conducted.

2.4. Roof

The third area identified (Figure 6) was in the roof and was circumstantially exposed to water leakage due to the blockage of the exterior water drainage system. The incoming water problem was solved and the elements were again dry and stable though showing some degradation (cubic rot).

Figure 6 – Roof - Location of the roof beams where treatment and consolidation was conducted. (A) “low” degradation; (B) “high” degradation and (C) sound

3. TREATMENT AND CONSOLIDATION

After selection, the elements were cleaned and visually inspected. Non-destructive tests with the *Pilodyn*® and *Resistograph*® apparatus were conducted as well as moisture measurements. This was followed by timber treatment, consolidation and second series of tests with *Pilodyn*® and *Resistograph*®.
The treatment product (a boron-based aqueous solution) was selected according to criteria of low toxicity for mammals, ease of application, good absorption capacity and permanence in indoors timber, and biocide efficiency (Obanda *et al* 2008). The impregnation depth achieved by such a solution applied to timber from an old building previously treated with an unknown product was previously studied by the same authors, having led to satisfactory results (Henriques *et al.* 2010a) and the compatibility to consolidant E was also known (Henriques *et al*. 2010b).
The product used (BC) has as active ingredients sodium oxide (14.70%) and boric oxide (67.10%) and water as solvent. The product was applied by brushing with repeated applications after cleaning of the timber surface (Figura 7a).
Consolidant E was applied 12 days after treatment when moisture content of the treated timber was back to the equilibrium moisture level. The resin and hardener mixture was done in situ (Figure 7b)

and the ambient temperature was 19ºC ± 2ºC. Repeated applications of the consolidant were done until the wood was clearly not absorbing more product (Figures 7c,d).
During the intervention, local temperature was registered and varied between 17º and 20ºC. Pavement 1 had the highest variation due to closer contact with the exterior walls.
Due to product limitation, consolidation was done exclusively on beams A that were moderately degraded and as such the target of this work.

a. Application of treatment product (Pavement1).

b. Mixing of consolidant components

c. Application of consolidant (Pavement2)

d. Application of consolidant (Roof)

Figure 7 – *In situ* application of treatment and consolidation products

4. NON DESTRUCTIVE TESTS

The evaluation of the physico-chemical characteristics of timber by NDT were done, as previously referred, using the *Pilodyn*® and *Resistograph*® apparatus (Figure 8) and moisture measurements were done whenever relevant with a contact moisture meter. The ability of the NDT equipments to perform these evaluations has been object of previous studies (Henriques et al. 2011) and the same procedure was applied here.

a. *Pilodyn* test in roof beam

b. *Resistograph* in Pavement2 beam

Figure 7 – *In situ* testing of elements

4.1. Pavement 1

In Pavement 1, three beams were tested. Beam A was initially involved by white fungal mycelia with the typical cubic rot damage visible on one of the faces. Further inspection and surface cleaning of the mycelia revealed that the beam seems to be less degraded than might be expected from a swift visual evaluation. The initial measurement done with *Pilodyn*® and *Resistograph*® apparatus were very close to the “control” values of Beam C with no apparent fungal degradation.
The values obtain for Beam C in terms of density, 500 and 550 kg/m^3, were comparable with those obtained in laboratory for clear specimens of the same species even though the moisture content was lower *in situ* (Henriques *et al.* 2011). Beam B was the more degraded tested element though with a still recognizable less degraded core section.
Resistograph® measurements and, to some extent also *Pilodyn*® results, put into evidence the observed initial differences between the beams. After treatment and consolidation, both values from Beams A and B were closer to the control Beam C, therefore confirming the consolidation effect under test.

Table 1 – Pavement 1 - Physical and mechanical measurements of beams A, B and C

	Beam A (“low” degradation)		**Beam B (“high” degradation)**		**Beam C (sound control)**	
	Initial	**Treated and consolidated**	**Initial**	**Treated and consolidated**	**Initial**	**Treated and consolidated**
Moisture content (%)	9,0	9,0	8,0	8,5	8,5	-
Resistograph®	10,8	11,1	8,2	11,6	11,7	__
Pilodyn® (mm)	19,7	18,2	37,3	27,1	16,6	__
Dimensions	9 x 22 cm		8 x 21 cm		8,5 x 21 cm	
Photos before cleaning						

4.2. Pavement 2

As referred, in Pavement 2, only two beams (low and high degradation) were tested as it was not possible to identify in this area an element that could be considered as sound. Reference control values from Beam C in pavement 1 were also used here for comparison.
Both tested beams showed by visual inspection a higher degree of degradation than the ones of pavement 1 and that was supported by the NDT measurements.
In the case of Beam A, the consolidation had a clear positive impact as shown by the high increase in the resistographic measurement.

Table 2 – Pavement2 - Physical and mechanical measurements of beams A and B

	Beam A ("low" degradation)		**Beam B ("high" degradation)**	
	Initial	**Treated and consolidated**	**Initial**	**Treated and consolidated**
Moisture content (%)	9.5	9.0	8.0	-
Resistograph®	9.1	12.3	6.0	-
Pilodyn® (mm)	24.4	19.1	38.1	-
Dimensions	8 x 22 cm		8.5 x 20 cm	
Photos after cleaning				

4.3. Roof

Unlike the pavement beams, roof elements did not show rot fungi mycelia on the surface but only some symptoms of their action. The moisture content of the selected beams was low and not supportive of fungal degradation.
It was assumed that degradation occurred some time ago and the source of moisture has been meanwhile found and solved. Moisture content of selected beams was far below safety values considered for use class 2 (EN335-2, 2006). Beam B had the lowest moisture content.
Beam A had no major section losses. However, it was possible to detect degradation in some areas, by visual inspection. Non destructive tests confirmed the existence of degradation, although in a low level. Beam C was well squared, which is characteristic of sound beams. Average values of resistance to drilling and impact indicated, by comparison with previous laboratory testing (Henriques *et al.*, 2011), an estimated density of 450 to 500 kg/m^3.
Again in the roof beams, *Resistograph®* measurements and, to some extent also *Pilodyn®* results showed a reasonable increase, mainly of the surface resistance, of the degraded timber.

Table 3 – Roof - Physical and mechanical measurements of beams A, B and C

	Beam A ("low" degradation)		**Beam B ("high" degradation)**		**Beam C (sound control)**	
	Inicial	**Treated and consolidated**	**Inicial**	**Treated and consolidated**	**Inicial**	**Treated and consolidated**
Moisture content (%)	9.5	9.0	7.0	-	9.0	-
Resistograph®	9.4	11.1	5.8	-	10.3	-
Pilodyn® (mm)	19.3	18.4	34.3	-	18.0	-
Dimensions	6.5 x 14 cm		7.5 x 16 cm		8 x 14 cm	
Photos before cleaning						

5. CONCLUSIONS

Visual inspection together with *Resistograph®* measurements performed in a previously reported case study (Henriques *et al.* 2008) and the work presently reported confirmed the applicability of this second technique to verify *in situ* several relevant properties of wood. *Pylodin®* also reveals to be an interesting, though not as relevant, tool of inspection.

Biocide treatment followed by *in situ* consolidation, which are necessary actions to the conservation of degraded wood in service, were successfully performed in three differently located beams (use class 2 of biological attack, EN335-2, 2006) at the Palace Ribeiro da Cunha.

A reasonable increase of mechanical resistance was observed either by visual inspection and also by NDT. Both drilling resistance tests results (obtained by *Resistograph®*) and impact resistance tests (obtained by *Pilodyn®*) showed an increase of mechanical performance of degraded beams surface, after biocide treatment and *in situ* consolidation, in comparison with the same tests performed previously.

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