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Improvements in Conservation and Rehabilitation – Integrated Methodologies

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PROCESSES OF TIMBER CONSERVATION AND CONSOLIDATION

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ABSTRACT

In the present paper a solution is developed to deal with timber in old buildings, moderately degraded by rot fungi and although not fully sound, have enough load-bearing capacity and should be maintained. The solution involves traditional methodologies used in the area of conservation and restoration of wooden artworks and is especially relevant to timbers in heritage buildings. It consists in the sequential application of a biocide product and a consolidant by impregnation. The efficiency of the proposed solution is tested with destructive and non-destructive laboratory and in situ tests.

INTRODUCTION

Built heritage is a non-renewable asset. Indeed, there are several cases of heritage buildings in an advanced degree of degradation that are lost every day, with the ensuing loss is historic, artistic and cultural value. This study is presented to invert this tendency. It addresses *Pinus sylvestris* L wood, with an age between 100 and 200 years, mediumly degraded by fungi. It is presented and testes a solution for the restoration of timber elements, with a mass loss lower than 20%. This value is considered a limit for the success of the interventions, because it roughly correspondents to the mechanical strengths considered in The C18 class (EN 338:2003) The methodology is based upon the application of a liquid preservation product, to alt the fungi activity, and subsequent consolidation by impregnation of the degraded elements with a low viscosity epoxy resin. Attention is draw to the fact that timber consolidation with impregnation products is a widely applied technique in conservation and restoration of works of art [1] but not much used in civil engineering [2]. However, Reinprecht, 2008 [3], and Henriques, 2011 [4] argue that the techniques used in this area can be applied in building components.

In fact, the contribution of biocide products, to cease fungi activity, and the subsequent use of acrylic or epoxy resins to consolidate degraded wood, has proven to be efficient in increase in strength of degraded wood, based on lab tests [5, 6]. The technical and economical repercussion that wood maintenance may represent should be noted. In fact, not only is built heritage preserved, but also a substantial saving is achieved.

It should be stressed that timber, as a construction material, may be considered one of the most durable [7, 8, 9, 10], as long as the environment conditions do not favour its biological degradation. However, enabled by humidity, the action of fungi, insects, bacteria and maritime organisms may result in the irreversible loss of mass and, as consequence, the structural failure

of the components [11, 12, 13]. It is thus essential to assess the conservation state and the real service condition of timbers in buildings.
However, on one hand the correct characterization of the physical-mechanical properties implies the use of destructive technique, such as bore sampling, on the other hand the conservation of built heritage and the preservation of patrimony implies the use of little invasive methodologies [4,14-17]. The present study includes laboratory testing, with destructive and non-destructive testing to evaluate the physical-mechanical efficiency of the applied treatment and consolidation products. It also includes non-destructive in situ tests, with the object of evaluating local degradation stage [15,14,18,19] and to evaluate the efficiency of the proposed treatment method. To that effect, a case study is presented, of a building built in 1877, in the centre of Lisbon, with *Pombalino* period construction techniques [20, 21]

MATERIALS AND METHODS

Samples

In the laboratory campaign, flawless sapwood samples of *Pinus sylvestris* L with 30 x 60 x 180 mm were used. The wood grain is parallel to the axis and the tops are flat and perpendicular to the faces. Samples were removed from several 100 to 200 year old buildings, to enlarge the scope of density and age, thus trying to represent wood in Lisbon buildings. O total of 34 samples were tested, with volumic masses between 400 and 700 kg/m3, calculated according to standard NP 616.1973, when stabilised at 12% of water content, this being the reference value.

Degradation in laboratory

Samples were degraded in lab with rot fungi. For this purpose a mixture of selected soils was used, and samples were placed in this mixture in an air-conditioned room at 80 ± 5% RH and 27 ± 2 ºC during seven to nine months, until the required degradation level was achieved, below 20% of mass loss. Soil preparation followed recommendations of standard DD CEN/TS 15083-2:2005. This methodology enabled the coexistence of several types of fungi, being close to real degradation conditions [22].

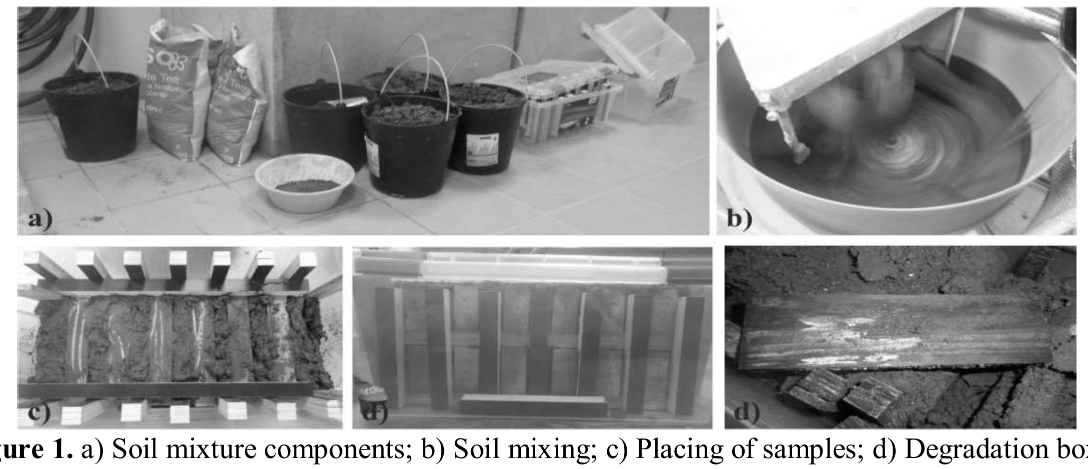

Figure 1. a) Soil mixture components; b) Soil mixing; c) Placing of samples; d) Degradation boxes; e) Degraded samples

Treatment and consolidation

The process consists in the initial application of a liquid preserver biocide, Bora-Care.
In a second stage, and after water content stabilisation, consolidant EPO155 was used. This is a fluid epoxy resins based solvent free product cold reticulated using a hardener. This couple of product was selected among others with a similar individual efficiency, because it proved to be the most mechanically effective [5, 6]
Both products were applied by brush. It is also possible to inject the product, whenever justifiable.

Resistograph – non-destructive testing

Resistograph is a drilling equipment with a drill bit up to 3 mm in diameter and a length varying according to the model. Its action can be considered non-destructive because it does not affect negatively the inspected elements. It allows for the reading of density profiles of the elements drilled, which can be stored in the internal memory or printed immediately in real size, enabling an analysis and the detection of internal defects and degradation situations.
Drilling resistance is registered each 0,04 mm. Because it was verified that degradation is greater at the surface and according to studies by Henriques, 2011 [4], the value of MR presented is the medium values of the readings in 15 mm, beginning at each end of the resistograph profile, excluding the first 2 mm (Fig.2), considered a perturbed zone. In the in situ measuring registering is made only at the element visible surface. MR is given by the expression (1) [23, 24, 25].

$$MR = \frac{\int_0^h \acute{A}rea}{h} \quad (1)$$

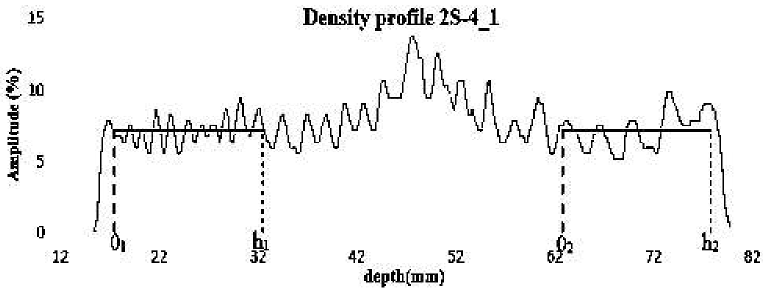

Figure 9. Treatment of a density profile

In the present study, a IML Resi-B-1280 (Fig.3 a) equipment was used, set at a penetration velocity of 20 cm/min.

Pilodyn® - Non-destructive testing

The dynamic impact method consists of introducing a metal pin (2,5 mm) in the timber with a given energy. Its result is based in the inverse proportion relation between the penetration depth at the hardness at the transversal direction [26, 27]. Penetration depth can be also a measure of the intensity and depth of the degradation [28].
In the present study a *Pilodyn®* 6J (Fig.3 b, c) was used, with a superficial reading depth scale (up to 40 mm).

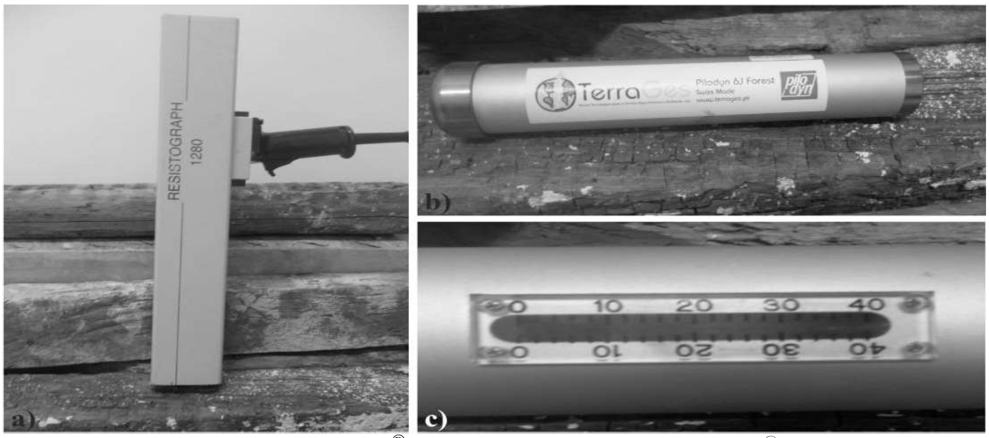

Figure 10. a) Test with Resistograph® IML Resi-B-1280; b) *Pilodyn*® 6J; c) Scale *Pilodyn*®

It should be noted that several studies [29, 23, 30, 31, 32] point to the possibility of correlations between test results with *Resistograph*® and *Pilodyn*® and the mechanical properties of the elements.

Compressive testing – destructive testing

The tests were carried out according to standard NP618:1973, by the application of increasing loads at a constant pace, until failure after about 3 minutes. Universal machine *Schimatzu* (Fig.2) was used, with the results being treated by the software *Trapezium2*® and the results presented in N/mm^2

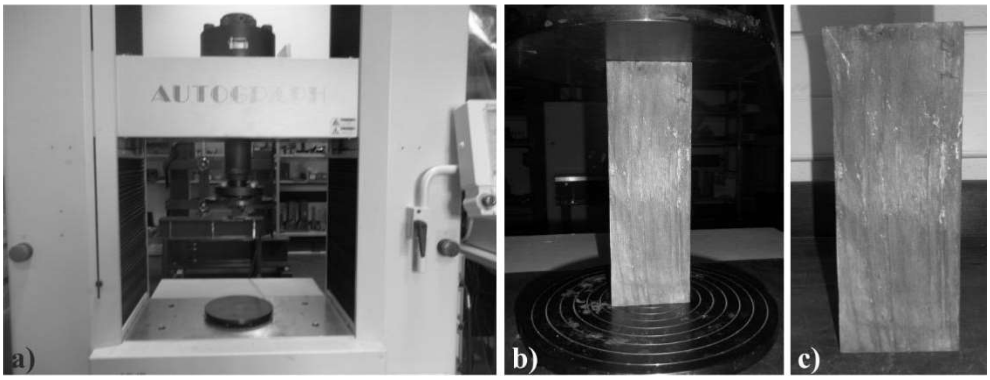

Figure 11. a) Testing machine Schimatzu; b) during test; c) After test

Static hardness test – destructive test

Static hardness tests (Fig.3) were carried out according to standard ISSO 3350:1975 – *Bois. Détermination de la dureté statique,* in the universal testing machine AMSLER with a capacity of 4000 kg. A sphere with a radius of 5,64 ± 1 mm was used, driven at a constant speed of 3 a 6 mm/min, under a progressively increasing load. After the test, resistance to indentation is presented in N.

Figure 12. a) Testing sphere; b) during test; c) After test

METHODOLOGY

The efficiency of the treatment and consolidation products was evaluated, with the following methodology:

In Laboratory

- Artificial degradation with rot fungi
- Axial compression, static hardness, *Resistograph*® and *Pilodyn*® tests on the artificially degraded samples.
- Application of treatment and consolidation
- New static hardness, *Resistograph*® and *Pilodyn*® tests on the same samples tested before. As far as compressive tests are concerned, samples with a similar initial volumic mass and loss of mass were tested

In situ

Selection of 6 test locations by means of visual inspection and simple cutting device
For each element to be tested, determination of 3 elements or testing zones respectively in sound wood, for control, mediumly fungi degraded wood, for the application of treatment and consolidation, and completely degraded by fungi, for comparison

- Tests with *Resistograph*® and *Pilodyn*® at the selected testing location;
- Application of the treatment and consolidation process studied
- New analysis with *Resistograph*® and *Pilodyn*®, to assess consolidation process effects.

LAB CAMPAIN RESULTS ANALYSIS AND DISCUSSION

Compressive strength parallel to grain, $f_{c,0}$

Analysing Figure 6, it is possible to verify that there is an increase in the compressive strength values for the treated and consolidated samples, this being more relevant for the more degraded samples.

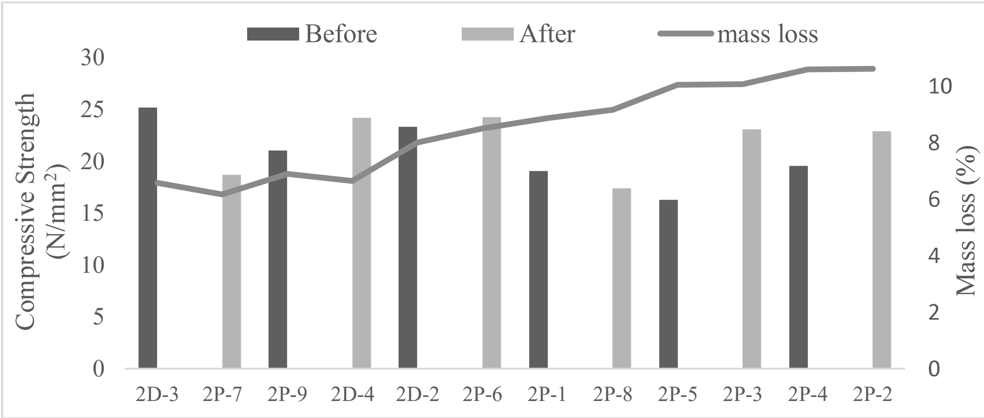

Figure 13. Values registered for compression strength results, before and after treatment and consolidation

In fact, polymeric impregnation products fill the degraded zone, soaking cells and free spaces between them [33], thus justifying an improvement in behaviour in more degraded woods, which present larges intercellular spaces.
It seems that the tested method is more efficient for higher mass losses. Attention is drawn to the fact that above 20% the method is not applicable, although this is nor verified in the present study

Resistance to indentation, $Hc_{,H\%}$

Static hardness test also confirmed the efficiency of the method. Except for sound samples, 2S-17 e 2T-9, an increase in mechanical strength was registered for most of the samples tested, as shown in Figure 7.

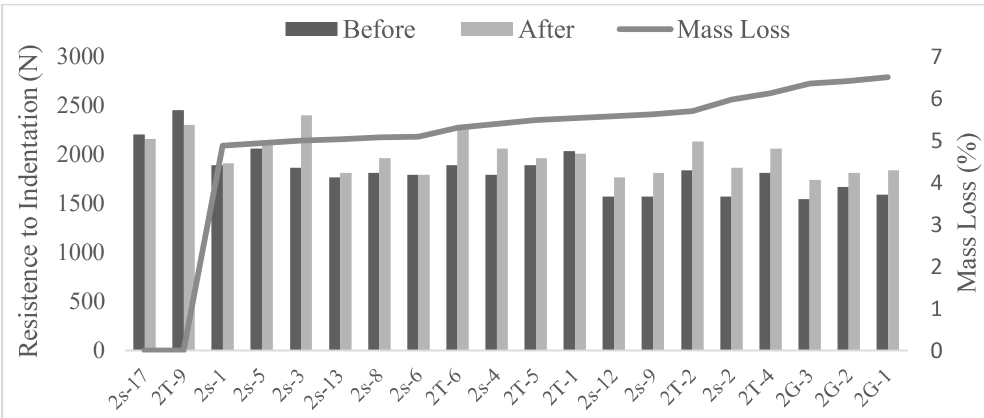

Figure 14. Values registered for resistance to indentation, before and after treatment and consolidation

Is was also verified that the strength increase is more regular for mass losses above 6%, which again emphasises the improvement in behaviour for treated and consolidated timber, for higher degradation levels.

Test with *Resistograph*® is little sensible to slight surface alterations. In fact, observing figure 8, little consistency is observed in the results presented for mass losses below 6%. From this value up, there is a slight increase in the mechanical strength for treated and consolidated samples, in line with what was verified for the static harness test.

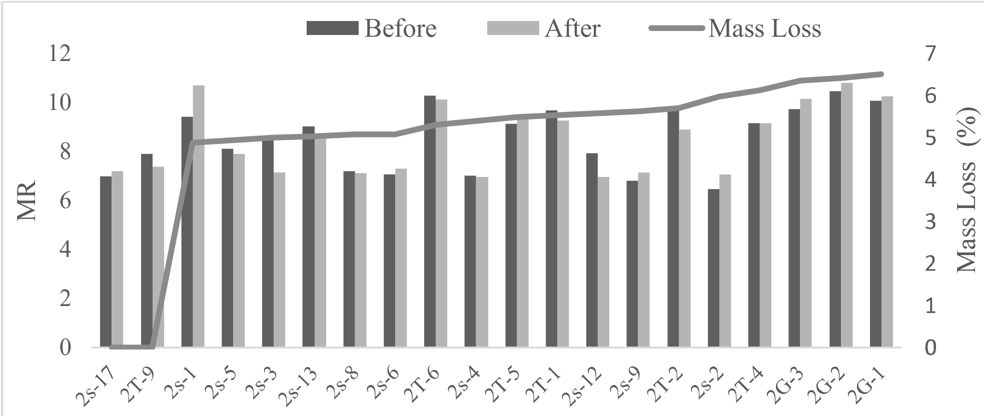

Figure 15. Values registered for resistographic measure, before and after treatment and consolidation

Depth with *Pilodyn®*

Pilodyn® test led to unexpected results. In fact, the reduced depth of this test led to believe in a greater sensibility in the evaluation of the treatment and consolidation effects. It was verified however *a great dispersion in the results obtained, as shown in figure 9.*

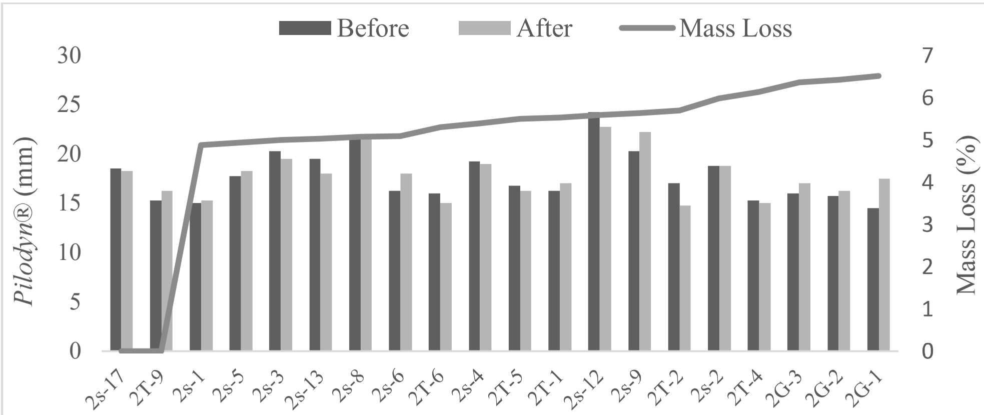

Figure 16. Values registered for Pylodyn® depth, before and after treatment and consolidation

It should be noted that even for degradation higher than 6% of mass loss, the results obtained are not in line with the increase in mechanical strength in the other tests.
Therefore it is considered that *Pilodyn®* does not present sensibility for the desired evaluation, Once again it should be noted that the large diversity in sample degradation and the reduced mass losses may justify these results.

In situ test

The results are presented in terms of medium values registered in the tests. Treatment and consolidation were applied to zone A, mediumly degraded by fungi. Zone B was very degraded, as comparison. Zone C was sound, for reference. Values for all tested elements are presented in table1

Table 1. Summary table of the tests performed

Element	Properties – mean values	A		B	C
		Initial	Treated and consolidated	Initial	Initial
Wall	Moisture content (%)	4	5	2	12
	Resistograph® Mr_{medium} (20cm/min)	8,5	9,2	-	13,1
	Pilodyn® (mm)	-	-	-	12,3
Stair	Moisture content (%)	10	10	7	9
	Resistograph® Mr_{medium} (20cm/min)	6,4	8,7	1,0	11,6
	Pilodyn® (mm)	14,1	11,4	17,8	11,4
Pavement 1	Moisture content (%)	7	8	3	7
	Resistograph® Mr_{medium} (20cm/min)	11,8	15,6	7,0	12,8
	Pilodyn® (mm)	14,8	13,9	21,3	16,2
Pavement 2	Moisture content (%)	9	9	8	8,5
	Resistograph® Mr_{medium} (20cm/min)	10,8	11,1	8,2	11,7
	Pilodyn® (mm)	19,7	18,2	37,3	16,6
Pavement 3	Moisture content (%)	9,5	9	8	-
	Resistograph® Mr_{medium} (20cm/min)	9,1	12,3	5,98	-
	Pilodyn® (mm)	24,4	19,1	38,1	-
Roof	Moisture content (%)	9,5	9	7	9
	Resistograph® Mr_{medium} (20cm/min)	9,4	11,1	5,8	10,3
	Pilodyn® (mm)	19,3	18,4	34,3	18,0

An increase in resistographic measure and a decrease in *Pilodyn*® penetration depth were verified in all the elements in the intervention, which points to a gain in strength after the treatment and consolidation proposed.

It should be noted that these values are mean values. However, for most individual tests this behaviour was also verified. As an example, figure 10 shows all the values for individual test results carried out on pavement 1

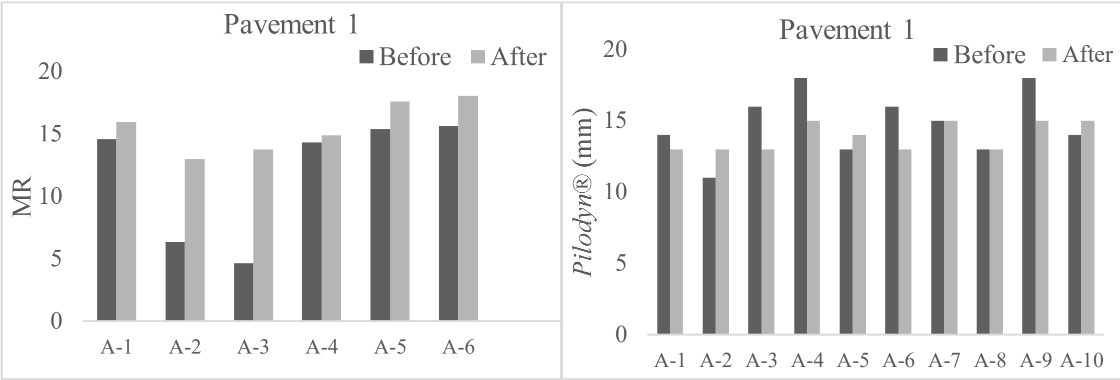

Figure 10 –Values registered by *Resistograph*® and *Pilodyn*®, before and after treatment and consolidation

The treatment seems to be more effective in zones that initially presented more degradation and, as a consequence, more intercellular space for the consolidant to flow [34], as exemplified by test A-2 and A-3 of the first graphic.

As far as Pilodyn® tests are concerned the tendency is, no doubt, for a gain in resistance after the application of the studied method. However, there are some tests which do not shown this phenomenon; these results can be due to zones where the consolidation was not effective, or simply to less adequacy of Pilodyn® for the desired evaluation, which was also the case in laboratory

CONCLUSIONS

After the lab campaign, with the conclusion of the studied tests, before and after the application of the treatment and consolidation of the artificially degraded samples, a gain in mechanical resistance was verified in the compressive strength and static hardness tests. However, the method appears to be effective only for values of mass loss above 6%.
Resistograph® and *Pilodyn*® proved to be not sensitive enough; it is believed that the reason lies in the proximity of the reduced values of mass loss and the diversity of sample degradation. Regarding the maximum mass loss limit for which the method is still effective, this was not verified in this study, the reference value being 20%, for the reasons stated in the introduction.
During the case study *Resistograph*® and *Pilodyn*® proved to be quite useful in the identification of the mechanical resistance increase after the application of treatment and consolidation. It is believed that the mass losses being significantly higher, allows for a greater consolidation effect and detection. Thus this method can and should be used both in structural and non-structural rehabilitation. The application of this treatment in situ is fairly easy, except for sloped elements, where the fixation of the products is more difficult

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