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New Methodological Approaches to the Survey on Timber Historical Foundations

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ABSTRACT: Waterlogged wooden artefacts coming from foundations are a very peculiar category in the huge world of cultural heritage. The present paper reports on the results obtained from a diagnostic survey on wooden samples from loggings made on the wooden foundations of two ancient belfries. The importance of a multidisciplinary approach is well known in the world of conservators, but in cases like these it is crucial to bring together different experts and skills of several fields, including for example architecture technology, wood technology, chemistry, restoration and dendrochronology, in order to take advantage of their experience in making a correct diagnosis of structures that very often are still working.
Authors want therefore to stress on the basic problem of the conservation of buildings with waterlogged foundations, through the promotion of an International comparison of experiences on the same research topic.

1 PREFACE

Waterlogged wooden foundations coming from two buildings of a same town of Northern Italy have been considered in this contribution. The buildings have been generically indicated by letters A and B, because the main aim of this work is that of considering a general approach to the diagnostic process for the very specific and relatively scarcely investigated case of wooden foundations. It could become of great interest for several European towns "founded" on wood (for example Venice, but also Hamburg, Amsterdam etc.).

The considered cases show some aspects that are common to all wooden foundations and others that are very peculiar:
- Degradation conditions, due to the service state and to the chemical, physical and biological interactions between wood and substrate in which timber structures have remained for a very long time.
- Structural decay due to the different alterations occurred during time in the distribution of loads, according to the applied interventions.
- Partial loos of the original functionality.

If the aspects of the variability in the behaviour of the different wooden species are considered, mainly if related to the environment of conservation during their service life, we can imagine that diagnosis, maintenance and restoration of the wooden artefacts coming from foundations are largely different from those of other categories of artefacts made of wood. Waterlogged wooden findings from archaeological excavations are in quite similar conditions, but normally they have lost their original functionality. On the contrary, the functionality of foundations is still expected, even if limited. Basically for such reason, the consolidation techniques and the maintenance criteria between archaeological findings and wooden foundations are completely different, even because there are different requirements and no needs of mechanical characterisation. Moreover, there is a complete lack in standards and guidelines for the diagnosis and conservation of this kind of objects.

This last theme is particularly relevant considering the recent proposal of regulation on waterlogged and archaeological wood in the frame of the Italian workgroup UNI NORMAL GL 20 – “Wood and wood based materials”: there is a specific need, at least at Italian level, of carrying out an interdisciplinary research activity, in which different disciplines can converge.

The paper therefore reports on the diagnostic approach and on the results obtained from a campaign of tests executed on wooden samples coming from several loggings made on the wooden foundations of two ancient belfries, generically indicated as building A and building B.

2 IDENTIFICATION OF WOODEN SPECIES AND DENDROMORPHOLOGICAL ANALYSIS

The aim of the xilotomic and dendromorphological investigations carried out in this initial phase of the research is the identification of wood species and the reconstruction of the dimensions of the poles. The identification is an indispensable premise for the characterization of the collected samples, and was conducted by examining thin slices of wood taken along the three main anatomical directions under the optical microscope. This exam allowed us to identify the samples coming from the foundation boarding (present only in the loggings of the building A) and those from the logging SI6 (about -470 cm in depth from the basement level), as larch wood (Larix decidua Mill.).

The other samples coming from the foundation poles of both buildings belong to oak wood (Quercus sp section Robur) and alder (Alnus sp.). Some samples of elm wood (Ulmus sp.) were identified in the case of the building B. All these species are indicated in the literature as suitable for underwater structures (Giordano 1980).

The reconstruction of the dimension of the poles was possible only for those that were obtained from decorticated trunks and conserved in the extracted samples the most external portion of the element. The localization of the pith for the samples, where it was not preserved, was detected through the examination of the direction of the medullary rays. The reconstruction allowed us to point out the presence of poles with reconstructed diameter of about 11 and 22 cm for the building A and of poles with reconstructed diameter of 9-13 and 18 cm for the building B. Can be concluded that the poles are obtained from young trees with an age of less than 30 years at the high of the sampling.

3 MATERIALS AND METHODS

For the other diagnostic investigations, 16 samples from the belfry of building A were taken and 10 from that one of building B, all of them extracted from several loggings at different depths (Fig. 1 and 2) and distributed both on the inside and on the outside of the buildings. Some of the samples coming from the loggings are shown in Figs. 3 and 4.

Physical, chemical and mechanical characterisations of wooden poles were achieved by comparing the results with those of cut reference woods, recently collected and without any alteration.

Figure 1 : One of the loggings extracted from building A. As evident, the stone basement of the belfry rests directly on the wooden poles foundation.

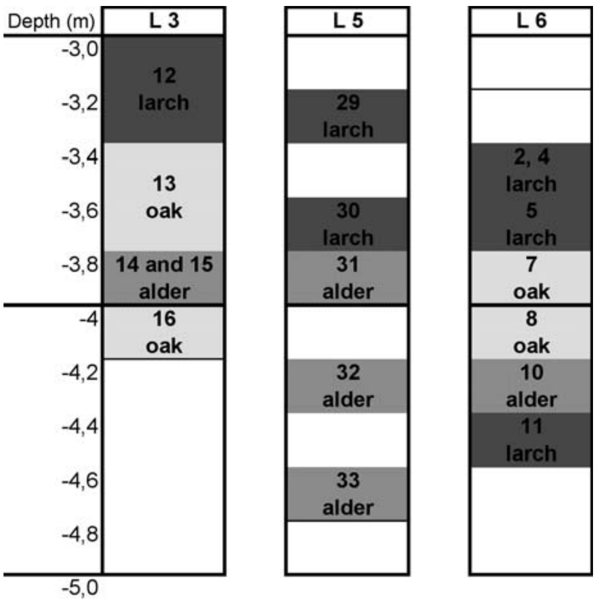

Figure 2 : An example of the distribution of species and depths of the collected samples for three of the loggings extracted from building A.

Figure 3 : Some of the oak (left) and alder (right) samples coming from the belfry of building A.

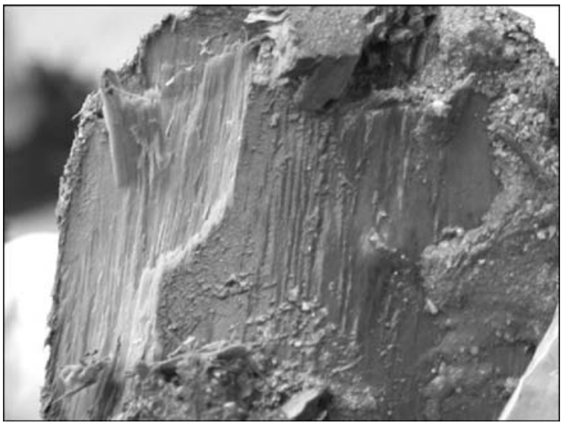

Figure 4 : One of the alder samples coming from the belfry of building B

4 PHYSICAL CHARACTERISATION OF WOOD

A small prismatic specimen following the anatomical directions was obtained from each sample, and weight and volume were measured at the saturated state. The specimens were then put in an oven at 103 ± 2 °C up to constant weight. The obtained values allowed to calculate some of the parameters most used to evaluate the decay of waterlogged wood (Schniewind, 1990): Basal Density (BD, g/cm^3, the ratio between anhydrous mass and wet volume), Maximum Water Content (MWC, %, the ratio between the mass of water in the specimen and the anhydrous mass of wood) and the Residual Basal Density (RBD, %, the ratio between the BD of samples and the BD of fresh wood of the same species).

5 CHEMICAL CHARACTERISATION OF WOOD

After a drying step, samples both by loggings and by fresh wood, were milled and the wood meal sieved in order to collect the fraction between 40 and 60 mesh (0,2 – 0,4 mm). The moisture content of the powder were then measured so allowing referring the results to the oven-dry conditions. For each sample the following analyses were carried out (Browning, 1967):

- organic extractives by using a toluene/ethanol mixture 2:1 v/v in a soxhlet extractor;
- water extractives by using a soxhlet extractor on the same powder already extracted with the organic solvents;
- lignin content, according to the Klason (or acid) method;
- ashes, by maintaining the powder in air at 600°C.

The holocellulose amount has been evaluated indirectly, as complement to the 100% total.

6 MECHANICAL CHARACTERISATION OF WOOD

Samples have been collected from the loggings, as appearing in sound conditions and taking in account for their inclination. Specimens were obtained by firstly cutting loggings in small wheels 2 cm thick, and then squaring the wheels to a base of approximately 1,3 cm x 1,3 cm. In such a way, some parallel-to-grain compression tests were carried out, directly on the completely saturated material. As reference, literature values for green wood of the same species have been considered.

7 RESULTS AND DISCUSSION

The results of the physical tests for the samples of alder extracted from the loggings from building A are reported in Fig. 5, whereas Fig. 6 shows the analogous results for building B.

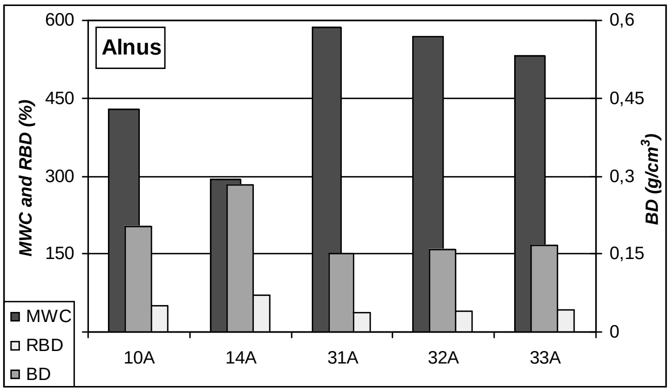

Figure 5 : Results of the physical characterisation of alder samples from building A.

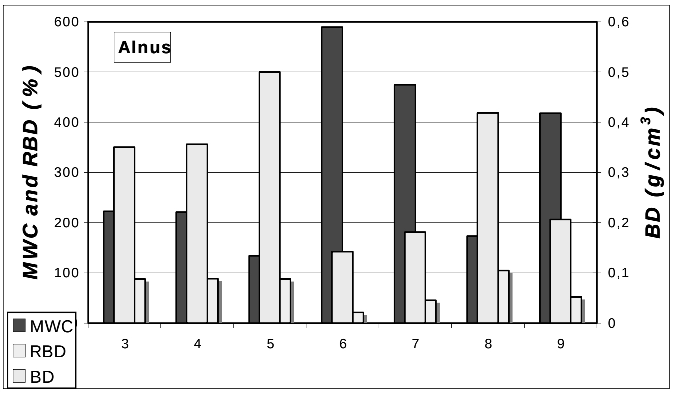

Figure 6 : Results of the physical characterisation of alder samples from building B.

As can be seen from the figures, the state of conservation of the samples is quite different for the two belfries, even if the same botanical specie (alder) is considered: in fact whereas values for building B show that (except in a few cases) the poles are in fair conditions with residual densities very close to 100%, i.e. generally close to the value of fresh wood, the alder poles of building A, are in a bad state of preservation, with values of MWC higher than 300-400%, i.e. degraded material (Macchioni, 2003). The same considerations can be made on the basis of chemical results.

Conversely, the larix samples, coming almost exclusively from the boarding layer immediately under the stone basement of the belfries, are in very good conditions: Fig. 7 shows that the holocellulose/lignin (H/L) ratio, i.e. the ratio of the two chemical structural components of wood (Hedges, 1990), is very close (in two cases substantially equal) to the analogous value for fresh larch wood. As example, the holocellulose/lignin ratio for alder samples from building A is often less than 0,5 (against a value of 3 for fresh alder) whereas the H/L ratio is roughly 2 for alder samples from building B.

By comparing Figs. 2 and 7 it is possible to note a trend for larch samples. In particular, it seems that the H/L ratio decreases (i.e. the decay increases) by increasing the depth. Unfortunately, the number of samples is too reduced to make reliable observations in such sense.

The mechanical tests evidence that also for samples considered in good conditions on the basis of physical and chemical data there is a certain reduction in the strength of the material, if values for green wood are considered as reference. Table 1 shows the results for the alder samples of building B and for a larch sample from building A.

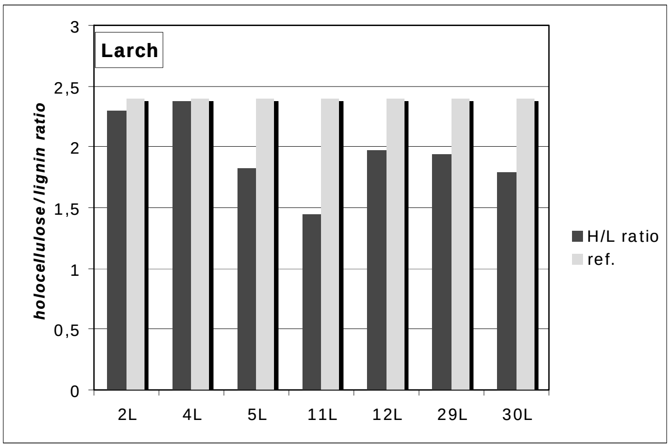

Figure 7 : Results of the chemical characterisation of larch samples from building A.

Such substantial reduction is attributable to the loss of polysaccharidic fractions of wood constituents (evidenced by chemical analyses) even if apparently a good exterior aspect of the alder samples is observable at the moment of their extraction from the loggings (as already shown in Fig. 4). In fact, the polysaccharidic substances (both cellulose and hemicelluloses) confer to wood the majority of its mechanical characteristics. On the other hand, conditions like those of the wooden foundations (partially decayed, completely and continuously wet material) are rarely found in the structural field and similar cases of selective loss of polysaccharides are only imputable to the cellulosolitic action of wood destroying fungi. In such cases, an appreciable reduction of strength is observed even in presence of a relatively limited mass loss (Curling et al. 2002).

Table 1. Results of the mechanical tests of samples from building B and from building A. Values in brackets are standard deviations for the compressive strength.

logging	specie	compressive strength (MPa)	compressive strength of green wood (MPa)	notes
1-S.ST	Alder	6,4 (± 0,6)	20,4	formation of evident ring shakes under load
2-S.ST		5,4 (± 1,3)		
3-S.ST		6,7 (± 0,4)		
4-S.ST		5,9 (± 0,5)		
5-S.ST		9,8 (± 1,4)		
6-S.MGF	Larch	16,6 (± 2,0)	25,9	

It is also interesting to look at the failure modes of specimens. In fact, whereas the majority of them break for buckling (Fig. 8), and hence in a manner that can be considered as ‘typical’ for a defect-free specimen, in some of the samples some ring shakes arise under load (Fig. 9), certainly due to pre-existing fractures, even if they were not visible to a naked eye.

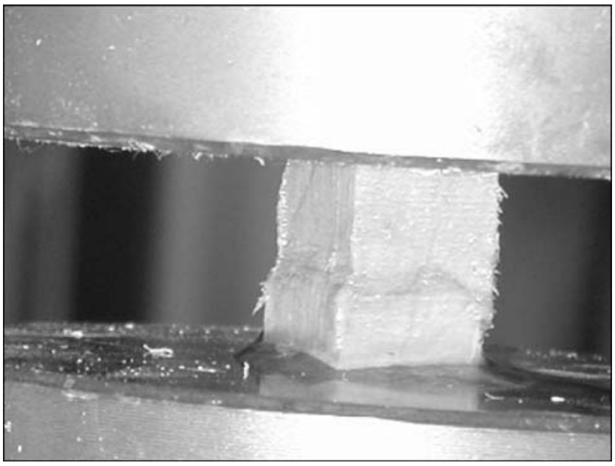

Figure 8 : Buckling of a specimen under load

Figure 9 : In some specimens some ring shakes arise during the loading phase. The pattern of such kind of cracks lets suppose that they were already present in the material, even if not visible to a naked eye, at the moment of cutting the specimens

8 RESISTOGRAPHIC SURVEY

A densitometric survey on samples coming from the wooden foundations were carried out with the Resistograph® F-400, an instrumented drill which registers the resistance that wood opposes to the entrance of its drill bit, equipped in its turn with a combined movement of rotation and progressive advancement at constant speed. Usually, densitometric surveys has the aim of investigating on the density of the analysed materials, in relation to humidity and wooden species, and allows to evaluate the existence or the loss of material, for example for fungal decay.

The instrument was set at first on the base of a simple differentiation between hard and soft wood and successively calibrated by using the parameter “soft” wood. A speed of penetration between 55 and 58 cm/sec was measured, thus allowing (after the identification of Taxon for each sample) the estimation of residual densities and hence the state of conservation of the materials. In the conclusive phase all the results were collected in synthesis tables in order to make a cross-reading of the analyses. This outcome evidenced different levels of decay for the materials.

9 CONCLUSIONS

All the considered diagnostic analyses show that:

- the comparison of several parameters enables a better resolution for the conservation state of the waterlogged wood samples
- the decay depends on the considered specie, with larch samples generally less degraded than alder ones
- the lying position of wooden elements has an also stronger effect. In fact, the same specie (alder) can be more or less degraded depending on the considered belfry, even if there is a not big difference in the main chemical soil parameters (pH, redox potential)
- for all the considered species the decay is mainly concentrated on the polysaccharides of wood, namely the holocellulose. This is a typical feature of the archaeological wood, but in the present case the involved period of time is relatively limited
- the material with an apparently good state of preservation has a reduced mechanical consistency, due to the great influence of polysaccharides loss (even if limited) on wood strength. Nevertheless these considerations strongly depends on the interested species

However, considering the complexity of the whole structural system (clay-water-wood) it should be desirable to initiate a systematic series of specific and targeted experimental tests, in order to evaluate the residual load capacity, and hence the reliability, of these unique kind of structures.

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