European Journal of Science and Theology, April 2018, Vol.14, No.2, 161-171

WOOD IN CULTURAL HERITAGE PROPERTIES AND CONSERVATION OF HISTORICAL WOODEN ARTEFACTS

Angela Lo Monaco[1*], Federica Balletti[1] and Claudia Pelosi[2]

[1] *University of Tuscia, Department of Agriculture and Forest Science (DAFNE), Via San Camillo de Lellis, 01100 Viterbo, Italy*
[2] *University of Tuscia, Department of Economics, Engineering, Society and Business Organisation (DEIm), Largo dell'Università, 01100 Viterbo, Italy*

(Received 27 September 2017, revised 9 November 2017)

Abstract

Wood is one of the most used materials in the human history for the production of artistic works, evidence that reflects not only the availability of wood but also its natural aesthetic qualities. The investigation of wooden artefacts supplies an interesting reference framework for better understanding the technical construction skills of the past and provides concurrently information on the significance of the artefacts, on their values and also on the historical period during which they probably were created. Changes in the structure of the wood can help conservators to know the characteristics of the past storage spaces, giving so indication for better understanding the conservation state evolution during time and to plan the optimal maintenance activities. Anamnesis and diagnosis are indispensable phases in wood restoration and conservation: they should become routine activities. The main aim of this approach is to choose the best intervention as possible in order to allow maintaining the cultural values of the artefact and, at the same time, preserving, valorising and transmitting it to the future generations. This paper provides a short review of case studies based on scientific investigation of wood artworks in order to increase their knowledge through objective data.

Keywords: wooden artefacts, conservation, diagnostics, wood

1. Introduction

Wood is one of the most used materials in the human history for the production of artistic works. This evidence reflects not only the availability of wood but also its natural aesthetic qualities such as colour, lustre, grain, and texture. A fundamental wood feature is versatility that made it the preferred material in any era or culture to obtain not only furniture, but also boats, defence tools, and structural part of buildings; it is used for household, ornamental, religious and recreational objects, due to its easy workability.

[*]E-mail: lomonaco@unitus.it, tel.: +390761357401, fax: +390761357250

The investigation of wooden artefacts supplies an interesting reference framework for better understanding the technical construction skills and provides concurrently information on the artefacts significance, on their values and also on the historical period during which they were probably created.

The modern approach to cultural heritage involves scientific investigation of materials in order to increase the knowledge through objective data and to support conservation activities fundamental for preserving cultural heritage assets. Such activities are required to stop or to limit the natural deterioration of materials, and the degradation pattern due to neglected maintenance, storing in unsuitable places, natural and anthropic disasters.

Degradation may be a particularly relevant for wooden artefacts as they are highly vulnerable to biotic deterioration as well as to physical and mechanical stresses. Changes in the structure of wood can help conservators to know the characteristics of past storage spaces and to obtain indication for better understanding the conservation state evolution during time and to plan proper maintenance activities.

This paper may be considered as a short review that aims to provide general background information about the characteristics of wood and the processes associated with its deterioration and decay. The main goal is to provide a sort of practical and logical basis for the conservation of wooden artefacts, showing some case studies in the literature based on this approach.

2. Operational goals

On the base of the approach widely defined in the Introduction, several studies were performed by our research group on various wood artefacts typologies: doors, panel painting supports, wooden models for buildings, sculptures. The technological evaluation of wooden objects and elements was generally performed by *in situ* careful observation, associated to measurement of the degraded areas, of zones with original defects, and of possible cracking. In order to improve the knowledge of the investigated objects, when possible, micro-samples from wood and painted layers were taken and subsequently analysed in the laboratory with microscope and spectroscopic methods. Wood species identification has been gathered by observing sample sections through microscope equipped generally with transmitted and reflected light, and UV sources and finally by scanning electron microscopy (SEM). The examined wood characters were compared with the descriptions reported in the literature [1, 2].

3. Outcomes

3.1. Diagnosis of botanical species

In the modern approach to cultural heritage studies, the scientific analysis of materials is fundamental to increase knowledge of the artefacts through objective data [3]. For historical and artistic wooden heritage, the identification of species has long been considered an essential prerequisite for any further investigations [4], although in practice it is rarely carried out with scientific and documented methodology.

In the investigation process of wooden artefacts, both from a technological and historical point of view, the diagnosis of the species is a relevant step [5, 6], sometimes achievable only for the systematic botanical category (*taxon*) as close as possible to the species. The reliably possibility to identify the botanical species of wood is conditioned by the integrity of the original microscopic structure of the wood assortment and by the conditions of the artefact, which must be accessible and with at least a portion of the wooden tissue observable at the macroscopic level [7]. After the identification of the macroscopic features, the microscopic identification can be performed with the aid of a microscope. Specimen can be collected taking care to use those parts that are already partially detached, in the less invasive modality. Each sample should be significant both in size and typology in order to guarantee of obtaining all information required for wood identification and diagnosis.

The description of the anatomical characters should be conducted according to the scientifically accredited nomenclature [8, 9] and as well as the declaration of identification keys should be included in the report.

3.2. The technological evaluation

The study of wood constituting an artefact or parts of it highlights the importance of knowing the construction design, technological and structural aspects, in order to make conservators able to plan interventions that do not deprive the cultural property of its values, but they lead to the preservation, enhancement and transmission to the future [10].

The technological evaluation of wooden artefacts implies a good knowledge of species, both from a theoretical and practical point of view. This is important for recognize the wood defects, the alterations caused by fungi, and the physical-mechanical characteristics. In the evaluation of the conservation state and of the historical-artistic context, the identification of taxon influences the restoring work and the choice of the storage places [11]. In fact, wood characteristics and behaviour in respect to numerous factors, such as protective and consolidating materials, biotic and abiotic agents, and the environment in general, could change according to the species. From a conservative point of view, the correct identification of wood species is imperative for choosing the best procedure: several wood species, without an adequate preservative treatment, may result exposed to the attack of xylophage insects, fungi, and bacteria. Neglected periodic treatments or inadequate monitoring for these species could cause serious risks for their conservation. On the other hand, some wooden species contain extractives, toxic organic compounds stored in cell lumina or walls, which have generally an antiseptic or preservative effect. A treatment would be an unnecessary cost for such wooden elements. Wood species identification allows to make rationale the maintenance and to plan correctly required restoration or conservation activities, as the different species show different residual properties, even after a biological attack [12-15].

A preliminary naked eyes observation of wood surfaces allows for mapping the wood defects that derive directly from the original characteristics of wood or from processing (sapwood, knots, pith, form defects, grain deviation, and sawn direction) and, also, for estimating the extension of the degraded zones owing to biological alterations caused by insects or fungi. The ability in observing the critical state derived from the wood defects can certainly contribute to the conservative restoration without producing further degradation phenomena in wood structures and artefacts. It allows preserving the original wooden material.

The holy conversation by Palma the elder [16] represents an interesting case. It is a masterpiece from the first half of the sixteenth century belonging to the collections of the National Museum and housed at the Royal Palace in Belgrade. Three boards constitute the support of the panel painting. The knots are mainly in the central panel, sawn in tangential direction. Insect attack has been detected at the board edges probably for the presence of glue. The support was built using poplar wood. Botanical species of the genus *Populus* are not distinguishable one each other from the anatomical characteristics of the wood. Poplar was the most widely used species in Italy for painting panels [4] due to technical reasons, i.e.: easy processing, no particular seasoning problems, light density that allows easy handling of large painted panels, anatomical features that ensure homogeneous surfaces, absence of coloured extractives.

3.3. The provenance

The identification of wood species does not limit its benefits to the context of maintenance and restoration, but it also supply information such as mechanical strength, rheological and hygroscopic behaviour, and durability, which allow to enlarge knowledge related to historical, ethnographic, commercial, trade, and forestry topics [17-21]. Sometimes it can help to specify or resolve the question of the provenance of an artefact [22].

At any time and in any region, the use of a specific type of wood depended on habits, empirical knowledge, availability and symbolic meanings of the materials. Therefore, there is a strong link between an artefact and the wood of which it is composed [23, 24].

The investigations performed in the following cases demonstrated that the choice of wood species mainly depends on some factors: the availability at local level and the aesthetical and durability properties of chosen wood species [25].

On the basis of the anatomical features the wooden support of the statue of Saint Joseph, attributed to the workshop of Ignaz Günther (18^{th} century) was identified as lime, the wood has been identified to genus level only [26]. Lime wood (*Tilia* sp.) was widely used for panel paintings, decorative carvings and sculptures, especially in Northern Europe, due to anatomical features such as diffuse porosity, moderate shrinkage, and fine texture, which ensure excellent finishing results being not prone to splitting [27]. Its use in the statue of St. Joseph further supports the attribution to the workshop of the German artist Ignaz Günther.

Wood species identification was fundamental for supporting, with scientific analysis, the provenance of the processional statue of Jesus Nazareno of Sonsonate (El Salvador) [28]. The faithful claim that the statue came from Florence, but the identified wood was *Cedrela odorata*, a species living in central South America.

The investigation on the '*Madonna dei Poveri e bambino*' (Madonna of the Poor with the Child), a devotional statue from Seminara, is another interesting study aimed at finding elements for establishing the provenance [29]. The analysis of wood samples allowed for identifying poplar, a name including several species, indistinguishable from the anatomical features of the wood and widespread in Italy, as previously discussed. Scanning electron microscopy (SEM) investigation made possible to put forward hypotheses concerning the state of preservation of the artwork. The presence of fungi, in fact, suggested that the statue was very probably stored in a moisture-rich environment which favoured the development of the bio-film observed within the vessels. The condition of the spores, which appeared non-vital, suggested that the attack occurred in the past (Figure 1).

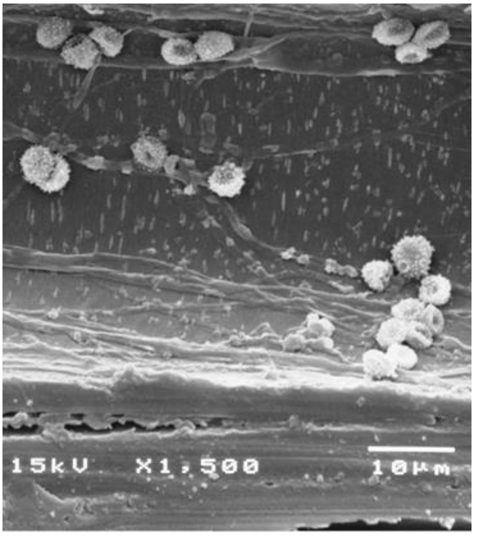

Figure 1. SEM observation shows spores and hyphae inside a vessel.

Another interesting case study concerns the use of chestnut wood, a species having a long time tradition in Italy [30, 31]. In Lazio region, chestnut was widely used for structural elements and also for objects with a demo-ethno-anthropological significance.

Identification of chestnut can be sometimes obtained *in situ* as in the case of the Holy Saviour triptych (Tivoli, Italy) [32], an important religious panel painting dated back to the 12th century. The identification of chestnut wood (*Castanea sativa* Mill.) contributed to the dating of the panel painting in comparison with the Virgin panel of Saint Angelo in Pescheria, a chestnut wooden panel dated back to the first quarter of the twelfth century [33].

Sometimes the identification of several species may indicate restoration works operated during time [34] as the case of the Model of *S. Maria della Consolazione*'s church (Todi, Italy) [35], where Pine and Poplar were identified.

Information gathered by archives and restoration reports are useful but wood identification needs to be detailed. Sometimes the archive documentation is not relevant, especially because the methodology is not reported. Sometime the local terminology can cause mistakes in wood identification [36].

Wood species identification, based only on macroscopic characters, could not always be reliable. This is due to possible colour changes caused by surface finishing or protecting products, and by photo-degradation phenomena induced by light radiation in the conservation environment [37-41].

Sometimes, if observations are executed by non-specialized personnel, rough errors can occur. An example is the case of a wooden mask for which the secondary xylem (dicotyledonous angiosperm wood) was erroneously mistaken for palm stem, as indicated in the inventory card [42]. This object, a wooden mask from Papua New Guinea, is stored in the National Prehistoric Ethnographic Museum 'L. Pigorini' in Rome and it may be dated back to the beginning of the 19th century. It is a typical ceremonial mask of the lower Sepik river decorated with cassowary plumes and shells. It is made of a single wood piece carved and painted. Some diagnostic analyses were performed in order to characterize the original and restoration materials and to state the authenticity of the object, since no archive documentation attesting the moving of the mask from Papua New Guinea to Italy were found. The collected diagnostic data, both on wood and painting materials, confirmed the authenticity of the mask, giving so important information to the Museum.

The most reliable method for wood identification is the classic one, but the long sample preparation process and the operator's knowledge and experience may be a hindrance to a more widespread application. In addition, although micro-invasive, this approach to cultural heritage objects could be regarded with concern.

3.4. Other methodologies utilized for identification

Totally non-destructive methods are also an important issue. Image processing techniques for wood species recognition were applied by various authors [43-45] to support and confirm the results obtained by classical methods.

Some species cannot be differentiated by traditional methods, so chemometrics and spectroscopic methodologies can help to identify species also through portable equipment [46-50]. However, these methodologies have not a general applicability yet and need further experimental tests to overcome some problems [51, 52].

These same methodologies, on the other hand, demonstrated their high potentiality in surface monitoring to assess the evolution of conservation state [53, 54].

Surface monitoring is a relevant factor in the study of wooden artefacts since the ageing phenomena on wood and on protective/consolidating materials, applied in conservation and maintenance activities, may highly affect the surfaces. Wood can undergo degradation phenomena due to natural ageing, associated to light irradiation, that generally cause colour variations of surfaces and, structural weakening. These changes are accelerated by UV component of light, which provokes photo-oxidative processes [55, 56]. Artefacts exposed to the inclemency of the weather and to high thermo-hygrometric variations may suffer damages both on the surface and within the internal structure because of water absorption/desorption phenomena. These cause swelling and shrinkage: as a result, entire fibre layers will detach due to the production of micro-cracks. An example of the degradative abiotic factors is the case of the Todi Cathedral door, exposed for many hours during a day and throughout the year to solar irradiation [57].

3.5. Dendrochronological analysis

A relevant contribution to the knowledge of wooden artefacts can be gathered from the dendrochronological analysis. This dating method, that allows resolution to one year, need the species identification, to match the growth ring series of the wooden artefact with master chronologies of the same species or a network of reference chronologies suitable for hetero-specific connections [58]. It enables dating the timber and, thereby, identifying the restoration phases and maintenance operations [59-63]; coupled with other methods, it offers a great potential in dating, authenticity confirmation and in establishing provenance hypothesis [64-68].

4. Conclusions

The depth knowledge of works of historical and artistic importance allows to assess the state of conservation and to support the choice of the most appropriate methods of intervention for the maintenance.

The study of wooden artefacts should always include the xylological analysis for determining the tree species used as constitutive material and on the occasion of restoration works.

The diagnosis of botanical species is fundamental for assessing the state of conservation of the artefacts, to support the choice of the most appropriate methods of intervention, to know the technological properties of wood and the natural durability guaranteed by the materials and to collect information on the working choices and methods of the past craftsmen. It can provide information about the historical and artistic context, as well as indications to support the restoration choices.

Wood properties are fundamental for the conservation of artworks. From this statement it derives that a shared investigation protocol should be used, based on in situ inspections and laboratory analysis, in order to supply a valid aid to the conservators for planning the restoration and maintenance activities. Anamnesis and diagnosis are indispensable phases in wood restoration and conservation: they should become routine activities. However, wood diagnosis is not often praxis in conservation, especially for artefacts considered less important, also due to the lack of funding.

In conclusion, this paper illustrated through a series of published case studies, the potentiality of wood analysis and diagnosis in conservation and the necessity of making these operations mandatory for preserving, valorising and transmitting wooden artworks to the future generations.

References

[1] R. Nardi Berti, *La struttura anatomica del legno ed il riconoscimento dei legnami italiani di più corrente impiego*, IVALSA, Firenze, 2006, 155.
[2] F.H. Schweingruber, *Anatomy of European woods: an atlas for the identification of European trees*, WSL/FNP Paul Haupt, Berne, 1990, 800.
[3] R. Bruzzone and M.C. Galassi, *Wood species in Italian panel paintings of the fifteenth and sixteenth centuries: historical investigation and microscopical wood identification*, in *Studying old master paintings. Technology and practice*, M. Spring (ed.), The National Gallery Technical Bulletin 30*th* Anniversary Conference Postprints, Archetype Publ., London, 2011, 311.
[4] J. Marette, G. Bazin and C. Jacquiot, *Connaissance des primitifs par l'étude du bois du XIIe au XVIe siècle*, A. et J. Picard, Paris, 1961, 384.
[5] E. Corona, *Il ruolo della xilologia nella caratterizzazione dei manufatti lignei storico artistici*, Atti del 2° Colloquio Internazionale Gestione Patrimonio Culturale, DRI, Rome, 1998, 38-42.
[6] A. Pellerano, F. Vona, F. Dentamaro and M. Marmontelli, *Sculture lignee e dipinti su tavola in Puglia. Cinque casi di studio dalla diagnostica al restauro*, Claudio Gerenzi Editore, Foggia, 2008, 1-144.
[7] M. Fioravanti, G. Di Giulio and G. Signorini, J. Cult. Herit., **27** (2017) 70-77.
[8] ***, IAWA Bull., **10** (1989) 1–332.
[9] ***, IAWA J., **25** (2004) 1–70
[10] G. Tampone, *Il restauro delle strutture di legno*, Hoepli, Milano, 1996.
[11] M. Capano, O. Pignatelli, C. Capretti, S. Lazzeri, B. Pizzo, F. Marzaioli, N. Martinelli, I. Gennarelli, S. Gigli, F. Terrasi and N. Macchioni, J. Archaeolog. Sci., **57** (2015) 370.
[12] T. Annesi, L. Calienno, R. Picchio, D. De Simone and A. Lo Monaco, Drewno, **58** (2015) 5-18.
[13] D. Dogu, N. Yilgor, G. Mantanis and F.D. Tuncer, Bioresources, **12(2)** (2017) 2433.
[14] M. Madhoushi, Bioresources, **11(2)** (2016) 5169.
[15] S.C. Kim and J. Choi, J. Korean Wood Sci. Technol., **44(6)** (2016) 897.

[16] R. Saccuman and A. Lo Monaco, *Relazione dell'intervento sul supporto ligneo*, in *La sacra conversazione di Palma il Vecchio. Restauro del dipinto su tavola di Belgrado*, A. Bianchi (ed.), Editoriale Artemide, Roma, 2007, 97-104.
[17] M. Abdallah, H.M. Kamal and A. Abdrabou, International Journal of Conservation Science, **7(4)** (2016) 1047-1064.
[18] E. Corona, Ann. Acc. It. Sc. For., **40** (1991) 211.
[19] E. Corona, Linea ecologica, **1** (1995) 56.
[20] G. Giachi, M.C. Guidotti, S. Lazzeri, L. Sozzi and N. Macchioni, J. Archaeol. Sci. Reports, **9** (2016) 340.
[21] Y. Ismail, A. Abdrabou and M. Abdallah, International Journal of Conservation Science, **7(1)** (2016) 15.
[22] N. Macchioni, G.M. Fachechi, S. Lazzeri and L. Sozzi, J. Cult. Herit., **16(1)** (2015) 57.
[23] J. Bontadi and M. Bernabei, IAWA J., **37(1)** (2016) 84.
[24] W. Tegel and C. Croutsch, J. Archaeol. Sci. Reports, **7** (2016) 123.
[25] M. Dong, H. Zhou, X. Jiang, Y. Lu, W. Wang and Y. Yin, IAWA J., **38(2)** (2017) 182.
[26] C. Pelosi, L. Calienno, D. Fodaro, E. Borrelli, A.R. Rubino, L. Sforzini and A. Lo Monaco, J. Cult. Herit., **17** (2016) 114.
[27] G. Giordano, *Tecnologia del legno. I legnami del commercio*, UTET, Torino, 1988, 905-910.
[28] A. Lo Monaco, T.V. Nedelcheva, M. Micheli, J.A. Orellana and A. Schirone, Eur. J. Sci. Theol., **13(2)** (2017) 41-49.
[29] A. Lo Monaco, *Indagine xilologica sulla statua della Madonna con Bambino di Seminara*, in *La Madonna dei Poveri di Seminara. Il culto la storia dell'arte il restauro*, F. De Chirico (ed.), Il Rubettino Editore, Soveria Mannelli (Cz), 2011, 211-214.
[30] G. Agresti, G. Genco, C. Giagnacovo, C. Pelosi, A. Lo Monaco and R. Castorina, Acta Hortic., **866** (2010) 51.
[31] F. Balletti, A. Lo Monaco, A. Agresti, L. Calienno and C. Pelosi, Eur. J. Sci. Theol., **13(2)** (2017) 13-24.
[32] A. Lo Monaco, C. Giagnacovo, C. Falcucci and C. Pelosi *The tryptic of the Holy Saviour in the Tivoli Cathedral: diagnosis, conservation and religious requirements*, in O.A. Cuzman, R. Manganelli Del Fà & P. Tiano (eds.), Proc. of the 6th European Symposium on Religious Art, Restoration & Conservation, Nardini Editore, Firenze, 2014, 153-156.
[33] A. Lo Monaco, C. Giagnacovo, C. Falcucci and C. Pelosi, Eur. J. Sci. Theol., **11(2)** (2015) 73-84.
[34] S.C. Kim and J.Y. Jang, J. Korean Wood Sci. Technol., **43(3)** (2015) 295.
[35] A. Lo Monaco, E. Mattei, C. Pelosi and M. Santancini, J. Cult. Herit., **14** (2013) 537.
[36] A. Villasante, Forest Systems, **22(1)** (2011) 152-155.
[37] G. Bonifazi, L. Calienno, G. Capobianco, A. Lo Monaco, C. Pelosi, R. Picchio and S. Serranti, Polym. Degrad. Stab., **113** (2015) 10.
[38] G. Bonifazi, L. Calienno, G. Capobianco, A. Lo Monaco, C. Pelosi, R. Picchio and S. Serranti, Environ. Sci. Pollut., **24** (2017) 13874.
[39] L. Calienno, A. Lo Monaco, C. Pelosi and R. Picchio, Wood Sci. Technol., **48(6)** (2014) 1167
[40] L. Calienno, C. Pelosi, R. Picchio, G. Agresti, U. Santamaria, F. Balletti and A. Lo Monaco, Stud. Conserv., **60** (2015) 131.

[41] C. Pelosi, G. Agresti, L. Calienno, A. Lo Monaco, R. Picchio, U. Santamaria and V. Vinciguerra, *Application of spectroscopic techniques for the study of the surface changes in poplar wood and possible implications in conservation of wooden artefacts*, Proc. of SPIE Optics for Arts, Architecture, and Archaeology IV, L. Pezzati & P. Targowski (eds.), SPIE, Munich, vol. 8790, 2013, 1-14.

[42] P. Baraldi, A. Lo Monaco, F. Ortenzi, C. Pelosi, F. Quarato and L. Rossi, Archaeometry, **56** (2014) 313.

[43] S. Hu, K. Li and X. Bao, *Wood species recognition based on SIFT key-point histogram*, Proc. of 2015 8^{th} International Congress on Image and Signal Processing (CISP 2015), IEEE, Piscataway (NJ), 2016, 702-706.

[44] N. Rosa da Silva, M. De Ridder, J.M. Baetens, J. Van den Bulcke, M. Rousseau, O. Martinez Bruno, J. Van Acker and B. De Baets, Ann. For. Sci., **74(2)** (2017) article n.30.

[45] K. Kobayashi, S.W. Hwang, W.H. Lee and J. Sugiyama, J. Wood Sci., **63(4)** (2017) 322.

[46] H.H. Cui and G.G. Fang, Chemistry and Industry of Forest Products, **35(6)** (2015) 96.

[47] F. Esteban, L.G. de Palacios, P.M. Conde, F.G. Fernández, A. García-Iruela and M. González-Alonso, Wood Sci. Technol., **51(5)** (2017) 1249-1258.

[48] P.D. Evans, I.A. Mundo, M.C. Wiemann, G.D. Chavarria, P.J. McClure, D. Voin and E.O. Espinoza, IAWA J., **38(2)** (2017) 266.

[49] V.A. Gerasimov, A.M. Gurovich, D.K. Kostrin, L.M. Selivanov, V.A. Simon, A.B. Stuchenkov, A.V. Paltcev and A.A. Uhov, J. Phys. Conf. Ser., **741(1)** (2016) 012131.

[50] L.F. Soares, D.C. Da Silva, M.C.J. Bergo, V.T.R. Coradin and J.W.B. Braga, Quim. Nova, **40(4)** (2017) 418.

[51] C. Lazarescu, F. Hart, Z. Pirouz, K. Panagiotidis, J.D. Barrett and S. Avramidis, International Wood Products Journal, **8(1)** (2017) 32.

[52] S. Nisgoski, A.A. de Oliveira and G.I.B de Muñiz, Wood Sci. Technol., **51(4)** (2017) 929.

[53] G. Capobianco, L. Calienno, C. Pelosi, M. Scacchi, G. Bonifazi, G. Agresti, R. Picchio, U. Santamaria, S. Serranti and A. Lo Monaco, Spectrochim. Acta, Part. A, **172** (2017) 34.

[54] G. Bonifazi, S. Serranti, G. Capobianco, G. Agresti, L. Calienno, R. Picchio, A. Lo Monaco, U. Santamaria and C. Pelosi, J. Electron. Imaging, **26(1)** (2017) 011003 1.

[55] G. Genco, C. Pelosi, U. Santamaria, A. Lo Monaco and R. Picchio, Wood res. **-** Slovakia, **56(4)** (2011) 511.

[56] L. Tolvaj, S. Tsuchikawa, T. Inagaki and D. Varga, Wood Sci. Technol., **49(6**) (2015) 1225.

[57] G. Genco, C. Maura, A. Lo Monaco, M. Marabelli and C. Pelosi, *A Methodological Approach to the Safeguard of the Wooden Door of Todi Cathedral*, Proc. of the International Meeting YOCOCU, De Vittoria, Rome, 2009, 217-221.

[58] M. Bernabei and J. Bontadi, J. Cult. Herit., **12(2)** (2011) 196.

[59] M. Bernabei, J. Bontadi, G. Quarta, L. Calcagnile and M. Diodato, International Journal of Architectural Heritage, **10(6)** (2016) 704.

[60] M. Bernabei, J. Bontadi, M. Diodato, Int. J. Archit. Herit., **11(3)** (2017) 305.

[61] C. Bertolini Cestari, C. Lombardi, E. Gubetti and O. Pignatelli, J. Cult. Herit., **3(1)** (2002) 53.

[62] K. Haneca and S. Van Daalen, Dendrochronologia, **44** (2017) 153.

[63] T.M. Olstad, J.M. Stornes and T.S. Bartholin, Eur. J. Sci. Theol., **11(2)** (2015) 159-169.
[64] A. Bayliss, P. Marshall, C. Tyers, C. Bronk, C.B. Ramsey, G. Cook, S.P.H.T. Freeman and S. Griffiths, Radiocarbon, **59(3)** (2017) 985.
[65] A. Daly and N.L.W. Streeton, Appl. Phys. A Mater., **123(6)** (2017) 123-431.
[66] M. Bernabei, G. Quarta, L. Calcagnile and N. Macchioni, J. Cult. Herit., **8** (2007) 202.
[67] V. Matskovsky, A. Dolgikh and K. Voronin, Dendrochronologia, **39** (2016) 60.
[68] T. Okochi, Dendrochronologia, **38** (2016) 1.