WEATHERING OF OUTDOOR BEECH WOOD AND METHODS OF CONSERVATION

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1. Introduction

Beech wood (*Fagus sylvatica L*) is one of the diffuse-porous hardwood types [1,2], and is characterized by its medium-high density, high resistance to shock [3], and its hardness and strength. For this reason, it is one of the most imported woods to have been used in ancient Egyptian civilization throughout the different ages. It was used for many purposes, such as in making statues, doors, windows, furniture and also in the outdoor elements of archaeological buildings. These outdoor elements are directly exposed to the damage resulting from various weathering factors which in turn lead to the appearance of deterioration on the outer surface and over time can reach the interior of the wood causing the loss of some of its surface parts.

Weathering is a term used to describe the process of slow decomposition that occurs in archaeological materials which are exposed to varying atmospheric conditions [4,5]. Weathering depends on many environmental factors such as moisture (relative humidity, dew, rain, and ground water), solar radiation (ultraviolet light, visible light, and infrared) and temperature [6,7]. These factors have a destructive effect on wood found in the external parts of archaeological buildings [8] and can cause complex damage [9] to the surface layers [8], including changes in the appearance of the ornamental elements and of the painted layers [10]. The impact of weathering begins with surface damage by directly affecting the coherence of the wood fibres and color layers [11]. In addition, weathering causes chromatic alterations, cracks and changes in surface texture [12,13]. This damage is the result of the joint effect of direct sunlight, water and erosion resulting from the wind, which contains sand particles [14,15]; this type of damage also causes a loss of wood mass [16]. In addition, the spread of fissures on the surface of archaeological wood creates a suitable environment for the penetration of biological factors of deterioration inside the wood [17].

2. Materials and methods

This study focuses on the beech wood used in the execution of wooden window grilles made of turned wood (Mashrabiya) in two archaeological Mosques: the Mosque of Prince Hassan and the Mosque of Khawand Asalbay (Figures 1 and 2). The Mosque

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of Prince Hassan is located in the city of Akhmim in the Sohag governorate, Egypt, and was established by Prince Hassan bin Amir Muhammad in 1704 AD (1117AH); it was completed in 1709 AD (1121AH) [18]. The Mosque of Khawand Asalbay, the wife of Sultan Qaytbay, is located in the Fayoum governorate, Egypt. It was built during the reign of her son Sultan Muhammad Ibn Qaytbay in 903 AH / 1499 AD [19].

The diagnosis of the damage and deterioration affecting these window grilles describes their condition at the time of the research. The images and the results of the sample examination were obtained before any restoration work was carried out for these two mosques.

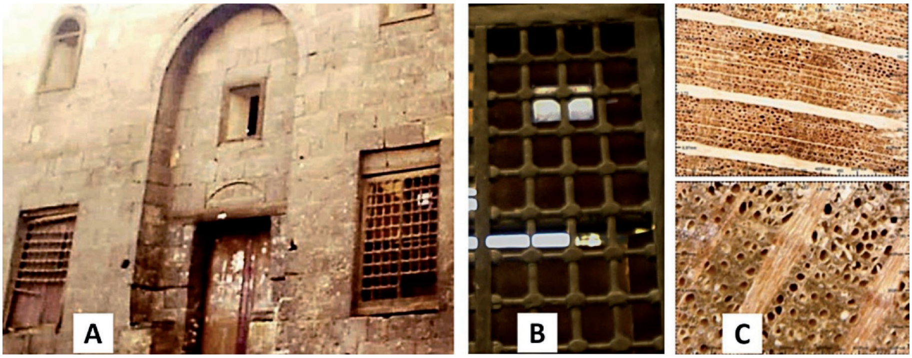

Figure.1 A. Prince Hassan Mosque; B. wooden window grilles made of turned wood (Mashrabiya); C. a cross-section of the beech wood (Fagus sylvatica. L).

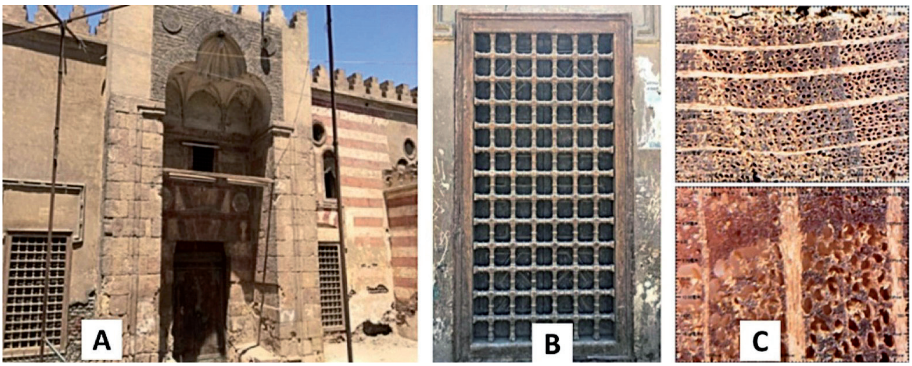

Figure.2. A. Mosque of Khawand Asalba; B. window grilles made of turned wood (Mashrabiya); C. a cross-section of the beech wood (Fagus sylvatica. L).

2.1. Main weathering factors surrounding the two mosques

Moisture

Wood is a hygroscopic material that is easily affected by variations in moisture levels [20]. There are many sources of moisture surrounding the two mosques, such as rain, dew, frost, and relative humidity which increases with high temperatures [21].

These mosques are also situated close to agricultural land which naturally leads to an increase in the amount of moisture. In addition, many ancient cities lack sewage networks which leads to an increase in moisture content and consequently affects the wood in these buildings.

The risk of damage from moisture is that it reacts with other deterioration factors surrounding the archaeological materials, such as air pollution. In high levels of humidity, some atmospheric pollutant gases turn into destructive acids for archeological wood and for its color layers [8]. Examples of these gases include sulfur and nitrogen dioxides which turn into sulfuric and nitric acids that cause the color of the wood to change [22]. Moisture, moreover, causes dust particles to adhere to the surface of the wood.

Temperature

The sun is a source of heat. Its high temperature leads to the destruction of outdoor wood used in archaeological buildings that are constantly and directly exposed to the excessive heat of high temperatures [23]. The swelling and shrinking of the wood, resulting from the fluctuations in relative humidity and in temperature, lead to the separation of the tongue and groove joints, the separation of other wooden pieces from one another, as well as to the overall dryness and fragility of the damaged wood [24]. Temperature causes a decrease in wood substance and strength and is related to other changes in wood polymers and structure [25].

Solar radiation

Most of the outdoor wood in archaeological buildings is directly exposed to the sun with its harmful ultraviolet, visible light, and infrared radiation [26]. Solar radiation is one of the main factors which causes notable changes in wood surfaces [27], in addition to other physical, chemical, and mechanical alterations in its properties [26].

The wood surface is affected by the photochemical deterioration caused by UV radiation [28]. It is a slow process that has an effect marked by only a few millimeters on the damaged surface, while the fibres of the wood below the surface remain coherent [29]. This process depends on the density, type of wood, and moisture content. The changes observed on the beech wood surface (such as fragility, disintegration, color changes, fibers dissociation, and roughness of surface) reflect the effect of UV radiation on the chemical compounds. Lignin, which is an adhesive for cellulosic polymers in the cell walls and the main component of middle lamellae [30], is severely affected by UV radiation [31]. These rays cause the chemical bonds of cellulose and hemicellulose to break down. Its effect on the cellulose can be observed in the following characteristics: a loss of strength, a change in the degree of polymerization, its color, tending toward yellow, and sometimes brown, and an increase in its solubility in alkalis [26]. Infrared radiation produces a heat that leads to a loss of absorbed moisture in the wood, which in turn changes the dimensions of the wood [32].

3. Results and discussion

Several examination methods and tests were carried out to better understand the effect of weathering on archaeological beech wood by using digital USB Microscopy, SEM Microscopy, Spectrophotometer OptiMatch 3100®, SDL Company, and FTIR. The results are reported as follows.

3.1. Physical changes

The direct exposure of outdoor beech wood in these two mosques to weathering factors has had a visible effect on the appearance and on the surface of this wood. We can notice that weathering has led to several changes in the appearance of the wood surface, such as roughness, weakness and fragility (Figures 3 and 4). The weakness of the fiber bonding of the wood surface has led to its crumbling very easily. Cracks are widely spread in all parts of the wood and range between fine, medium, and large cracks (Figures 5 and 6). These cracks develop gradually with continuous exposure to weathering factors, so we find that the small cracks get bigger and become wider, thus enabling the side edges of the wood parts to be readily observed [33, 34,12]. The spread of these cracks in the surface of the wood, moreover, facilitates the permeation of the various weathering factors to the inner layers of the wood. The cracks therefore are also considered suitable areas for the spread of wood decaying fungi [35].

Swelling and shrinking processes have led to the separation of the wooden joints especially when two pieces of wood are joined together in different directions [36] (Figure.5. D). The accumulation and adhesion of dust particles on the wood surface can also be observed. This is the result of the dust in the area surrounding the two mosques. Humidity and temperature also contribute to the adhesion of dust particles on the wood surface [37] (Figure.7).

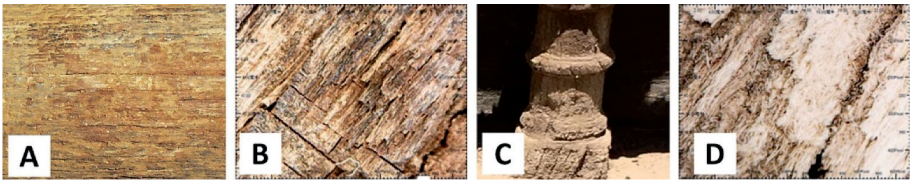

Figure.3. Detail of the roughness of the surface. A-B) Mosque of Prince Hassan; C-D) Mosque of Khawand Asalbay.

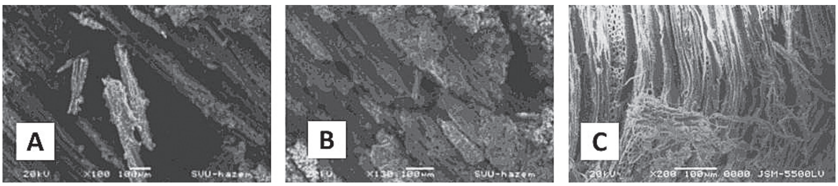

Figure 4. SEM micrographs. A-B) fragility and breakdown of the beech wood fibers, Mosque of Prince Hassan; C) loss of the bonding between beech wood fibers, Mosque of Khawand Asalbay, Fayoum. (A - 100 X; B – 130 X; C - 200X).

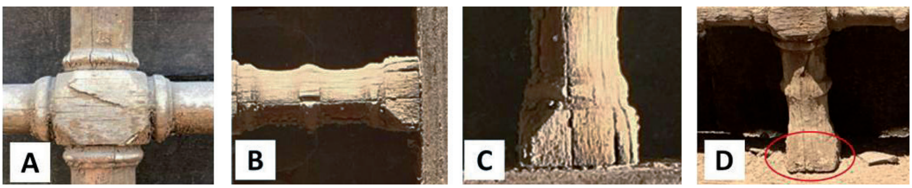

Figure 5. A, B, C) Spread of various cracks and checks on the beech wood surface; D) separation of joints, Mosque of Khawand Asalbay.

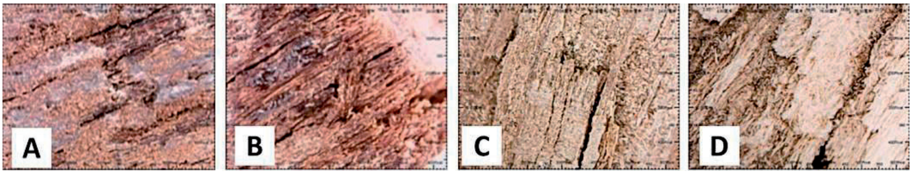

Figure 6. Dryness and spread of fine cracks on beech wood surface; A-B) Mosque of Prince Hassan; C-D) Mosque of Khawand Asalbay (Digital Microscope).

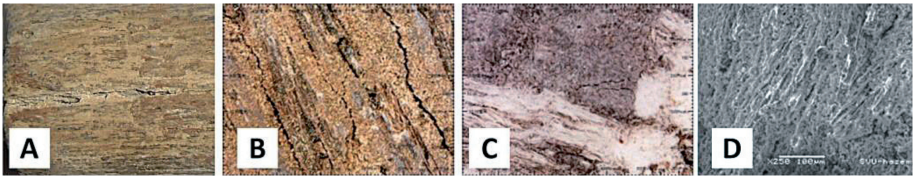

Figure 7. A, B, C, D) Adhesion of dust particles on the beech wood surface. B-C) Digital Microscope; D) SEM micrographs 250X.

Weathering causes color changes in the surface of the archaeological wood indicating that there are chemical changes. This process depends on several factors such as the type of wood and the duration of its exposure to weathering factors. The color of the wood surface turns gradually to yellow or brown, and as the degradation increases, the surface color turns into a very thin gray layer [8,17,38,39]. This process is clearly evident when the wood is exposed to weathering factors in dry climates or coastal areas [40]. The color change in wood surfaces occurs as a result of the photodegradation of chemical compounds in the wood, such as lignin and wood extractives by sunlight [8,38].

Color measurement

The (CIE-L*a*b*) system was used to measure the color changes of beech wood caused by the effects of weathering. L* indicates the lightness of the surface (0 = black to 100 = white), a* and b* clarify the chromaticity coordinates (+a* indicates the red color and -a* indicates the green color), (+b* indicates the yellow color, and –b* indicates the blue color). ΔE* clarifies the total value of color differences. The following equations were used to calculate the differences in ΔL*, Δa*, and Δb* and calculate the total color differences ΔE*:

$$\Delta L = L^* - L^*_0 , \Delta a = a^* - a^*_0 , \Delta b = b^* - b^*_{0.}$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$ [5,6,31,41-45].

In this research, some samples of beech wood, taken from the two mosques, were used to measure the color changes. We measured the change in color of the wood surface to find the difference in color between the external parts (surface) that are exposed to weathering factors and the internal parts (3mm from the surface).

Table 1 indicates the changes in the values: L*, a*, b*, and ΔE* of the samples S1 (external surface), S2 (internal parts) taken from the Mosque of Prince Hassan), and samples S3 (external surface), S4 (internal parts) taken from the Mosque of Khawand Asalbay).

Table 1. *Measurement of color changes of the beech wood surface (S1 and S3) and internal parts (S2 and S4)*

Sample	L*	ΔL*	a*	Δa*	b*	Δb*	ΔE*
S2	55.11	-------	6.29	-----	13.32	-------	-----
S1	48.07	- 7.04	1.68	- 4.61	5.68	- 7.64	11.37
S4	55.30	-------	1.31	------	7.35	-------	-----
S3	49.17	- 6.13	2.09	0.78	6.08	- 1.27	6.31

We can observe through this table that there is a clear decrease in ΔL* values (S1= -7.04) and (S3= -6.13) which indicates the darkening of the wood surface compared with the internal parts. A previous study indicated that the darkening of wood was the result of hemicellulose degradation caused by heat [46]. We can also notice a strong color change that can be easily observed by the naked eye on the external surface of the beech wood (ΔE* for sample S1=11.37) and (ΔE* for sample S3 =6.31).

3.2. Chemical changes

The effect of weathering on the main compounds of archaeological beech wood (cellulose, hemicelluloses, and lignin) can be observed by using FTIR spectra. The differences in the intensity, shape, and position of FTIR bands indicate the chemical changes in the deteriorated wood [47]. To better understand the changes in the chemical compounds, we compared the beech wood samples from the two mosques using FTIR analysis. The surface samples – "S1 and S3", the internal samples – "S2 and S4") and beech wood which was not exposed to weathering factors was used as a control sample (S5) (Table 2 and Figures 8 and 9).

Table 2. FTIR spectra results of beech wood samples.

Wavenumber (cm^{-1})	Functional group	Assignment
3410-3425	O-H stretching	Cellulose, lignin and hemicellulose [48]
1731 -1735	C=O unconjugated	Xylan (hemicellulose) [49,50]
1640	Absorbed O-H and conjugated C-O	Loss of water [51]
1595	C=C stretching of the aromatic ring	Lignin [52]
1508	C=C stretching of the aromatic ring	Lignin [53,52]
1463	Asymmetric bending in CH3	Lignin [52]
1421	CH2 bending	Cellulose (crystallized and amorphous) [54,52]
1384-1346	C-H bending	cellulose, hemicellulose [55]
1330-1320	C–H and C1-O vibration	In cellulose and syringyl units [48]
1267	C-O stretching	Lignin and hemicellulose [48,52]
1158	C-O-C vibrations	Cellulose [50]
897-898	C-H deformation	Cellulose [56]

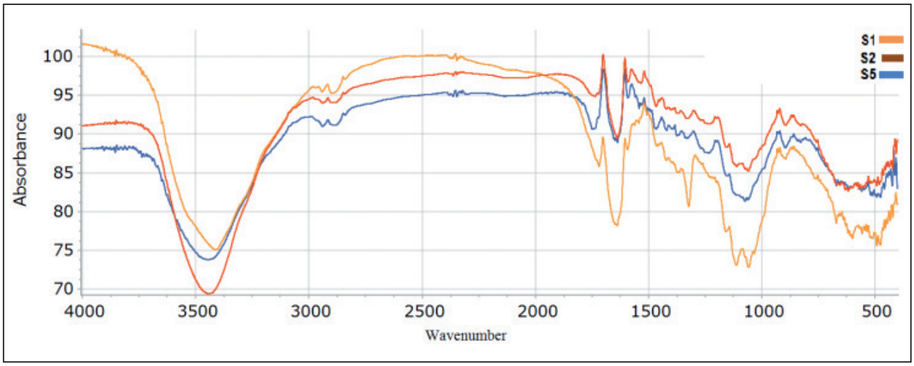

Figure 8. FTIR transmission spectra of the control sample (S5), surface (S1) and internal part (S2); Mosque of Prince Hassan.

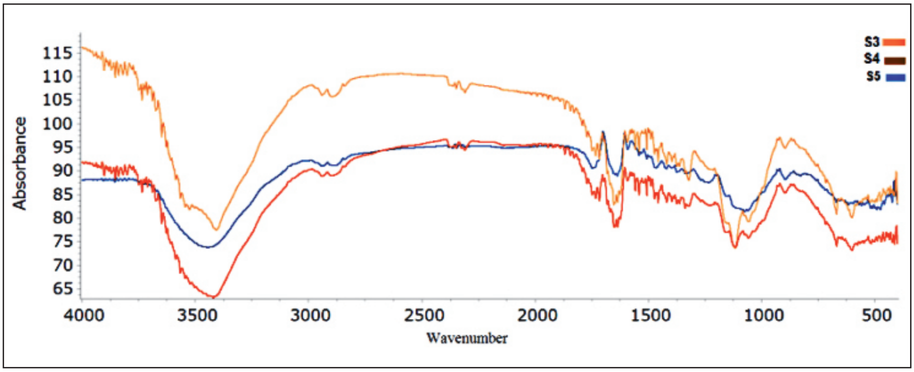

Figure 9. FTIR transmission spectra of the control sample (S5), surface (S3) and internal part (S4); Mosque of Khawand Asalbay.

We can notice a decrease in the O-H stretching band which appeared in some samples in the range of (3410- 3425cm^{-1}) with sharper peaks (S1 and S3 samples). The decrease in the intensity of the water absorption band at (1640cm^{-1}) resulted from the loss of water from the wood after its continuous exposure to high temperatures [49,57].

Two bands at 1730-1735cm^{-1} were observed in the samples S3 and S4, but in samples S1 and S2, the disappearance of the band of C=O stretching in hemicelluloses at 1733cm^{-1} was noted, compared with the control sample that had one band at 1733cm^{-1} which is due to the deterioration of the hemicellulose [4,6,58].

It was clearly noticed that the intensity of the lignin bands at (1595, 1508, 1421 and 1267cm^{-1}) decreased in both the S1 and S2 samples and was due to the effect of weathering factors, especially UV light [41,59].

The decrease of the C-O-C stretching bands at 1159 in all the samples indicate the breaking of the cellulose chains [60,49,57]. The decrease in absorption at 897cm^{-1} bands (C_1–H deformation of glucose ring) in all samples, refers to a diminution of the amorphous form of the cellulose [61].

3.3. Treatment

The treatment process includes cleaning and consolidation for some small samples which were separated from the wooden window grilles (Mashrabiya) in the two mosques as a result of the effect of weathering factors.

Cleaning

The cleaning process is one of the most difficult steps in the treatment for two reasons:

The spread of cracks full of dust and dirt on the surface.

The extreme vulnerability of the beech wood.

There are two kinds of cleaning: mechanical and chemical cleaning.

Mechanical cleaning

Mechanical cleaning is a very important process and any kind of damage to the surfaces, which are often very fragile and weak, must be avoided at all costs. During the accurate treatment of this archaeological wood, this process is carried out with great patience and a great deal of time. It is also an important step in detecting the extent of the erosion and damage [62]. The purpose of this process is to break down the bonds of the accumulated dirt on the archaeological surface [63]. The digital microscope and SEM micrographs revealed that the surface of the beech wood was covered with a layer of dust. Due to the weakness of the wooden surface, we used some brushes and small scalpels with great caution to remove the dust from the surface and cracks. The results showed that this method was inadequate and did not remove all the dust from the surface [63].

Chemical cleaning

Chemical cleaning was used to remove the remaining dust adhering to the external surface of the archaeological wood by using chemical solvents to break the bonds that join together the atoms of dirt [22]. In this research, Ethyl alcohol was used to remove the dust by using brushing. It gave good results in removing the dust on the surface and made no significant impact on the appearance of the wood surface. A previous study showed that the use of ethyl alcohol has little effect on the structure of wood [64].

Consolidation

In general, the main objective of the consolidation process is to bring back coherence and to stabilize the archaeological wood deteriorated by chemical, mechanical, and biological factors [65]. It helps also in the restoration of some mechanical properties of the damaged wood. Due to the fragility of the surface, the beech wood samples were consolidated with paraloid B.72 dissolved in acetone (3% w/v) [66] using soft brushes. The purpose of the consolidation is to ensure the adhesion of the separated fibers and parts that have become detached from the wood surface (Figure.10).

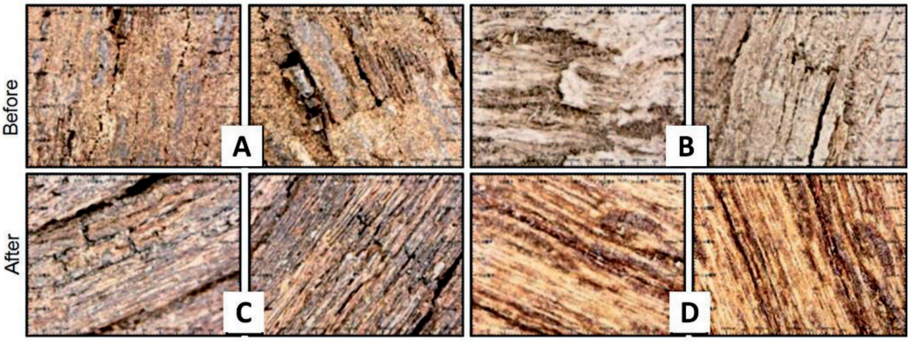

Figure 10. Some samples of the wooden window grilles made of turned wood (Mashrabiya). A) Mosque of Prince Hassan; B) Mosque of Khawand Asalbay, before treatment processes; C) Mosque of Prince Hassan; D; Mosque of Khawand Asalbay, after treatment processes (Digital Microscope).

4. Conclusions

The exposure of wood in archaeological and historical buildings to weathering factors is an inevitable reality. The situation and conditions, therefore, need to be constantly monitored and examined, even after all the treatment processes have been completed. In this research, the deterioration of the wooden surface resulted from the exposure of beech wood to moisture, temperature, and intense sunlight. By using the scanning electron microscope (SEM), the USB digital microscope, and spectrophotometer and FTIR analyses, this research clearly highlighted the changes in the beech wood surface, such as the spread of several cracks, its roughness and fragility, and the changes in color. The highest rate of color change appeared clearly on the beech wood used in the Mosque of Prince Hassan, as the color tended toward dark brown and is the result of hemicellulose degradation. The FTIR results showed the deterioration and deformation of the main compounds of the archaeological beech wood (Cellulose, Hemicellulose and Lignin) by the weathering factors. This deterioration and deformation appeared in both the surface and the internal samples (up to 3mm below surface).

The purpose of the treatment process on several small samples, which were found detached from the windows, was to benefit as much as possible from the research results. These results enabled us to select suitable methods and materials for the successful treatment of the deteriorated archaeological wood, instead of using modern paints or varnish and replacing some of the archaeological parts with new ones, which would have inevitably led to distorting the wooden artifacts and the loss of their archaeological, historical and artistic value. This is, however, a situation which can be observed in some historical mosques that have been treated in previous periods. In this research, we suggest appropriate scientific methods for correctly treating beech wood.

References

[1] Jourez, B. (2010). Anatomie et identification des bois, Université de Liège, p. 54.
[2] Noyer, E., et al. (2017) Xylem traits in European beech (Fagus sylvatica L.) display a large plasticity in response to canopy release, INRA and Springer-Verlag France, p. 2.

[3] Skarvelis, M., Mantanis G. I. (2013). Physical and mechanical properties of beech wood harvested in the Greek public forests, *Wood research*, Vol. 58, p. 2.

[4] Yildiz, S., et al. (2011). The effects of natural weathering on the properties of heat-treated wood, *BioResources* 6 (3), pp. 2504-2521.

[5] Teacă, C., et al. (2013). Structural Changes in Wood under Artificial UV Light Irradiation Determined by FTIR Spectroscopy and Color Measurements–A Brief Review, *BioResources* 8(1), pp. 1478-1507.

[6] Ozgenc, O., et al. (2013). Wood surface protection against artificial weathering with vegetable seed oils, *BioResources*. 8(4), pp. 6242-6262.

[7] Jankowska A. (2015). The study of influence artificial weathering on color changes of selected wood species from Africa, Annals of Warsaw University of Life Sciences - SGGW. *Forestry and Wood Technology*, N.92, pp. 131-136.

[8] Feist, W. C. (1990). *Outdoor wood weathering and protection*, In: Archaeological wood: Properties, Chemistry and Preservation, American Chemical Society, Washington, D.C., pp. 268-269- 276- 280- 564.

[9] Sell, J., Feist, W.C. (1986). US and European finishes for weather- exposed wood a comparison, *Forest Products Research Society*, Vol. 36, N.4, p. 37.

[10] Jankowska, A. Kozakiewicz, P. (2014). Comparison of outdoor and artificial weathering using Compressive properties, *Wood research*, Vol. 59(2), p. 245.

[11] Williams, R.S. (1991). Effects of acidic deposition on painted wood, *Journal of coating technology*, Vol. 63, N. 800, p. 55.

[12] Pfeffer, A., et al. (2012). Weathering characteristics of wood treated with water glass, siloxane or DMDHEU, Eur. *J. Wood Prod*. 70, pp. 165-176.

[13] Ozgenc, O., et al. (2012). Weathering properties of wood species treated with different coating applications, *BioResources* 7 (4), pp. 4875-4888.

[14] Williams, R.S., Feist, W. (1999). Water Repellents and Water- Repellent Preservatives for wood, *Forest Service*, U.S, p. 3.

[15] Oberhofnerová, E., et al. (2017). The effect of natural weathering on untreated wood surface, *Maderas. Ciencia y tecnología* 19(2), pp. 173-184.

[16] Evans, P. D, et al. (2000). Weathering of chemically modified wood surfaces natural weathering of Scots pine acetylated to different weight gains, *Wood Science and Technology* 34(2), pp. 151–165.

[17] Riggio, M., et al. (2013). Degradation of wooden surfaces in historical buildings: integrated sensing and modelling techniques for monitoring and conservation, *Conference: Built Heritage. Monitoring Conservation Management*, pp.898-905.

[18] Rashidi, W. B. (2007). Wood works in Islamic religious cities in upper Egypt from the beginning of the Ottoman period to the end of the 19th century AD archaeological study (923 AH - 1517 CE - 1317H - 1899 AD), Master Thesis, Department of Islamic Archeology, Faculty of Arts, South Valley University, p. 91.

[19] Al-Thammi, A. A. (2011). Tourism development of Fayoum Islamic sites) An environmental archaeological study, *Conference of the Fourteenth General Union of Arab Archaeologists*, Book of the Fourteenth Conference of the General Union of Arab Archaeologists, pp. 961- 962.

[20] Eaton, R. A., Hale, M. D. C. (1993). Wood decay, pests and protection, Chapman& Hall, Ist Ed, London, p. 47.

[21] Feilden, B. M. (2003). Conservation of Historic Buildings, 3rd Ed, Elsevier, p.103.

[22] El Hadidi, N. (1997). Treatment and Conservation of Wood - Application on Two Coffins at the Egyptian Museum of the Faculty of Archaeology Cairo University, Master Thesis, Conservation Department, Faculty of Archaeology, Cairo University, pp. 134,136.

[23] Cronyn, J. M. (1990). The elements of archaeological conservation, Routledge, New York, pp. 18-75.

[24] Mustaček, M. (2011). *Cause of the decay of archaeological Material*, In: Conservation of Underwater Archaeological Finds Manual, International Center for Underwater Archaeology in Zadar, 1st Ed, pp. 17- 20.

[25] Winandy, J. E., Rowell, R. M. (2005). *Chemistry of wood strength*, In: Handbook of Wood Chemistry and Wood Composites, CRC Press, USA, p. 309.

[26] Hon, D. N. S. (2001). *Weathering and Photochemistry of wood*, In: Wood and Cellulosic Chemistry, 2nd Ed, Marcel Dekker, Inc, pp. 513: 541.

[27] Tolvaj, L., Varga D. (2012). Photodegradation of timber of three hardwood species caused by different light sources, *Acta. Silva. Lign. Hung*, Vol. 8, p. 146.

[28] Milklečić, J., Rajkouić, V. J. (2011). Accelerated weathering of coated and uncoated beech wood modified with citric acid, *Drvna Industrija* 6, pp. 277-282.

[29] Sanderg, D., Söderstöm, O. (2005). Environmentally friendly wood linings for outdoor exposure, *International conference on durability of building materials and component* Lyon-France, p. 2.

[30] Novaes, E., et al. (2010). Lignin and Biomass: A Negative Correlation for Wood Formation and Lignin Content in Trees, *Plant Physiol*. Vol.154, pp. 555–561.

[31] Petrillo, M., et al. (2019). Chemical and appearance changes of wood due to artificial weathering–Dose–response model, *J. of Near Infrared Spectroscopy*, p. 1,4.

[32] Creangã, D. M. (2009). The conservation of archaeological wood, *European Journal of Science and Theology*, Vol. 5, N. 2, pp. 281- 283.

[33] Liu, R. (1997). The influence of didecyldimethylammonium chloride (DDAC) treatment on wood weathering, Ph.D. Thesis, University of British Columbia, pp.15-16.

[34] Shrivastava, M. B. (1997). Wood Technology, Vikas Publishing House PVT Ltd, New Delhi, p. 111.

[35] Sivrikaya, H., et al. (2011). Natural weathering of oke (Quercus Petrae), and chestnut (Castanea Sativa) coated with various finishes, *Color research and application*, Vol 36, N.1, p. 72.

[36] Glass, S. V, Zelinka S. L. (2010). *Moisture relations and physical properties of wood*, In, Wood handbook wood as an Engineering material, Forest Products Laboratory, U. S. Department of Agriculture Forest Service, Madison, Wisconsin, Centennial Edition, pp. 3-5.

[37] Ali, M. (2019). The Deterioration of Domestic Wooden Surfaces of Historical Buildings in Upper Egypt, *Athens: ATINER'S Conference Paper Series, No: ART2019-2697*.

[38] Huanga, X., et al. (2012). A spectrocolorimetric study on color modification of heat-treated wood during artificial weathering, *Applied Surface Science*, Vol. 258, Issue 14, pp. 5360-5369.

[39] Belie, N. D., et al. (2000). Durability of building Materials and components in the agricultural Environment: part I, The agricultural environment and timber structures, Silsoe Research Institute.75, p. 234.

[40] Williams, R. S. (2010). *Finishing of wood*, In: Wood handbook wood as an engineering material, Forest Products Laboratory, United States Department of Agriculture Forest Service, Madison, Wisconsin, Centennial Edition, p. 12.

[41] Huang, X. (2012). Study on the degradation mechanism of heat-treated wood by UV light, Ph.D. Thesis, University of Quebec at Chicoutimi, pp. 54-57.

[42] Darwish, S. S. (2013). evaluation of the effectiveness of some consolidants used for the treatment of the XIXTH century Egyptian cemetery wall painting, *International journal of conservation science*, Vol. 4, Iss. 4, pp. 413-422.
[43] Matsuo, M. (2011). Aging of wood - Analysis of color changing during natural aging and heat treatment, *Holzforschung, De Gruyter*. 65 (3), pp. 361-368.
[44] Bekhta, P., Niemz, P. (2003). Effect of High Temperature on the Change in Color, Dimensional Stability and Mechanical Properties of Spruce Wood, *Holzforschung*. 57, pp. 539–546.
[45] Matsuo, M., et al. (2010). Color changes in wood during heating: kinetic analysis by applying time−temperature superposition method, Applied Physics A, *Materials Science & Processing*, vol. 99, 1, p. 47−52.
[46] Kocaefe, D, et al. (2012). Study on weathering behavior of jack pine heat-treated under different conditions, *9th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics*, pp. 980-985.
[47] Dobrică, I, et al. (2008). FTIR spectral data of wood used in romanian traditional village constructions, Analele UniversităŃii din Bucureşti–Chimie, Anul XVII (serie nouă), vol.I, pp. 33–37.
[48] Pandey, K. K., Pitman, A. J., (2003). FTIR studies of the changes in wood chemistry following decay by brown-rot and white-rot fungi, *International Biodeterioration & Biodegradation* 52, pp. 151.160.
[49] Zidan, Y., et al. (2016). examination and analyses of a wooden face at the museum storage at the faculty of archaeology, Cairo university, *Mediterranean Archaeology and Archaeometry*, Vol. 16, No 2, pp. 1-11.
[50] Rudakiya, M, D., Gupte A, (2019). Assessment of white rot fungus mediated hardwood degradation by FTIR spectroscopy and multivariate analysis, *Journal of Microbiological Methods.157*, pp. 123–130.
[51] Ganne-Chédeville, C., et al., (2012). Natural and artificial ageing of spruce wood as observed by FTIR-ATR and UVRR spectroscopy, *Holzforschung*, Vol. 66, pp. 163–170.
[52] Lionetto, F; et al, 2012, Monitoring Wood Degradation during Weathering by Cellulose Crystallinity, *Materials.5*, pp. 1910-1922.
[53] Genestar, J. P, 2006, SEM–FTIR spectroscopic evaluation of deterioration in an historic coffered ceiling, *Anal Bioanal Chem*, pp. 987–993.
[54] Timar, M, C., et al., (2016). Color and FTIR analysis of chemical changes in beech wood (Fagus sylvatica l.) after light steaming and heat treatment in two different environments, *BioResources* 11(4), pp. 8325-8343.
[55] Bodîrlău, R., et al., (2008), Chemical modification of beech wood: effect on thermal stability, *BioResources* 3(3), pp. 789-800.
[56] Rana, R., et al., (2008). FTIR spectroscopy in combination with principal component analysis or cluster analysis as a tool to distinguish beech (Fagus sylvatica L.) trees grown at different sites, *Holzforschung*, Vol. 62, pp. 530–538.
[57] Hamed, S, et al, (2020). Investigating the Impact of Weathering and Indoor Aging on Wood Acidity Using Spectroscopic Analyses, *BioResources* 15(3), pp. 6506-6525.
[58] Xing, D., et al. (2015). Effect of Artificial Weathering on the Properties of Industrial-Scale Thermally Modified Wood, *BioResources*, Vol.10, N.4, pp. 8238- 8252.
[59] El Hadidi, N. (2017). Decay of softwood in archaeological wooden artifacts, *Studies in Conservation*. Vol. 62, NO. 2, pp. 83-95.
[60] Darwish, S., et al., (2013). The effect of fungal decay on ficus sycomorus wood, *International journal of conservation science*, Vol.4, Issue 3, pp. 271-282.

[61] Kubovský, I. (2020). Structural Changes of Oak Wood Main Components Caused by Thermal Modification, *Polymers*. 12, 485, p. 6.
[62] Rodgers, B. A. (2004). The archaeologist's manual for conservation, A Guide to Non-Toxic, minimal intervention artifacts stabilization, Springer science, Business media, Inc, New York, p. 44.
[63] Moncrief, A., Weaver G. (1992). *Cleaning*, Vol.2, Museums&Galleries Commission, London & New York, p. 21.
[64] Hamed, S, et al. (2013). Assessment of commonly used cleaning methods on the anatomical structure of archaeological wood, *International Journal of Conservation Science*, Vol. 4, N.2, pp. 153-160.
[65] Unger, A., et.al. (2001). Conservation of wood artifacts, Springer-Verlagberin Heidelberg, Germany, p. 362.
[66] El Hadidi, N, Darwish, S. (2014). Preliminary study on the different effects of consolidation treatments in heartwood and sapwood of a decayed gymnosperm wood, *Egyptian Journal of Archaeological and Restoration Studies*, pp. 1-11.

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Summary

The aim of this study is to highlight the appearance of deterioration resulting from weathering effects on the beech wood used in the ornamentation of wooden window grilles (Mashrabiya) in the Mosque of Prince Hassan, in Akhmim-Sohag and in the Mosque of Khawand Asalbay, in Fayoum, Egypt. This wood was accurately examined with a Digital microscope and Scanning Electron Microscope (SEM) to diagnose the deterioration processes on the surface of the wood. Fourier transform infrared (FTIR) was used to identify the changes in the main components of the beech wood resulting from weathering factors. The chromatic change of the beech wood surface was measured by spectrophotometer and the results were calculated by using the CIE-L*a*b* system. Results showed the physical and chemical changes that had occurred in the degraded beech wood. The results helped to develop a treatment plan using already experimented materials that do not harm the wooden artifacts.

Riassunto

Lo scopo di questo studio è quello di evidenziare l'aspetto del deterioramento derivante dagli effetti degli agenti atmosferici sul legno di faggio utilizzato nell'ornamento delle grate delle finestre in legno (Mashrabiya) nella "Moschea del principe Hassan", Akhmim-Sohag e nella "Moschea di Khawand Asalbay", Fayoum, Egitto. Questo legno è stato accuratamente esaminato con un microscopio digitale e un microscopio elettro-

nico a scansione (SEM) per diagnosticare i processi di deterioramento sulla superficie del legno. L'infrarosso in trasformata di Fourier (FTIR) è stato utilizzato per identificare i cambiamenti nei componenti principali del legno di faggio dovuti a fattori di alterazione. Il cambiamento cromatico della superficie in legno di faggio è stato misurato mediante spettrofotometro utilizzando il sistema CIE-L*a*b*. I risultati mostrano i cambiamenti fisici e chimici verificatisi nel legno di faggio degradato. Tali risultati hanno contribuito a sviluppare un piano di trattamento utilizzando materiali già sperimentati che non danneggiano i manufatti in legno.