WOODEN SURFACE INVESTIGATION: AN OPTICAL APPROACH BASED ON SHADOW MOIRÉ

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ABSTRACT

This paper deals with the wood behaviour when this orthotropic material is subjected to sudden variations in humidity content. Models of different wood species (Swedish pine, pitch pine, red fir, oak and chestnut) have been realized, as well as a proper climatic chamber equipped with sensors, humidifier, sample-housing and other particular features to allow the non contact surface measurement in real-time. In fact, a modified shadow moiré technique has been implemented in order to monitor the wooden surface shape variation during testing (the uncertainty was within 30 μm). The samples have been subjected to a known hygrometric cycle consisting of a humidification phase (24 hours) and a successive dehumidification phase (12 hours); the surface topography has been registered acquiring a fringe pattern every 45 minutes (except for the last 12 hours during the humidification phase). Besides the measured surface itself, other synthetic parameters (scalar and vectorial) have been considered as efficient and effective in describing the actual wooden surface condition (such as the actual position of the surface centroid, the absolute volume difference between the current surface and the initial one) and the variation of the surface in time (such as the derivative of the absolute volume difference above mentioned).

Results have showed how differently various wood species behave; all the species studied act similarly in response to a step-wise increase in humidity and almost all of them are not in equilibrium with the external environment at the end of the humidification phase. The wooden species behave quite differently instead when undergone to a step-wise decrease in moisture content and most of them gain a stable surface configuration after just 12 hours. On the ground of the so far obtained results, the optical technique selected appears fit and effective in monitoring wooden surface variations during hygrometric changes.

Introduction

The interest in the mechanical behaviour of wood is a very important task due to the increasing role played by wood structures in modern architecture as well as its applicability in restoration of ancient buildings and in restoration and conservation of wooden art works. In particular, the behaviour of wooden surfaces experiencing variable humidity conditions is of great importance both with concern to performances of wooden building’s structures and to ensure correct restoration and conservation of art works like wooden sculptures and panel paintings [1]. It is in fact well known that in preservation of wooden artworks there are three main reasons of deterioration: bio-chemical contamination, thermal shock and hygrometric shock. These latter are often acting within museums and warehouses where a poor or sometime lacking air conditioning system can determine uncontrolled thermo-hygrometric excursions. These variable environmental conditions cause moisture gradients within the wooden matrix which are responsible for swellings or withdrawals that could propagate up to the painted surface, severely damaging the aspect of the artwork.

In the literature there are only a few studies dealing with the influence of moisture on the physical properties of wood [1,2]. The characterization of the behaviour of wood related to changes in the humidity level could make easier restoration and preservation of wooden artefacts. In the last years, the increasing development of technology allowed the application of non contact whole-field measurement techniques. These techniques can play a fundamental role in the analysis of the mechanical behaviour of materials such as plastic and wood. Among these techniques: Digital Image Correlation, Structured Light, Electronic Speckle Pattern Interferometry (ESPI) [3]. Recently some real-time 3D wood panel surface measurement using laser triangulation [4] and light shadow scanning [5] have been proposed.

The goal of the present study is to investigate the applicability of a modified shadow moiré technique [6-8] combined with an ad-hoc image processing procedure based on the use of the 2D Fast Fourier Transform (2D-FFT) capable to measure shape along wooden surfaces. The measurement of wooden surfaces undergoing hygrometric variations is performed to characterise
the different behaviour of wooden species. Besides the known drawbacks of shadow moiré applications (such as poor automation and resolution, concavity/convexity recognition, fractional fringe orders measurements, and so on), other issues have been addressed. They were mainly related to the standard appearance of wooden surfaces (not a white matt look at all, also presenting an intrinsic fringe systems) and – in particular – to the need of a common frame of reference to which several measured surface have to be referred. In the next section, the shadow moiré technique will be briefly reviewed taking into account the new arrangement that allowed a profitable application of the Fourier Transform Method (FTM) and the concern related to the common Frame of Reference (FoR). Then the experimental facilities that were utilized or realized on purpose will be described, as well as the characteristics of the performed experiments. At this point, the results will be presented and discussed in detail.

The modified Shadow Moiré technique adopted

The optical shadow moiré system adopted in the present investigation includes:
- a monochrome light source (SUWTECH laser, \(\lambda=532\) nm and \(P=105\) mW),
- moiré grids on glass plate (Graticules mod. SAG4),
- a Dalsa DS-21-02M30 digital camera with frame grabber microEnable-III,
- a Nikkor AF lens (focal length 60 mm).

A quasi-standard lay-out was set-up (the grid was tilted in order to introduce a carrier fringe pattern). The shadow moiré technique does not need to fulfill stringent requirements on stability of instrumentation and quality of the light source. Shadow moiré patterns can be observed when a master grating is placed close to the surface to be measured and is illuminated at an angle \(\theta\) using a collimated (or divergent) light beam. The opaque lines on the grid will project shadows on the surface. Optical interference will occur between these shadows and the actual master grating. Under proper conditions, the resulting moiré pattern is the contour map of the surface (in Figure 1.a, a synthetic fringe pattern - that simulates typical data when the wooden surface measurement has to be addressed - is showed).

\[
i_{\text{in}}(x,y) = i_0(x,y) + i_1(x,y) + i_2(x,y) + i_3(x,y) + \cdots + i_n(x,y) = i_0(x,y) + i_1(x,y) + i_2(x,y)
\]

where:
\[ F[I_m] = I_0(\omega_x, \omega_y) = I_0(\omega_x, \omega_y) + I(\omega_x - \omega_{xx}, \omega_y - \omega_{yy}) + I(\omega_x + \omega_{xx}, \omega_y + \omega_{yy}) + I_n(\omega_x, \omega_y). \]  (2)

where, as usual, \(\omega_x\) and \(\omega_y\) represent the spatial frequencies along the x and y directions (the over-sign denotes the complex conjugate value). Regardless of the \(I_n\) noise term – whose energy is, at worst, uniformly distributed over the \(\Omega\) plane – the other terms correspond to three distinct peaks (as observed in the simulated case study - Figure 1.b):

- \(I_0\) related to the low frequency \(I_0\) term of the \(I_m\) fringe pattern;
- \(I\) and \(I_n\) distributed with polar symmetry with the origin of the \(\Omega\) plane and related to the frequency content of the in-phase signal \(I_0\).

The standard application of the 2D-FTM is a direct extension of the algorithm proposed by Takeda [9,10]. The 2D approach allows a more efficient noise removal and localization of the information of interest in the \(\Omega\) plane. The \(I\) term is isolated and frequency shifted towards the origin of the \(\Omega\) plane (accomplishing the so-called frequency demodulation). Influence of \(b_0\) and \(b_i\) is therefore highly reduced. The \(\phi\) estimation is performed by standard operations. Filtering in the Fourier domain to localize the phase information is, however, a critical issue. It is usually based on applying windows of different size and shape to the frequency plane. The accuracy to which the phase can be estimated depends on the size and shape of the 2D frequency filter used to select the order; also the spatial resolution depends on it.

In [11] an alternative approach in designing filters is implemented. Wood shape variations have been measured by means of a shadow moiré technique based on this method. In what follows, the basic principles of the mentioned approach are summarized. In order to obtain the \(I_0\) measurement, the frequency spectrum \(I_0(\omega_x, \omega_y)\) is modified by removing both the low frequency signal component \(I_0\) and the high frequency noise component \(I_n\). The removal of the high frequency noise component \(I_n\) is performed by an automatic procedure consisting of few steps:

- statistical characterization of the noise by means of a region of the fringe pattern spectrum with no phase information;
- spectrum segmentation using a threshold value calculated on the ground of the above mentioned statistical step;
- automatic design of a 2D band-pass filter by processing the obtained binary image; the designed filter is able to extract the harmonics related to the in-phase signal;
- final band-pass filtering operation to extract the in-phase signal \(I_0\) by rejecting the high frequency noise component \(I_n\).

Having measured the carrier fringe pattern in some independent way, the demodulation step is performed in the spatial domain. As a matter of fact, by the above described operations, the \(\Psi(x,y)\) quantity is gained; hence, the desired \(\phi(x,y)\) quantity is obtained by subtracting the carrier plane \(\omega_{xx}X + \omega_{yy}Y\).

Taking into account the same synthetic fringe pattern, the procedure described above is summarized in Figure 1. Figure 1.b shows a 3D perspective of the spectrum, while in Figure 1.c one can see the two-dimensional band-pass filter designed to capture the in-phase information, \(b\). The result of the application of the filter is displayed in Figure 1.d. Continuous phase information – and so surface data - is measured by standard operations based on the application of the Oppenheim algorithm [12]. Figure 1.e and Figure 1.f show respectively measured and synthetic surfaces. The measurement accuracy has been calculated by theoretical and experimental analyses in [11]; as far as the latter investigations are concerned, the uncertainty was within 30 \(\mu\)m for the two-dimensional approach. In the present case study, the accuracy has been improved by modifications in the experimental set-up and in the signal processing algorithm itself in order to allow the measurement of the tiny shape changes that result from hygrometric variations.

As mentioned in the introduction, the present investigation deals with measurement of surface profiles over time: i.e., the aim is to finally make a comparison of the observed wooden surface while the humidity content varies along time. In order to accomplish this, all the measured surfaces - related to the same investigated wooden sample - have to be referred to the same FoR. This characteristic is not an inherent property of the shadow moiré set-up adopted, because no contact-point between grid and wooden sample is allowed (and so, no zero order fringe). In fact, the wooden surface is supposed to freely expand and contract itself depending on the humidity content variation. To establish a unique FoR, further post-processing is needed. Once fringe-data are processed, a limited region of the \(I_0\) information is investigated along time. The purpose of this research is to figure out the coordinate of a point – within each limited domain of the current acquired data – which shows along elapsed time the same \(I_0\) value. As a matter of fact, this value is related to the fractional fringe order and so to the final phase map value. Once the coordinates of this point are calculated for all the acquired images, imposing the same phase values to this point results in establishing a unique FoR. As an example, in Figure 2.a some of the fringe limited domains - that were taken into consideration in a case study - are displayed; a red cross indicates the position of the calculated iso-phase profile along time. In Figure 2.b, one can see the phase values that have to be added - to each obtained phase map - to establish a unique FoR.
Aim of the experimental tests is to measure along time the surface of wooden specimen subjected to high content of moisture variation in order to evaluate surface shape modifications. To perform these tests the wooden specimen is placed within a proper climatic chamber, in order to isolate the sample from the external environment. The specimen is hold by means of three M5 screws with conical tip which are screwed to a rigid frame. The conical tips of the screws grip the wooden specimen at three different points on its lateral surfaces, aligned on a plane parallel and close to the surface to evaluate. This approach, adopted to minimize translation of the specimen due to strain along different directions and due to volume changes, enables to observe on the investigated surface only those changes due to variations in moisture content.

The climatic chamber was realized in order to test wooden samples undergoing hygrometric variations; hence, it has to fulfil some requirements. In particular, it has got a transparent front surface and allows the housing of a mechanical system inside in order to tilt precisely the moiré grid (see Figure 3.a and Figure 3.b for the realized climatic chamber and its features). An ultrasonic humidifier was chosen to vary the moisture content of the air inside the chamber and probes were installed to measure both humidity and temperature.

Several wooden samples were realized (83x83x20 mm$^3$) made by Swedish pine, pitch pine, red fir, oak and chestnut, whose features are summarized in Table 1. All samples have been obtained from wooden tables by hand saw and then turning to get a precise circular sample; the inscribed squared portion is the final sample. All four lateral sides, for each sample, have then
been sealed by using wax to inhibit moisture to penetrate through these surfaces; this way, the condition of a wooden table characterized by infinite extension has been reproduced. Finally a layer of talcum powder was spread over the sample surface that was supposed to be checked by the shadow moiré technique in order to increase the image contrast. In Figure 4, the general design of the sample, as well as some pictures of a pitch pine model, are displayed.

Table 1. Wooden sample characteristics

<table>
<thead>
<tr>
<th>Wood type</th>
<th>L_a</th>
<th>L_b</th>
<th>L_c</th>
<th>L_d</th>
<th>Thick_A</th>
<th>Thick_B</th>
<th>Thick_C</th>
<th>Thick_D</th>
<th>Thick_E</th>
<th>Thick_F</th>
<th>Thick_G</th>
<th>Thick_H</th>
<th>Mass (bef)</th>
<th>Mass (aft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swedish pine</td>
<td>81.70</td>
<td>82.70</td>
<td>84.22</td>
<td>84.26</td>
<td>19.80</td>
<td>19.80</td>
<td>19.72</td>
<td>19.72</td>
<td>19.80</td>
<td>19.80</td>
<td>19.70</td>
<td>19.70</td>
<td>57.916</td>
<td>63.846</td>
</tr>
<tr>
<td>Pitch pine</td>
<td>81.30</td>
<td>81.10</td>
<td>81.50</td>
<td>81.16</td>
<td>19.82</td>
<td>19.72</td>
<td>20.00</td>
<td>19.94</td>
<td>19.86</td>
<td>19.90</td>
<td>19.90</td>
<td>84.350</td>
<td>87.797</td>
<td></td>
</tr>
<tr>
<td>Red fir</td>
<td>84.42</td>
<td>83.70</td>
<td>83.20</td>
<td>82.16</td>
<td>19.90</td>
<td>19.90</td>
<td>19.94</td>
<td>19.92</td>
<td>19.94</td>
<td>19.96</td>
<td>20.00</td>
<td>58.501</td>
<td>60.541</td>
<td></td>
</tr>
<tr>
<td>Oak</td>
<td>84.16</td>
<td>84.18</td>
<td>83.90</td>
<td>81.40</td>
<td>19.74</td>
<td>19.80</td>
<td>19.80</td>
<td>19.80</td>
<td>19.80</td>
<td>19.90</td>
<td>19.90</td>
<td>96.268</td>
<td>99.070</td>
<td></td>
</tr>
<tr>
<td>Chestnut</td>
<td>84.30</td>
<td>83.30</td>
<td>82.16</td>
<td>83.10</td>
<td>19.60</td>
<td>19.74</td>
<td>19.80</td>
<td>19.80</td>
<td>19.76</td>
<td>19.62</td>
<td>19.62</td>
<td>79.385</td>
<td>82.879</td>
<td></td>
</tr>
</tbody>
</table>

Subscripts of L (a,b,c,d) and of Thick (A,B,C,D,E,F,G,H) are declared in Figure 3.a. "bef" and "aft" indicate that the mass has been measured "before" and "after" the superposition of wax and talc.

Figure 4. Wooden sample investigated. a) Design of the sample; b) front view of the "pitch pine" sample; c) lateral view of the same sample

All samples were subjected to a seasoning phase before the investigation. Afterwards, the humidification and dehumidification test was performed. Each model was placed inside the chamber and subjected to variable humidity, H, at constant (and monitored) temperature, T. In particular, from an initial state characterized by H=55%, each sample was located inside the chamber for 24 hours at H=85% (humidification phase). During the first 12 hours, shadow moiré fringe patterns have been acquired roughly every 50 minutes; this way, shape variations of the model were monitored during the first half of the humidification phase by means of the 2D-FFT based post-processing technique. Afterwards, the model underwent to a dehumidification phase (T=24 °C and H=55%) for 12 hours and, again, the wooden surface shape was measured at a definite rate. A typical hygrometric cycle history is shown in Fig. 5, in which both the designed and realized thermo-hygrometric trends are displayed.

In the current application, instead of proceeding by means of the standard spatial demodulation, a different approach was chosen. In fact, in order to simplify the optical measurement, the spatial carrier was retrieved by processing the fringe pattern that results from the measurement of the undeformed specimen (before the beginning of the humidification phase). Actually, besides the obvious simplification, this has allowed to detect real tiny variation from the initial undeformed condition, rather than the actual shape of the deformed wooden surface. This way, the gained map of the total phase \( \Psi_0(x,y) \) obtained by a bilinear regression was afterwards used to spatially demodulate each acquired successive fringe patterns. Once a unique FoR has been definite for all the surface maps, two synthetic parameters are calculated. They were thought to be representative of the current wooden surface characteristics:

- the absolute of the volume difference \(|\Delta V|\) (a scalar quantity); it indicates the absolute amount of volume variation among the current situation and the initial one before the beginning of the humidification phase;
- the centroid of the volume difference \( G_{\Delta V} \) (a vector quantity), whereas - this time - \( \Delta V \) is the algebraic difference. This parameter provides information regarding the eventual direction towards which the surface has warped during the humidity variation and keeps therefore into account any asymmetric behaviour of the wooden model.

Besides the above mentioned main parameters, other quantities will be provided. They are directly related to the former ones. Starting from the trend of the \(|\Delta V|\) parameter versus time, five parameters are calculated; they are related to the speed of variation of the absolute volume in some key-instants of the process and provide then information about the wood response to a sudden humidity content variation or about the gained hygrometric-equilibrium. The actual value of \(|\Delta V|\) is also given in some
peculiar times, such as the end of the humidification phase ($\Delta V_{\text{end-hum}}$) and the end of the test ($\Delta V_{\text{end-exp}}$). The ratio between the latter and the former will give the deformation factor ($DF$); the more this adimensional parameter approaches zero the more the final shape of the wooden sample has come back to its original configuration.

Figure 5. Comparison between the real (or measured) and the ideal hygrometric cycle

From the variation of the volume $V$ versus time (by using which the vector quantity $G \Delta V$ is calculated), three other parameters are provided, namely:
- $Max z_{\text{mean}}$, that indicates the “maximum mean” drift of the surface as a whole during the process (this parameter should be low, since we are interested in shape variation rather than volume one);
- $\Delta z_{\text{tot}}$ and $\Delta z_{\text{init}}/\Delta z_{\text{tot}}$, that provide absolute and normalized information regarding the amount of shape variation;
- the Centroid Shifting Area (CSA), related to the dimension of the maximum rectangle within which the centroid of the surface moves itself during the experiment. This information informs on eventual asymmetric behaviour of the wooden sample.

Results and comments

In this section, results will be presented and commented. As an example, in the following Figure 6 four key-instants related to the “red fir” investigation are displayed.

In Figure 7 the $|\Delta V|$ vs time and the $G \Delta V$ trend are shown, regarding the “Swedish pine” and the “oak” wooden samples. In the $|\Delta V|$ plot it is worth to notice the actual values at the end of the humidification phase ($|\Delta V|_{\text{end-hum}}$) and at the end of the process ($|\Delta V|_{\text{end-exp}}$), as it was mentioned in the previous section. In the cases displayed even if the equilibrium was gained (the derivative of $|\Delta V|$ is no more negative and seems approaching zero), the wood retains a certain amount of deformation; this is also evident observing the value assumed by $DF$. The value of the derivative of $|\Delta V|$ calculated at the beginning of the experience (time=0) and at the beginning of the dehumidification phase (time=24 h) tells plenty of information about the wooden response to step-wise variation of the environmental humidity content. Similarly, computing the derivative at the end of the process can acquaint the researcher about the gained/not gained equilibrium. In the displayed examples, even if the equilibrium was probably reached at the end of the dehumidification phase, the same was not true at the end of the monitored humidification phase. In those instants the wood was still changing its shape rapidly.

On the right of the same Figure 7, the vectorial information related to the position assumed by the surface-barycentre is shown. In all the case-studies analyzed, the surface moved itself in such a way that its centroid remained always confined within a really tiny area located in the geometrical centre of the model. The maximum extension of the CSA was registered in the “oak” experiment (Figure 7.d). In this case the minimum rectangle containing the centroid movements was characterized by $8.8 \times 2.65 \, \text{mm}^2$.

Table 2 the results on the wooden samples investigated are summarized. Imposing a step-wise increase in the humidity content, all the models showed a rapid variation of their volume at a rate of $27.8 \, \text{mm}^3/\text{h}$. The “red fir” sample had the lowest value ($25.0 \, \text{mm}^3/\text{h}$). The acquisition time chosen was too short as it is evident monitoring the derivative of the $|\Delta V|$ (second row in the table). Except for the “chestnut” sample, no other wooden sample reached its hygrometric equilibrium. Nothing can be stated regarding the not monitored period of time (between time=12 h and time= 24 h). A great scatter was registered as a response to the step-wise humidity variation at the beginning of the dehumidification phase: a really slow inertia is shown by
the sample made by "red fir" (-121.0 mm³/h). On the contrary, the "pitch pine" sample shows a big inertia in varying its shape (-11.0 mm³/h).

At the end of the humidification phase, all the samples showed a positive drift in the average surface position corresponding to a general expansion of the model. This drift is however very low (its mean value is 41 μm) and is related to the housing approach chosen for the sample: it was in fact designed to allow just modification in shape rather than in volume. Modifications in shape are taken into account by monitoring the extreme values of the measured surface. Row seven in the object table provides the related information in different ways: absolute and normalized (numerically and visually). Under the action of the humidity variation, the wooden shape changes its extremes and generally expands itself. The maximum variation in shape has been so registered studying the "Swedish pine" sample (the normalized parameters is 0.39). On the other side, pitch pine does not vary too much its shape.

The last three rows informs about parameters related to the |ΔV| trend. The actual values of this function in some specific instants are valuable for the understanding of the behaviour of wood. In some cases (chestnut, pitch pine, red fir) these values cannot be used, because the observation time was too short to monitor the gaining of the hygrometric equilibrium. Regarding oak’s and Swedish pine’s models, the dehumidification phase was actually over; even though the DF indicates values respectively 0.63 and 0.80. In other words, the above mentioned samples were not able – during the time of observation – to
come back to the undeformed configuration. Their final shape retains a certain amount of deformation due to the absorbed humidity.

**Table 2. Synthetic results of the experimentations**

<table>
<thead>
<tr>
<th></th>
<th>Chesnut</th>
<th>Oak</th>
<th>Pitch Pine</th>
<th>Red fir</th>
<th>Swedish pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hum-step response [mm/h]</td>
<td>29.2</td>
<td>27.7</td>
<td>27.4</td>
<td>25.0</td>
<td>29.7</td>
</tr>
<tr>
<td>Hum-end acquisition [mm/h]</td>
<td>5.1</td>
<td>18.4</td>
<td>22.4</td>
<td>14.5</td>
<td>12.3</td>
</tr>
<tr>
<td>Hum-end phase [mm/h]</td>
<td>6.2</td>
<td>11.2</td>
<td>2.0</td>
<td>13.5</td>
<td>13.6</td>
</tr>
<tr>
<td>Dehum-step response [mm/h]</td>
<td>-66.1</td>
<td>-57.1</td>
<td>-11.0</td>
<td>-121.0</td>
<td>-17.5</td>
</tr>
<tr>
<td>Dehum-end acquisition [mm/h]</td>
<td>-5.1</td>
<td>7.8</td>
<td>4.5</td>
<td>-3.0</td>
<td>-0.1</td>
</tr>
<tr>
<td>Max $z_{end}$ [mm] - End Hum</td>
<td>24</td>
<td>56</td>
<td>26</td>
<td>53</td>
<td>48</td>
</tr>
<tr>
<td>$\Delta z_{end}$ [mm]: $\Delta z_{real}/\Delta z_{opt}$ [adim.]</td>
<td>0.44</td>
<td>0.76</td>
<td>0.47</td>
<td>0.67</td>
<td>0.48</td>
</tr>
<tr>
<td>CSA [V/um total area]</td>
<td>0.050</td>
<td>1.100</td>
<td>0.410</td>
<td>0.710</td>
<td>0.270</td>
</tr>
<tr>
<td>$</td>
<td>\Delta V</td>
<td>_{min}$ [mm$^2$]</td>
<td>235</td>
<td>495</td>
<td>155</td>
</tr>
<tr>
<td>$</td>
<td>\Delta V</td>
<td>_{max}$ [mm$^2$]</td>
<td>92</td>
<td>313</td>
<td>189</td>
</tr>
<tr>
<td>DF [adim]</td>
<td>0.39</td>
<td>0.63</td>
<td>1.22</td>
<td>0.32</td>
<td>0.80</td>
</tr>
</tbody>
</table>

**Conclusions**

Preliminary experimental investigations have proven the capabilities of the optical approach in object to monitor wooden surface variations during hygrometric changes. Results showed how differently various wood species behave; all the species studied act similarly in response to a step-wise increase in humidity and almost all of them are not in equilibrium with the external environment at the end of the humidification phase (24 hours). On the contrary, the wooden species behave quite differently when undergone to a step-wise decrease in moisture content and most of them gain a stable surface configuration after just 12 hours. A new campaign of experiments is currently being carried on varying the duration of the humidification and dehumidification phases, monitoring at a higher rate the surface shape nearby the step-wise humidity change and including more wooden species.

Further developments will take into account the wood response to changes in both temperature and relative humidity reproducing those acting in museum environments; as a matter of fact, these environmental parameters are quite often not adequately controlled. This investigation will be carried on taking into account the observed wooden surface changes related to the imposed hygrometric cycles.

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