An integrated approach to the conservation of a wooden sculpture representing *Saint Joseph* by the workshop of Ignaz Günther (1727-1775): analysis, laser cleaning and 3D documentation.

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ABSTRACT

This paper reports the conservation procedure applied to a wooden sculpture representing *Saint Joseph* attributed to the workshop of Ignaz Günther (1727-1775).

The component material of the wooden sculpture was identified by observing the thin sections under an optical microscope; the materials layered on the surface were analyzed by optical microscopy, micro-Raman and Fourier Transform Infrared spectroscopy. The laser cleaning tests were carried out with a Q-switched Nd:YAG system. The surface was examined before and after the cleaning with the aid of a video microscope, reflectance spectrophotometer and scanning electron microscopy.

The steps of the work were documented on a digital tri-dimensional model of the sculpture created by a close range image system in order to carefully register scientific, technical, conservative, and material aspects.

The microscopic observation of wood thin sections allows identifying it as lime tree. The analysis of the surface materials highlighted the presence of lead white applied by a siccative oil and barium sulphate. The infrared spectroscopic analysis of the brown surface layer revealed the presence of shellac. The laser cleaning proved an effective method to remove the surface dirt and to reduce the aged protective layer without affecting negatively the wood. The diagnostic analysis carried out prior and during the cleaning process was fundamental to verify the applicability of the laser to the wood surface in order to obtain an efficient cleaning action without secondary damaging effects. In addition, considering the reduced number of laser cleaning examples applied to wooden material available in literature, the documentation of the adopted working process could be a useful reference for the divulgation and sharing of the obtained data.

Keywords: wood sculpture/ microscopy/ Fourier Transform Infrared spectroscopy/ micro-Raman spectroscopy/laser cleaning/3D documentation.

1. Research aims

Aim of this paper is to report the work experience with the conservative procedure on an 18th wooden sculpture including preliminary diagnostics, documentation with close range image system, and laser cleaning evaluation. The research aims at finding the optimum laser condition to clean the sculpture surface without damaging the wood and altering the original painting traces. To reach this goal an integrated approach was necessary by different investigation techniques and professionals operating in the field of cultural heritage.

2. Introduction

The focus of this paper is to report the work experience with the conservation procedure on a wooden sculpture representing *Saint Joseph* (**Figure 1A**) and attributed, according to stylistic features and comparison with other artifacts of the same school, to the workshop of Ignaz Günther (1727-1775), an important artist operating in Bavaria during the 18th century [1].

Before starting the conservation work the sculpture was investigated in order to characterize the constitutive materials and the state of preservation. In particular, wood and surface materials were investigated by optical microscopy, Fourier Transform Infrared (FTIR) and micro-Raman spectroscopy. In fact, any intervention on objects of cultural heritage interest has to be well documented and performed in accordance with the original materials. The analysis of the constituent materials and of the stylistic features of artworks provides useful information about provenance and authentication [2]. It also provides a valid aid to a better comprehension of the usage and of the significance of the investigated objects within peoples worship traditions [3]. The extensive knowledge of the artifact obtained by scientific methodologies allows to evaluate the state of preservation and to support the conservation work methodologies [4-5]. The diagnosis of the botanic species is of crucial significance in the study of a wooden artifact. It allows to outline the wood physical and mechanical characteristics, its durability and workability, and to provide information on the historical-artistic contest [6-7].

The conservative intervention on the sculpture was aimed **at** the removal of the surface aged layer taking into account that wood exhibits peculiar features that often inhibit the use of traditional cleaning procedures, mechanical or solvent-based [8-10]. Wood is a very porous material that can absorb the organic solvents and the water solutions usually adopted by the restores for the surface cleaning. Moreover the wood surface can be easily scratched [8, 11-12]. In this case the protective coating applied on the sculpture surface **has been losing** its transparency, elasticity and mechanical strength due to the exposure to environmental parameters such as different kinds of radiation and high temperature. This protective coating appears fragmentary and characterized by an orange fluorescence under ultraviolet radiation, as can be observed in the **Figure 1B**. Dirt deposits are also visible on the surface.

Usually the conservative intervention involves the removal of this brownish layer and dirt by mechanical or potentially hazardous solvents. In our work laser cleaning was chosen as possible alternative method to overcome the difficulties in the cleaning of the above mentioned material. **The laser irradiation and cleaning tests were carried by selecting energy and fluence values in accordance to previous results** [8-10, 13]. **The morphological and colour changes were evaluated by using a video**

microscope, a reflectance spectrophotometer and scanning electron microscopy to compare irradiated and non-irradiated surface areas.

A phase of the work was devoted to the collection of the information needed to prepare the condition record including data acquisition, documents, graphics and photographs. As stated in the European Standard EN 16095 [14], the organizations responsible for the conservation of tangible cultural heritage are required to maintain a record of its condition. The condition record has an historical value and contains all essential and relevant information in a logical and well-organized order [15]. In general, during a documentation process it is common to use a two-dimensional system to record the alteration, decay, additions, sampling points, etc. of museum objects. In the present work it was decided to use a close range image system to obtain a 3D digital model of the object under investigation and conservation. The data, significant for the assessment of the results, were interactively transferred on the 3D generated model.

2. Experimental section

2.1 Sampling

As the artefact was made of several pieces joined together, it was necessary to collect seven samples which could be representative of the entire sculpture. The choice of the micro-samples was made taking into account both the laboratory technique requirements and the respect of the work of art. For this reason the wood samples were chosen in the inner part of the sculpture to avoid damaging the surface.

Two micro samples (1 and 2) were taken from the back side of the sculpture in order to characterize the white painting materials and the brown surface layer on wood respectively.

2.2 Wood sample analysis

In order to identify the botanical species, thin sections of wood samples were examined under a Polyvar 100 optical microscope equipped with a PIXeLINK digital camera. They were described according to the standard of the IAWA list of microscopic features for hardwood identification and the wood taxa identification was carried out according to literature dichotomous keys, as previously described [5].

2.3 Microstratigraphic analysis of surface layer

The microstratigraphic analysis was performed on a part of the sample 1 mounted as polished cross-section embedded in polyester resin. The sample was examined using a Zeiss Axioskop polarizing microscope at 25x-400x magnification both in incident visible and in UV light. For the UV excitation Zeiss filter 01 (excitation: BP 365/12, beam splitter: FT 395, emission: LP 397) was used. Photomicrographs were taken with a digital Zeiss AxioCam MR.

2.4 Fourier transform infrared spectroscopy (FTIR)

FTIR spectra were obtained on samples 1-2 using a Nicolet Avatar 360 Fourier transform spectrometer. For each sample 128 scans were recorded in the 4000 to 400 cm^{-1} spectral range in diffuse reflection modality (DRIFT) with a resolution of 4 cm^{-1}. Samples were ground with spectrophotometric KBr grade (1% sample in KBr) in an agate mortar. Binders and other materials were identified through infrared spectrometry by comparing the experimental spectra with literature data, spectral databases [16-17] and standards created in our laboratory.

2.5 Micro-Raman spectroscopy

The micro-Raman analysis was performed directly on sample 1 cross-section by a Labram Model spectrometer of the Horiba Jobin Yvon with a spatial resolution of 1 µm and the possibility of fast detection owing to the use of a CCD detector with 1026 x 256 pixels cooled to -70°C by the Peltier effect. The spectral resolution was 1 cm^{-1}. The exiting wavelength was the 632.8 nm red line of a He-Ne laser. Integration times varied between 10 and 20 s with 5 accumulations. Pigments were identified through micro-Raman spectroscopy, by comparing the obtained spectra to literature references [18] and databases [19-20].

2.6 Laser cleaning tests

Laser tests were performed under different conditions in order to find the threshold values of fluence that are useful to remove the dirt and the brownish surface layer without damaging the wood. A MDTT45 Q-switched Nd:YAG system supplied by MEDICAM was used for the tests**, choosing the 1064 nm wavelength. The following conditions were chosen,** also based on previous experiences [8-10, 13]:

A) distance 30 cm, spot diameter 7 mm, energy 4 mJ, fluence 0.01 J/cm^2

B) distance 15 cm, spot diameter 2 mm, energy 20 mJ, fluence 0.64 J/cm^2

C) distance 20 cm, spot diameter 4 mm, energy 20 mJ, fluence 0.16 J/cm^2.

The effectiveness of **cleaning** was evaluated by video-microscope, reflectance spectrophotometer, and scanning electron microscopy (SEM).

2.7 Video microscope acquisition

Video microscope acquisitions were performed in the three tested area, by comparing irradiated and non-irradiated areas. Video microscope acquisitions were performed by a Veho VMS-004D portable USB system equipped with a 20x-400x objective. The acquisitions were taken at **20x** magnification.

2.8 Colour measurements

Reflectance spectra were obtained, before and after the laser irradiation, by using an X-Rite CA22 reflectance spectrophotometer. The measuring conditions **were** the following: illuminant D65; standard observer 10°; geometry of measurement 45°/0°; spectral range 400-700 nm; spectral resolution 10 nm; measurement area diameter 4 mm; white reference supplied with the instrument. Ten measures for each point were performed, **and then** average values and standard deviations were calculated [21].

2.9 Scanning electron microscopy

Scanning electron microscopy (SEM) was carried out using a Jeol model JSM-5200 system. The wood samples were sputter-coated with gold in a Balzers MED 010 unit.

2.10 Photographic documentation and 3D model generation

The photographic documentation was made with a Nikon D880S camera equipped with 105 mm lens. The camera was positioned on a tripod and it was moved around the sculpture for 360° in order to obtain 153 pictures at different angles. The pictures were then elaborated by the Photoscan software, a basic program for 3D model generation from still images [22]. The reconstructed mesh, produced by Photoscan, was then elaborated by MeshLab, source software developed by the Institute of Information Science and Technology (ISTI), **National Research Council of Italy** [23]. MeshLab allowed obtaining a metric 3D model thanks to the introduction of some real measures directly gathered from the sculpture. Lastly, the freeware viewer Rapidform 2006 was applied to insert the texts bubbles anchored to specific points of the model surface in addition to a colour-coded overlay system [24]. The 3D model was used as reference base for recording all the areas of alteration, decay, additions, repair, intervention and diagnostic investigation.

3. Results and discussion

3.1 Wood analysis

The study of the anatomical features of wood samples allowed for identifying lime tree (*Tilia* sp.). The transversal section exhibits the following anatomical characteristics (see **Figure 2A**): diffuse porous wood, vessels solitary or arranged in files and in cluster, their shape being slightly polygonal; distinct growth rings; apotracheal axial parenchyma arranged in tangential uniseriate bands; small rays, pluriseriate and monoseriate; larger rays flare at the ring boundaries. The radial section highlights distinct spiral thickening on vessel walls (**Figure 2B**). The tangential sections show the rays wide up to tetraseriate (2-4 cells, **Figure 2C**), simple perforation plate and distinct spiral thickening on vessel walls (**Figure 2D**). On the basis of these anatomical features *Tilia cordata* Mill. and *Tilia platiphillos* Scop. can be identified, as a consequence, the wood in the present study has been identified to genus level only, *Tilia* sp.

Lime wood (*Tilia* sp.) was widely used for panel paintings, decorative carvings and sculptures in Europe [25] due to its anatomical features such as diffuse porosity and fine texture, which ensure excellent finishing results being not prone to splitting [26]. The lime wood exhibits a good strength in relation to density, and a moderate shrinkage. It dries easily and has slight dimensional variations in work [27-28].

3.2 Surface material analysis

The FTIR analysis of sample 1 revealed the presence of lead white (bands at 3541 cm^{-1}, 1421 cm^{-1}, 1047 cm^{-1}, 839 cm^{-1}, 780 cm^{-1} and 681 cm^{-1}) applied by a siccative oil (bands at 2922 cm^{-1}, 2852 cm^{-1}, 1738 cm^{-1}, 1177 cm^{-1}, 984 cm^{-1} and 724 cm^{-1}) and barium sulphate (bands at 1089 cm^{-1}, 637 cm^{-1} and 612 cm^{-1}) (**Figure 3A**).

Sample 1 cross-section is shown in **Figure 4**. A thick white layer (150 μm), characterized by a pale yellow fluorescence under UV radiation, is visible on the wood. The white pigment is mixed with smalt fragments well-visible under UV (**Figure 4B**).

Smalt or glass particles were usually added to the painted layers in order to give a glossy appearance that could simulate the marble [29-30]. In fact, it is probable that originally the sculpture was completely covered by a white layer to simulate the marble as observed for other sculptures attribute to the same workshop of Ignaz Günther [1]. On the top of the cross-section a thin transparent layer (few microns), characterized by a pale orange fluorescence under UV, and some dirt particles can be observed.

The presence of lead white and barium sulphate was confirmed by micro-Raman analysis performed directly on the painting layer of the cross section (**Figure 5**). The weak band at 987 cm^{-1} can be associated to barium sulphate. The strong doublet at 1051-1055 cm^{-1} is due to cerussite ($PbCO_3$) and hydrocerussite $Pb_3(CO_3)_2(OH)_2$, the main components of aged lead white [18].

The FTIR analysis of the surface layer (sample 2) revealed the presence of shellac (bands at 3420 cm^{-1}, 2921 cm^{-1}, 2852 cm^{-1}, 1714 cm^{-1}, 1470 cm^{-1}, 1420 cm^{-1}, 1243 cm^{-1}, 1173 cm^{-1}, 1051 cm^{-1}, 782 cm^{-1}, **Figure 3B**), a natural organic resin used frequently as surface treatment for wood and also for other sculpture materials [13, 31-32]. In the spectrum of **Figure 3B** traces of calcium carbonate (bands at 879 cm^{-1} and 712 cm^{-1}) and proteins (bands at 1551 cm^{-1}, 1450 cm^{-1} and 1082 cm^{-1}) are also visible.

3.3 Laser cleaning tests

Surface areas, on which the three laser tests were performed, are shown in **Figure 6**. The video microscope acquisitions in the same areas, between cleaned and uncleaned parts, can be observed in **Figure 7**. From the observation of the figures it can be derived that laser conditions used in the tests A and C were not enough to remove the shellac producing only a reduction in thickness. On the other hand, test B allowed the complete removal of the dirt and a reduction of the shellac layer revealing the original wood surface.

The comparison of the reflectance spectra and the first derivatives shows a clear increase of reflectance in the entire visible range for test B whereas for tests A and C the increase occurs particularly in the yellow-red region of the spectrum (**Figure 8**). The increase of the violet/blue shades caused by the test B correlates with a decrease of the yellow/red component suggesting the reduction of the brownish shellac layer.

SEM micrographs of surface portions before and after the tests A, B and C are shown in the **Figure 9**. The surface, before laser irradiation, appears covered by unhomogeneous layer of resin with rounded particles of dirt and also fungal hyphae. After the laser cleaning the surface dirt particles and the fungal hyphae appear removed, under the three test conditions. However in A and C the shellac layer is clearly still visible and homogeneous, whereas in B the wood structure can be partially observed. This result confirms that the conditions used in test B allowed a greater removal of shellac in respect to those used in test A and C but that the shellac is not completely removed due to its penetration in wood.

3.4 Photographic documentation and 3D model

At last, in **Figure 10** an example of the documentation report is shown. The bubbles anchored to the reconstructed model give information on the state of preservation, on the analysis, on the laser cleaning tests. The advantage of this kind of documentation in respect to a traditional bi-dimensional system is due to the possibility of **reporting** all work phases and annotations in a single file linked to the object without the necessity of having several thematic maps for the different kinds of information required [15]. Virtual reconstruction of full resolution three dimensional model, as similar as possible to **its** original resolution, allows a continuous and complete inspection of the object at any time and in a single file.

4. **Conclusions**

This paper has been reported the methodology used in the conservation work on a wooden sculpture representing Saint Joseph and attributed to the workshop of Ignaz Günther (18^{th} century). The cleaning intervention was preceded by the characterization of the constituent materials through different laboratory techniques. Optical microscopy applied to wood thin sections **allowed** identifying it as lime tree. The analysis of a sample of the white painting visible on the back of the sculpture enabled the detection of a thick layer made of lead white mixed with smalt and a superimposed thin layer made of barium sulphate. The analysis of the brownish surface protective by FTIR spectroscopy revealed the presence of shellac. This material appeared clearly aged and darkened making necessary its removal. Due to the difficulties and to risks in cleaning the wood surface for shellac with common procedures based on mechanical or solvent systems, laser cleaning was tested. The laser tests, performed under different conditions, allowed finding the suitable parameters making possible to reduce the shellac layer and to remove the surface dirt deposits without damaging the wood surface. The effectiveness of the laser cleaning was explored by means of video microscope observation and reflectance spectrophotometry, simple and non-invasive methods giving immediate and easy to understand data to evaluate the surface changes. SEM observation confirmed the results derived by the above mentioned techniques: in all cases the surface dirt particles were removed whereas shellac layer was reduced particularly under the conditions used in test B (fluence 0.64 J/cm^2).

It is possible to assess that the laser cleaning offers an effective non-contact method to remove the surface deposits without damaging the wood. Laser cleaning, appropriately tested and verified, is an extremely precise and controlled method to remove the dirt layers and aged protective materials in a selective and highly controlled modality from different kinds of materials used for sculptures.

All working steps were carefully documented by a close range image system that allowed for obtaining a 3D model on which the information gathered during the conservative procedure were inserted. In the field of conservation, the advantages to report the information in a single file linked to the object that, when necessary, can be used to update the full-resolution three-dimensional data, represent a valuable tool for documentation.

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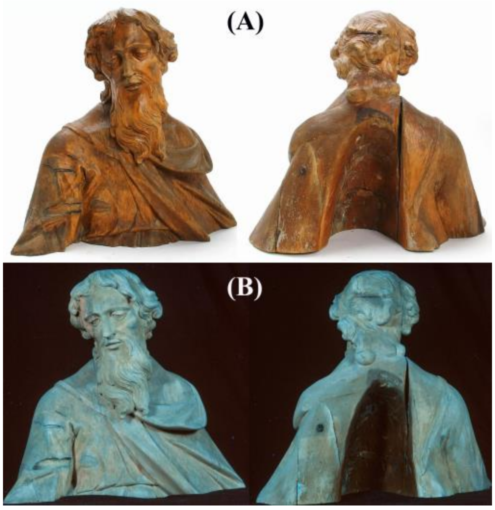
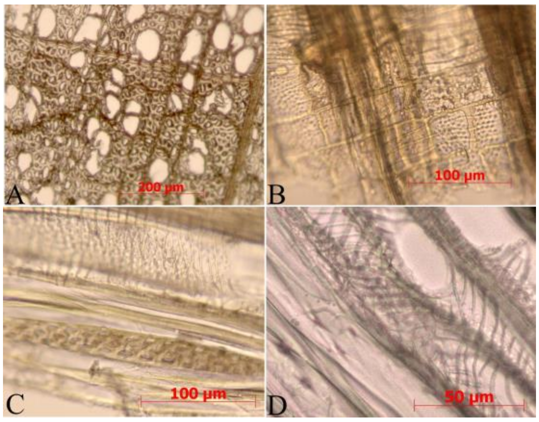


Figure 1



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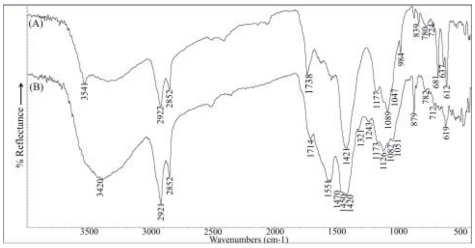

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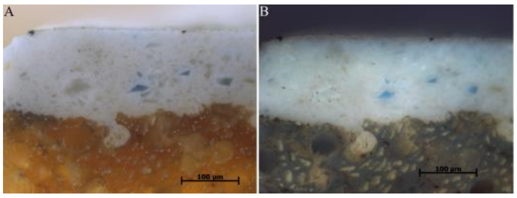

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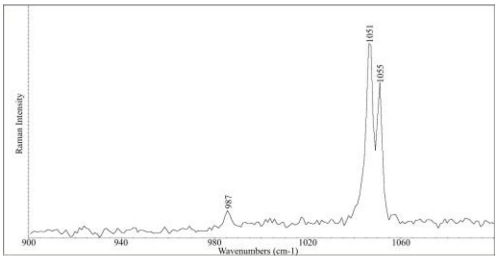

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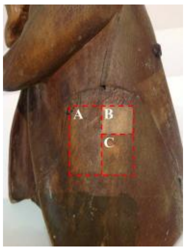

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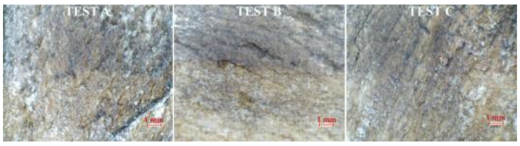

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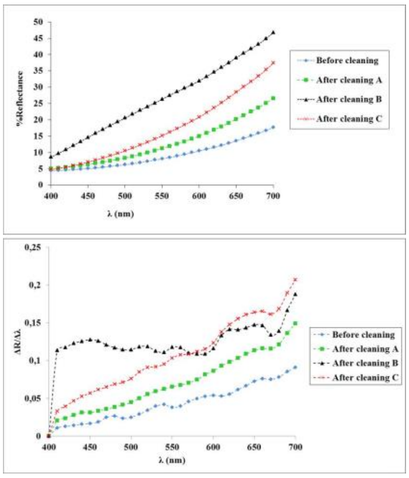

Figure 8

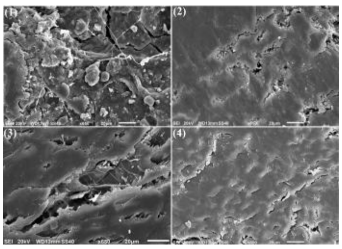

Figure 9

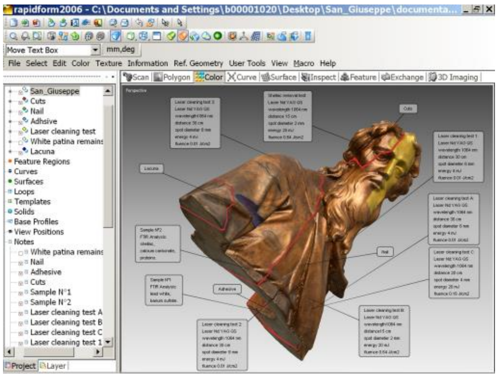

Figure 10

Captions

Figure 1 -Photographs of the Saint Joseph (40 cm high) by the workshop of Ignaz Günther, front and back of the sculpture. (A) visible light; (B) ultraviolet fluorescence.

Figure 2 -Microphotographs of wood sections under the microscope. A) transversal section; B) radial section; C) and D) tangential sections.

Figure 3 - FTIR spectra of the microsamples 1 and 2 taken from the Saint Joseph back surface. (A) sample 1; (B) sample 2.

Figure 4 - Photomicrographs of the cross section of sample 1 from Saint Joseph. A) reflected light; B) UV fluorescence.

Figure 5 – Raman spectrum of the white layer, sample 1

Figure 6 - Photograph of a particular of the Saint Joseph sculpture with the three laser tests: A) fluence 0.01 J/cm2), B) fluence 0.64 J/cm2, C) fluence 0.16 J/cm2; wavelength 1064 nm.

Figure 7 -Videomicroscope acquisitions between the cleaned and uncleaned areas. The tests A-C are explained in the caption of figure 8 (magnification 20x).

Figure 8- Reflectance spectra and their first derivatives of the three measured points on the Saint Joseph sculpture, before and after the laser tests. A, B and C test conditions are reported in the caption of Figure 8.

Figure 9 – Electron micrographs of un-cleaned (1) and laser-cleaned wood surface, under the different laser conditions: (2) test A; (3) test B; (4) test C.

Figure 10 - 3D model of the sculpture with the text bubbles anchored to specific points of the surface. The texts specify the preservation state of the surface, the conditions of laser cleaning tests, the scientific analysis.