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Multianalytical investigation and 3D Multiband modeling: an integrated survey of the Garnier Valletti pomological collection

Emanuela Grifoni[1], Letizia Bonizzoni[1], Marco Gargano[1], Jacopo Melada[1],
Ilaria Mignani[2], Nicola Ludwig[1]

[1] Department of Physics A. Pontremoli, University of Milan, via Celoria 16, Milan,
emanuela.grifoni@unimi.it, letizia.bonizzoni@unimi.it, marco.gargano@unimi.it,
jacopo.melada@unimi.it, nicola.ludwig@unimi.it
[2] Department of Agricultural and Environmental Science, University of Milan, via Celoria 2, Milan
ilaria.mignani@unimi.it

***Abstract* – Digital Close-Range Photogrammetry allows to acquire high-fidelity models useful to document Cultural Heritage with a high level of detail. This technique also has an analytical potential able to gain new knowledge about works of art and their state of preservation. This project carries out a diagnostic survey using 3D Multiband modeling, High Resolution Digital X-Radiography and Pulsed Thermography to document and evaluate from a conservative point of view the polymaterial exemplars of the Garnier Valletti pomological collection. The analytical integration of Imaging techniques and 3D modeling provides information from the superficial, sub-superficial and innermost layers of the object, respectively, capturing both accurate morphometric, spectral and density data. The paper presents the results obtained on the particular case study of polymaterial and multilayer artifacts for which Pulsed Thermography has proven to be a highly predictive technique from a conservative point of view.**

I. INTRODUCTION

Nowadays Digital 3D models play a fundamental role in the representation, documentation, conservation as well for the measurement of Cultural Heritage (CH). After pushing traditional methods to take an increasingly computational approach, modeling is now an established practice in the Digital Humanities (DH) which – beyond the current levels of visual depictions in high-fidelity models – reserves an analytical potential to gain new knowledge about material works of art by generating and manipulating their external representations [1].

With the advent of passive sensors and new image-based 3D data acquisition methods new scenarios have consequently opened up involving the use of Multiband (MB) imagery (Visible Fluorescence Induced by Ultraviolet radiation - UVF, Vis, Near-Infrared reflectography - NIR) namely what is generally defined as High Resolution Technical Photography (Hi-ResTP) [2-8]. Starting from the assumption that the best 3D modeling results are obtained by integrating different measurement techniques, some recent studies have proposed a data fusion method that integrates the analysis of radiometric content using 2D MB images and the 3D morphometric details of a work of art in a single coordinate referenced system. In this way it is possible to obtain a 3D model characterized by a high level of spectral and morphometric detail that collects complementary and heterogeneous information – both quantitative and qualitative – for a multi-temporal evaluation process [9-14]. In addition to shape reconstruction and MB rendering, the useful application of Digital Close-Range Photogrammetry (DCRP) for

Fig. 1. Calibrated Visible images of Dürfeld (Dü) pear Britanische Herbstbirne (left)and Garnier Valletti (GV) pear Fusone di Lombardia (right).

accurate volume estimation should certainly be highlighted [15].

Active Infrared Thermography (a-IRT) is an imaging technique notoriously appreciated in the wide field of CH science thanks to its ease of use, high thermal resolution and non-invasiveness. From the 1960s to the present, several studies attest to its extreme versatility in the inspection of a variety of historical-artistic materials and their respective decay phenomena in order to determine their preservation state. A-IRT involves the use of an external source to thermally stimulate the target and to highlight the regions of interest (thermal anomalies) [16-20]. There are various methods and related configurations for data acquisition via a-IRT. Those mainly applied to Conservation studies and CH are Pulsed Thermography (PT) and Lock-in Thermography (LT) exploited using optical thermal stimulation (e.g. flash lamps, incandescent lamps, quartz lamps) [21-22]. In the case of artworks realized with particularly heat-sensitive materials, protracted exposure may be highly discouraged. In order to prevent any further damage, PT is the most appropriate among the different active thermographic configurations for those distinctive artworks typology referred as ceroplastic.

While PT highlights the presence, the extent and the depth of the sub-surface anomalies and discontinuities, High Resolution Technical Photography (Hi-ResTP) and High Resolution Digital X-Radiography (Hi-Res DXR) provide information from the superficial and innermost layers of the object, respectively, capturing both accurate spectral, spatial and density data. The analytical integration of the imaging techniques mentioned so far together with DCRP is clearly essential to obtain a great richness of informative contents. The preliminary study reported here takes this crucial aspect into account: it presents an analytical protocol aimed at the optimization of the multimodal and multilayer data capturing strategy, focusing on a selection of polymaterial artifacts belonging to the Garnier Valletti (GV) collection of the University of Milan (UNIMI).

The documentary and diagnostic campaign is also completed by the essential surface material characterization through a digital microscope observation and a series of non-invasive chemical-physical investigations such as XRF, Raman and FORS spectroscopies for a qualitative identification of pigments, binding and surface finishing materials whose results are not in the aim of this paper.

A. The Garnier Valletti collection and the project aims

The GV pomological collection, preserved at the Department of Agricultural and Environmental Science of the University of Milan, gathers 1674 naturalistic models of fruits representing the many taxonomic lines of the European fruit germplasm that existed until the mid-nineteenth century. The models realized by the famous ceroplast Garnier Valletti are incredibly realistic as they exactly reproduce not only the shape and color but also the tactile effects and the weight of the original fruits. They preserve a high cultural value as they emulate varieties now extinct from our current fruits production as well as a historical and artistic value for the excellent technical quality reached. The manufacturing technique is not entirely well known as the artist always wanted to jealously keep the secret of his recipes. Thanks to some manuscript documents and to a previous study, we have partial information on the use of materials such as wax, Dammar resin, alabaster powder, metal elements and organic natural elements directly taken from the original fruits and inserted in their artificial model [23]. Other modelers, such as Dürfeld, used papier-mâché covered with gypsum and wax. These artifacts are therefore very complex multilayered systems whose analytical study is particularly challenging. The presence of heterogeneous and/or anomalous materials whose formulations, reactions and degradation processes are ignored, combined among them on the basis of recipes kept secret by their author, poses significant problems of preservation, restoration and transmission to the future. Moreover, the current conservative storage is not appropriate to correctly preserve the entire collection: uncontrolled microclimatic conditions, repeated mechanical shocks with consequent loss of fragments, large deposits of atmospheric particulate are contributing to their degradation process. Lastly, over the years many exemplars have lost their identification labels bearing the name of the fruit variety, the author's name and their order of classification.

From this huge collection two exemplars have been selected, one referring to Garnier Valletti (pear Fusone di Lombardia) and the other to Dürfeld (pear Britanische Herbstbirne) (Fig. 1), as they present two different preservation conditions even though they have always been kept in the same micro-environmental conditions: the first almost intact and the second with conspicuous swellings and falls of the pictorial film.

The aims of this research – just started and still in progress – are *i)* to document the pomological models of the GV collection in their current state of preservation; *ii)* to carry out an initial screening to indicate which artifacts present the most critical and fragile preservation conditions; *iii)* to distinguish and isolate exemplars realized by different manufacturers; *iv)* to retrace the history of the "multiples" in connection with casts, plaster moulds and different variants.

II. MATERIALS AND METHODS

For the characterization of each exemplar, the following experimental analysis framework was designed: first the three digitization sessions in the different spectral bands were planned; then the PT session and lastly the Hi-Res DXR session were performed (Figg. 2-3).

For the visible light photography and the first two high resolution imaging techniques, the same digital single-lens reflex (DSLR) Nikon D700, modified to extend the sensitivity from 350 nm to 1000 nm and coupled with a Nikkor 55mm f/2.8 D macro Lens, was chosen for the acquisition of 14-bit RAW images of 7360 × 4912 pixels. The lighting was chosen according to the different purposes: in the case of the UVF, the objects were irradiated with two 365 nm UV LED lamp, each of 3 W. In the case of the Vis and NIR two 150 W halogen lamps with diffused light were placed symmetrically at 45° to the object surface; they were used at a proper distance not to cause any heating of the surface. Regardless to the different surface texture and finishing effects (mat / semi-glossy / glossy) the single object have been placed inside a softbox in order to obtain the most diffused and homogeneous lighting possible. UV/IR cut filters were used for the image in the visible range while, to acquire NIR images, a 850 nm high-pass was used. UVF images were realized using a high-pass filter of 420 nm together with an UV/IR cut filter to reduce the contribution of the small reflection of the blue component emitted by the UV sources.

As far as the XR is concerned, the portable and real-time Hi-Res CR scanner Dürr HD-CR-35ndt, with 30 µm of spatial resolution, was chosen using a Gilardoni Artgil radiographic tube (80 kV max, 5 mA) and imaging plates of 30x40 cm in size.

The PT inspection was exploited using an Avio R500EX-Pro (8-14 µm spectral range, sensitivity of 0.025 °C at 30 °C and 0.87 mrad of spatial resolution) with a framerate of 30 Hz. Two Godox WITSTRO AD360 flashes with 360 W of maximum emission were used for the thermal stimulation of the target.

A. Multiband Photogrammetric Planning

In order to *i)* make the 3D MB models more comparable, *ii)* maximize the accuracy of the results, *iii)* reduce photogrammetric errors, *iv)* make the shooting conditions repeatable in the future, a rigid overall camera network geometry has been defined (as shown in Fig. 4). The accuracy level of the 3D models is closely related to the overlap criterion between contiguous frames: to perform a shooting campaign with 360° of sweep and an overlap ratio of 60%, each object was placed on a turntable and images were recorded every 20°. With this overlap ratio, it was sufficient to capture about 36 images, making three full turns at different heights, to obtain highly satisfactory 3D models. Consequently, the tripod and the lighting setup have been arranged in a static location. Focusing the camera at 0.5 m distance and using the nominal value of the focal length, the image texture spatial resolution (Ground Sampling Distance – GSD) resulted 0.005 mm/px on the sharp focus plane. Finally, to optimize the alignment of the images and to resize the photogrammetric results, markers and reference scale bars were used and included in each single photo.

Fig. 2. UVF (left), NIR (center) 3D models and RX (right) image. (Dü) pear Britanische Herbstbirne.

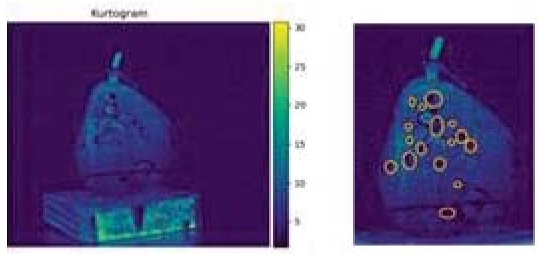

Fig. 3. PT image and detail. (Dü) pear Britanische Herbstbirne.

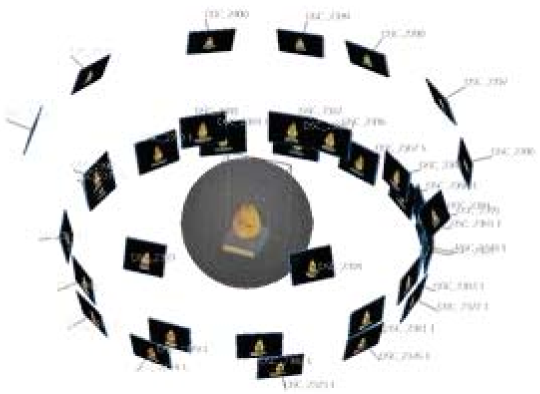

Fig. 4. The overall acquired camera network

B. Raw photogrammetric data pre-processing

All the input photo images were captured in native 14-bit RAW format. Medium-low ISO values have been used to prevent the sensor luminance noise, maintaining the exposure under the clipping limit value. The pre-processing phase of the images consisted basically in the operations of color management - white balance using the color reference target X-Rite ColorChecker®; after that, the images were saved in .jpeg format to be loaded into 3D modeling software.

C. Photogrammetric data processing

A recently released automated commercial software was used for the creation of the multi-band 3D models. The photogrammetric workflow consisted of an initial phase of automatic images orientation and self-calibrating bundle adjustment for automatic matching of image features and consequent extraction of tie points. The inclusion of markers and scales of information has improved the accuracy evaluation: the Root Mean Square (RMS) reprojection errors averaged over all tie points on all images resulted in 0.24 pixels. The dense image matching phase generated a high quality 3D point clouds of ≈ 5 million points. Recognition of object surfaces in point clouds is often the first step in extracting evidence from a native, non-manipulated format output. In fact, dense clouds provide explicit morphometric information on geometry, shape and the structure of time-varying surfaces that, properly treated, can provide guidelines for diagnostic investigations [24-25]. From dense clouds were subsequently generated triangulated meshes with ≈ 200.000 faces on which limited editing operations were conducted to repair some shadow and textureless areas without reconstruction (Fig. 5). Since the exemplars are limited in size, there was no need to decimate the meshes to reduce their resolution for visualization purposes. Finally, the textures were automatically created by transferring color information from multiband images to meshes, enabling blending mode and color correction.

Fig. 5. Photogrammetric data processing. From sparse cloud to mesh. (GV) pear Fusone di Lombardia.

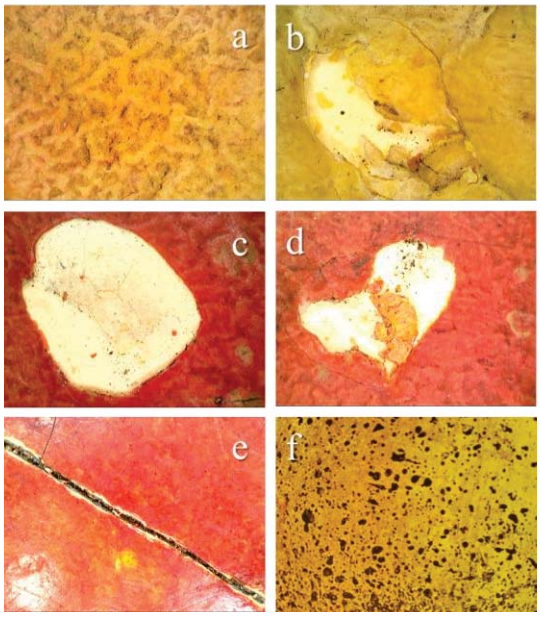

Fig. 6 Details under the digital microscope (200x) of the (Dü) pear Britanische Herbstbirne showing wrinkles of the pictorial film (a), consequent loss of color (b-d) and micro-cracks (e). Widespread non-fluorescent tiny dots on the (GV) pear Fusone di Lombardia under UV light (f).

III. RESULTS AND DISCUSSION

A. 3D MB modeling

The complete package of information obtained from the data fusion technique used for this study was useful in exploring the relationship between spectral reflectance, fluorescence emission and shape of the pomological models. First, the acquisition of optimally calibrated photographs in the Vis spectral region provided models with precise color rendering and surface details at very high geometric resolution that give credit to the artist's extraordinary skill and mastery of the pictorial palette. Secondly, it accounted for the surface treatment adopted by the artist to qualify the specific fruit (smoothness, roughness, opacity, glossy, presence of artificial lint, etc.). It was then possible to document the state of conservation by circumscribing micro-splits, cracks, wrinkling of the paint layer resulting from mechanical stress and/or microclimatic variations in order to set an eventual monitoring project (Fig. 6a-6e).

UVF imagery showed a diffuse, homogeneous and moderate fluorescence in both models. However, it was not possible to qualitatively discriminate the contribution of fluorescence given by the binder component of the paint materials from that given by the finishing varnish because of the co-presence in both layers of the same Dammar natural resin, as also reported in the handwritten recipe book by GV later published by his biographer Michele del Lupo [26]. The white fluorescence of the bulk material – visible due to the loss of paint film in the Britanische Herbstbirne pear of Dürfeld – is noteworthy as well as the widespread presence of non-fluorescent tiny dots on the Fusone di Lombardia that Garnier Valletti has obtained by spraying the color by repeatedly bending the bristles of the brush at a distance to mimetically simulate the typical texture of the cultivar (Fig. 6f). Finally, the characteristic bluish and bright fluorescence of dust deposits has been noted suggesting the need for routine cleaning operations. This unfortunately contrasts with the warnings dictated by the author and his epigone about the necessary conservation of the models from dust due to the difficult selective removal and the high risk of loss of artificial lint, denoting a modern and avant-garde sensitivity to what will be understood as "preventive restoration" more than fifty years later [27].

B. Pulsed Thermography

The micro-detachments of the external pictorial film of the objects were evaluated analyzing the temperature evolution registered by the a-IRT. In order to highlight their localization an algorithm based on the fourth standardized central moment (kurtosis) was used (Fig. 3) [28-30]. PT proves to be a highly predictive technique able to help preventing or limiting the loss of pictorial film in multi-material and multi-layer artifacts such as pomological models. Moreover, in this specific case allow to quickly distinguish the exemplars produced by a more accurate manufacture in the choice of the durability of the materials – such as that of Garnier Valletti, from a more perishable and less careful manufacture – such as that of Dürfeld.

C. High Resolution Digital X-Radiography

Hi-Res DXR has allowed to inspect the internal structure of the pomological models in question, largely confirming the information known from the recipe books but also revealing further details. For example, the (Dü) pear has a higher density material (*impasto*) in the lower half of its volume; in the upper half there could be a cavity or a less radio-opaque filling material such as papier-mâché. The latter element would be validated in the literature [31]. In addition, the peduncle is totally radiotransparent because it is made of wood contrary to those present in the (GV) models made with an iron wire. In both cases, however, we observe a characteristic funnel shape resulting from the insertion of the peduncle in the still plastic and malleable material of the mixture.

Comparing the Fusone di Lombardia pear with other similar models by GV we have confirmation of the variability of the internal constitution: this in fact depends on the different quantity of melted paste that the artist added inside or made it flow out if in excess in order to achieve the same weight of the real fruit increasing the true resemblance.

IV. CONCLUSION

With 3D CH modelling as standard practice, very realistic products obtained in digital form will certainly be passed on to future generations for historical documentation, cross-comparison, monitoring of shape, color and ageing deterioration, computer-aided restoration, multimedia museum exhibitions, etc. [32]. Certainly, the more fragile, perishable or ephemeral are the digitized works of art, the greater will be the historical value of this practice, especially if their digital models are even the last representation of entities now extinct as in the case of the polymateric exemplars of the Garnier Valletti pomological collection.

This study represents a first starting point towards the comprehensive digitalization of this extraordinary collection and demonstrates how the optimization of the multimodal and multilayer data capturing strategy has enhanced the potential insights into data analysis of particularly complex artworks such as those examined in this research project. Multiple developments would arise from this: at the same time as an extensive 3D MB documentation, it would be useful to conduct a systematic and accurate multi-temporal spectrocolorimetric survey and microclimatic campaign in order to assess the occurrence of any color alteration and/or shape deformation. For this reason, setting up a new exhibition environment would be highly desirable to *i*) keep the rate of the autoxidative process and consequently yellowing phenomenon low; *ii*) have controlled thermohygrometric conditions; *iii*) avoid harmful dust deposits; 3) optimize the accessibility to the pomological models. A broad Hi-Res DXR documentation would make it possible to highlight intriguing and unusual constituent details used by the artist for the realization of the different fruits and cultivar - although weakly radiopaque - like the original achenes in the strawberry models or the original grape seeds inside the resin berries. Finally, PT conducted on selected artefacts would provide a priority scale of the most fragile models to be the first subjected to immediate restoration.

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