Hyper-dimensional visualization of Cultural Heritage. A novel multi-analytical approach on 3D pomological models in the collection of the University of Milan

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Digital close-range photogrammetry allows to acquire high-fidelity tridimensional models useful to document cultural heritage objects with an impressive level of detail. In addition, this technique carries a strong analytical potentiality, able to gain improved knowledge of cultural objects and their preservation conditions. This project is focused on a comprehensive diagnostic survey using 3D multispectral modeling, high resolution digital radiography, pulsed thermography, XRF, FT-IR, and FORS spectroscopies to document and characterize from a conservative point of view the poly-material objects that belong to the "Garnier Valletti" pomological collection. A unique collection both from scientific and artistic point of view. The analytical integration of imaging techniques, 3D modeling, and spectroscopic techniques provides information from the surface, sub-surface and innermost layers of the object, respectively, capturing both accurate morphometric, spectral and compositional data. The paper presents the results obtained on typical poly-material and multilayered objects of this collection for which the combination of the considered techniques provided important data to the technical knowledge of the realization highlighting a particular predictive ability from a conservative point of view.

CCS CONCEPTS • Image Processing and Computer Vision→Digitization And Image Capture • Image Processing and Computer Vision→Reconstruction • Computer Applications→Physical Sciences and Engineering • Computer Applications→Arts and Humanities

Additional Keywords and Phrases: 3D digitalization, photogrammetry, virtual color reconstruction, multispectral imaging, materials characterization, pomological models, ND techniques

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1 INTRODUCTION

Nowadays digital 3D models play a fundamental role in the representation, documentation, conservation as well as 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, which – beyond the current levels of visual depictions in high-fidelity models – reserves an analytical potential to gain new knowledge about CH objects by generating and manipulating their tridimensional virtual copy [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 (MS) imagery (Visible Fluorescence Induced by Ultraviolet radiation (UVF), Visible (Vis), near-infrared (NIR) and short-wave infrared (SWIR) reflectography IRR) 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 MS images and the 3D morphometric details of a work of art in a single coordinate referenced system [9-14]. In this way, it is possible to obtain a 3D Structure from Motion (SfM) model characterized simultaneously by both a high level of morphometric detail and a radiometric informative content corresponding to the selected spectral band (Vis, IR or UV). The overlapping of multiple levels of analysis allows an advanced digital representation to be semantically enriched to potentially derive complementary and heterogeneous information - both quantitative and qualitative - for a conservative monitoring over time. In addition to shape reconstruction and MS rendering, the useful application of Digital Close-Range Photogrammetry (DCRP) for 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 proved 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 artwork's typology referred to as ceroplastic.

While PT highlights the presence, the extent, and the depth of the subsurface anomalies and discontinuities, High-Resolution Technical Photography (Hi-Res TP) and High-Resolution Digital X-Radiography (Hi-Res DXR) provide information from the outer 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 considers this crucial aspect: it presents an analytical protocol aimed at the optimization of the multimodal and multilayer data capturing strategy, focusing on a selection of poly material artifacts belonging to the Garnier Valletti (GV) collection of the Università degli Studi di Milano (UniMI).

As required by a well-established protocol [23], the documentary and diagnostic campaign was also completed by the essential characterization of the surface material through microscopic imaging and a series of non-invasive chemical-physical investigations such as X ray fluorescence (XRF), Fourier-transform infrared spectroscopy (FT-

IR) and fiber optic reflectance spectrometry (FORS) for the qualitative identification of pigments, binding and surface finishing materials.

2 THE GARNIER VALLETTI COLLECTION AND THE PROJECT AIMS

The GV pomological collection, preserved at the Department of Agricultural and Environmental Science of the Università degli Studi di Milano[1], 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 specific weight of the original fruits. They preserve a high cultural value as they emulate varieties now extinct from our current fruit 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 [24]. Other modelers, such as Dürfeld (Dü), 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.

For the present study, two exemplars have been selected from this huge collection as the most representative of the entire collection having two very different preservation conditions although the same micro-environmental conditions of conservation (Fig. 1). The first exemplar, fairly intact and in perfect condition, is a reproduction of the pear called Fusone di Lombardia made by Garnier Valletti; the second specimen, on the other hand, has noticeable swelling and loss of the paint film, and is a reproduction of the pear called Britanische Herbstbirne made by Dürfeld. A third exemplar of the GV collection (apple Rome Beauty) has also been selected on which XRF, FT-IR, FORS, and Hi-Res DXR analyses have been performed.

[1] https://www.orticola.org/orticola/?page_id=1465

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

The aims of this research – at the beginning 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 molds, and different variants.; v) to expand the knowledge of researchers in non-destructive techniques (NDT) to be applied in this important area between cultural and scientific heritage.

To achieve these goals and to collect this amount of data on a larger scale it is planned to: a) follow the same protocol of acquisition of high-accuracy and high-resolution raw data for each pomological artifact so that each 3D digital models are comparable to the others; b) store and interconnect on a provisional relational database all the multimedia data produced, such as: 2D digital images, 3D digital models, reflectance spectra, and textual data. In the case of textual data, identifying information are provided according to the catalographic standards of the Italian Central Institute for Catalogue and Documentation (ICCD), dedicated to artworks (OA) [25] and objects of scientific and technological heritage (PST) [26], i.e.: the title of the artefact, the historical-artistic context, the inventory number, the measurements, the materials and techniques with which it is made, the state of conservation, the mapping of any restoration work, etc.; c) store metadata and paradata associated with the 3D digital object and the digitization project itself, i.e.: acquisition technique, spectral band involved, system and software specifications, reconstruction quality, equipment and methods used, workflow, formats, and the actors involved, etc., adopting metadata standards for Cultural Heritage consolidated internationally to guarantee the interoperability of the data collected [27]; d) interconnect and index these multimedia resources in a database that can manage them according to polysemous interpretative models; e) progressively transfer the provisional database into the much larger and more articulated database currently used by the University of Milan and dedicated to its collections. This operation will make the data interoperable with other digital archives on the web.

3 MATERIALS AND METHODS

For the characterization of each exemplar, the following experimental analysis framework was designed: first step image analyses, the three digitization sessions in the different spectral bands were planned; the PT session and the Hi-Res DXR session were performed (Fig. 2 and 3). As a second step spot analytical techniques: XRF, FT-IT, FORS.

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

For the visible light photography and the first two high-resolution imaging techniques, the same digital single-lens reflex (DSLR) Nikon D810, modified to extend the sensitivity from 350 nm to 1000 nm and coupled with a Nikkor 50mm f/1.8 D Macro Lens AF-S, was chosen for the acquisition of 16-bit RAW images of 7360 × 4912 pixels. The lighting was chosen according to the different purposes: in the case of the UVF, two 365 nm 3 W UV LED lamp, were used. 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 of the different surface texture and finishing effects (mat/semi-glossy/glossy), the single object has 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, an 850 nm longpass filter was used. UVF images were realized using a longpass filter with a cut-on wavelength of 420 nm together with a UV/IR cut filter to reduce the contribution of the small reflection of the blue component emitted by the UV sources.

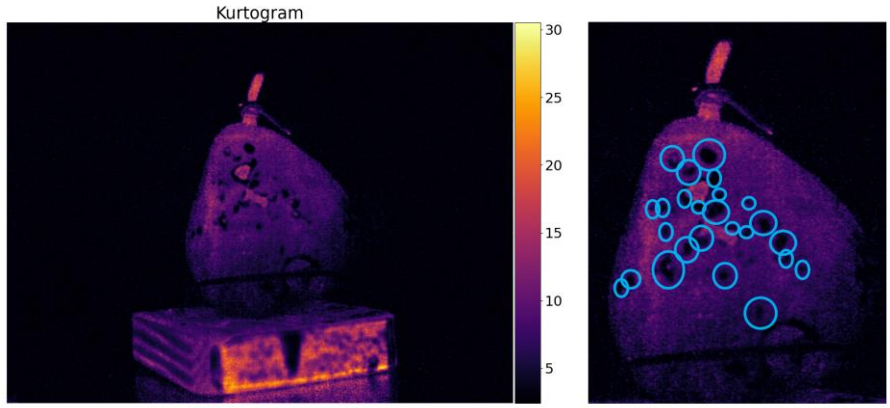

Figure 3: UVF (left), NIR (center) 3D models

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 (63 kV, 30 sec.) and imaging plates of 30 × 40 cm in size.

The PT inspection was exploited using a high-resolution thermal imaging camera Avio R500EX-Pro (microbolometer 480 × 640 pixels, 8-14 μm spectral range, thermal resolution of 0.05 °C at 30 °C and 0.87 mrad of spatial resolution) placed at 15 cm from the artifact. The frame rate was set to 30 Hz in order to achieve a tradeoff between computational costs and signal resolution. Two Godox WITSTRO AD360 flashes with a power peak of 360 W were used for the thermal stimulation of the target. The acquisition of the thermograms sequences following the thermal impulse proceeded by keeping the position of the thermal camera fixed while rotating the artifact on itself in order to acquire data of different sides of the object. To visualize the presence of sub-superficial detachments, each sequence was processed by high order statistical analysis. This elaboration methodology allows compressing the thermograms sequence into a single image based on the descriptive statistic of the temporal evolution of the temperature of each pixel.

XRF analysis was performed in Energy Dispersive mode, exploiting a Lithos300 spectrometer (Assing S.p.A.) equipped with a Mo anode X-ray tube (25 kV, 0.3 mA and 100 s) and a Peltier cooled Si-PIN detector. The radiation is monochromatic at Mo Kα energy by means of Zr transmission filter, with a 4 mm diameter collimator. The irradiation area on the sample is about 25 mm^2; the distance between X-Ray tube and samples, and between samples and detector, were both 100 mm. XRF analysis allowed the identification of medium-high Z elements with a non-destructive investigation, mandatory when working on such kind of objects.

FT-IR analyses were performed by the spectrometer Bruker Alpha equipped with an attachment for external reflection measurement. The spectra were acquired in the range from 7000 to 400 cm^{-1} as a sum of 200 scans, with resolution 4 cm^{-1}. The measurement area has a diameter of 0.6 cm.

FORS analysis were acquired using an Ocean Optics spectrophotometer with a spectral range between 360 and 1100 nm. Reflectance spectra were acquired using a coaxial optical fiber probe in a 45°/45° geometry with a spot of about 2 mm of diameter.

3.1 Multiband Photogrammetric Methodology

In order to i) make the 3D MS 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 by keeping the shooting point fixed and rotating the object on a turntable (as shown in Fig. 4). Consequently, the tripod and the lighting setup have been arranged in a static location. 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 image was shot every 20° horizontally and 20° vertically, corresponding to a vertical shift of 15 cm. 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.

Considering the data acquisition parameters (shooting distance: 0.5 m) and the available optical equipment (lens focal length: 50 mm; sensor size: 35.9 x 24 mm), the estimated spatial resolution of the image texture (Ground Sampling Distance - GSD) is 0.048 mm/px on the sharp focus plane, as shown in Table 1. 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.

The photogrammetric computer vision approach adopted is based on SfM feature matching algorithms such as the SIFT (scale-invariant feature transform) algorithm that allows to estimate the epipolar geometry, the external orientation of the images and to reconstruct the 3D geometry of an object, starting from 2D images [28].

Shooting Distance [m]	**Lens Focal length [mm]**	**Sensor size [mm]**	**Image size [px]**	**Estimated GSD [mm/px]**
0.5	50	35.9 × 24	7360 × 4912	0.048

Table 1: Technical details for GSD estimation.

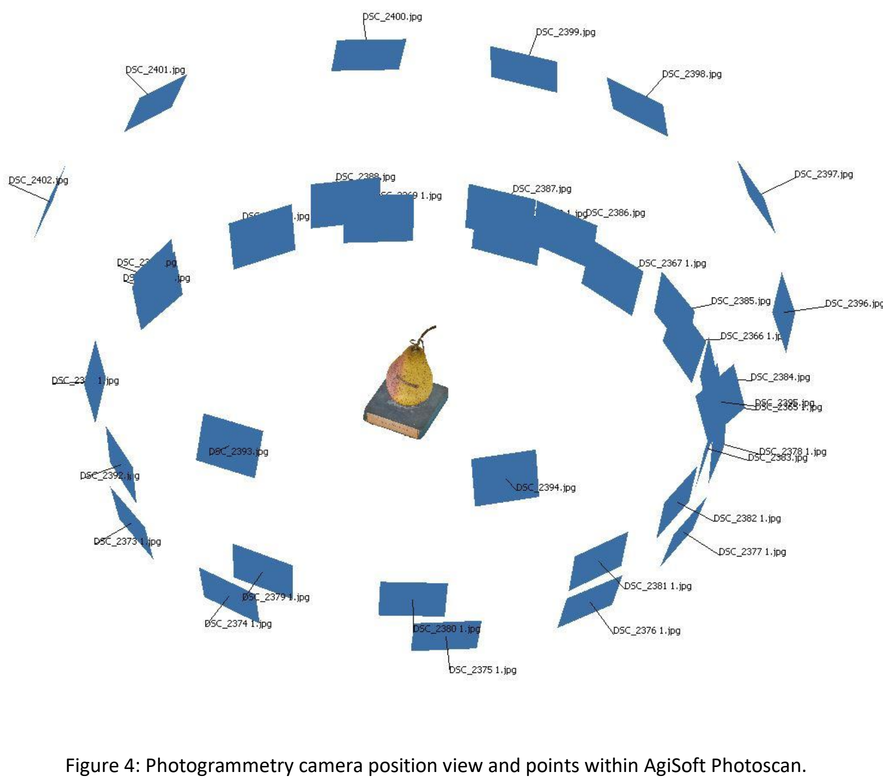

Figure 4: Photogrammetry camera position view and points within AgiSoft Photoscan.

3.2 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 step of the images consisted basically in the operations of color management – ICC color profiling using the color reference target X-Rite ColorChecker®; after that, the images were saved in .jpeg format to be loaded in the 3D modeling software.

3.3 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 step of automatic image orientation and self-calibrating bundle adjustment for automatic matching of image features and consequent extraction of tie points. The inclusion of markers and scale bars has improved the accuracy evaluation: 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 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 [29-30]. 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 "generic" mapping mode, “mosaic” blending mode and color correction.

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

4 RESULTS AND DISCUSSION

4.1 3D MS modeling

The complete package of radiometric and morphometric 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 a 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 [31]. The white fluorescence of the bulk material – visible due to the loss of paint film in the Britanische Herbstbirne pear by Dürfeld – is noteworthy as well as the widespread presence of non-fluorescent tiny dots on the Fusone di Lombardia. The latter were made by spraying the paint by repeatedly bending the bristles of the brush 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 [32].

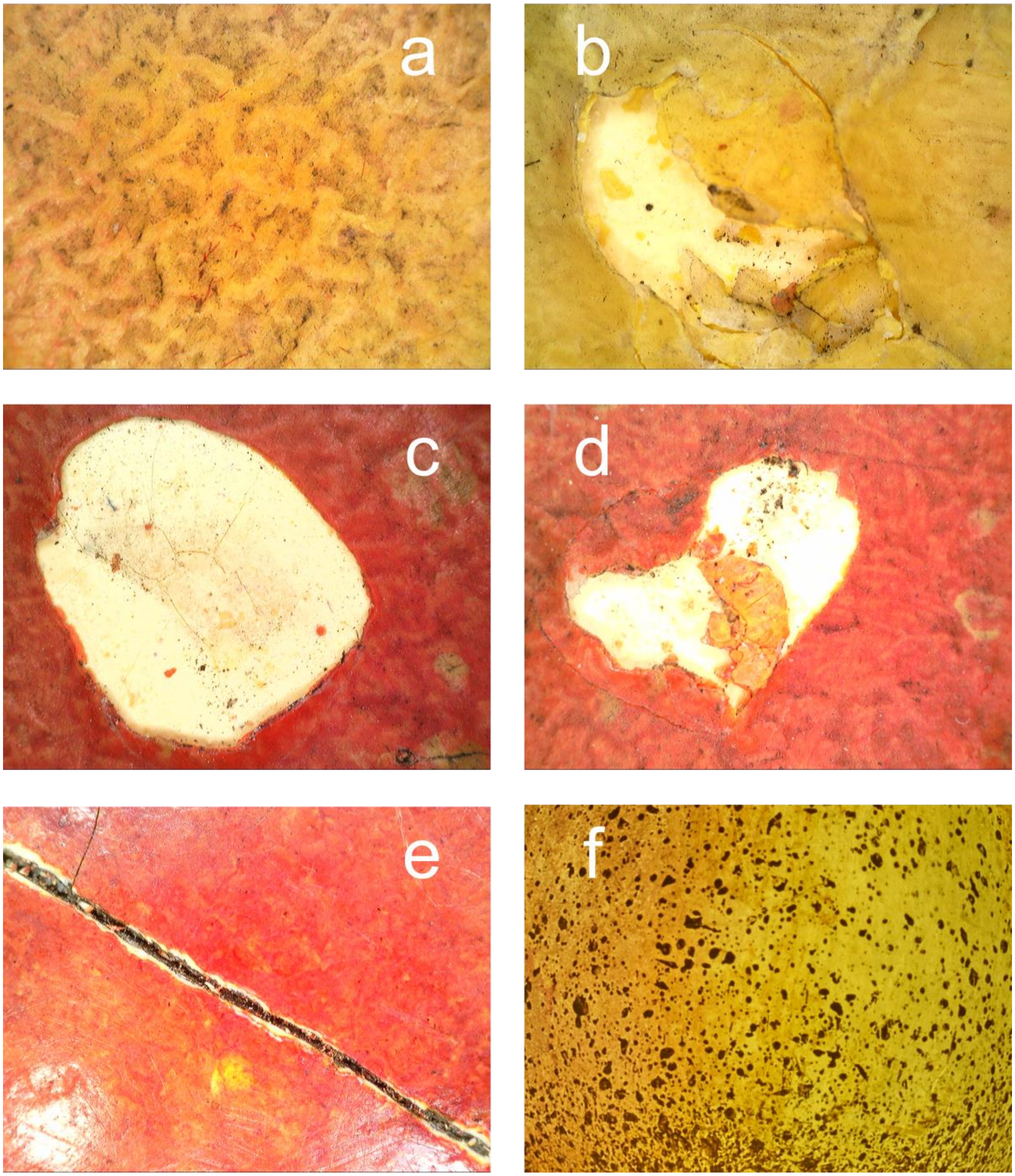

Figure 6: Details acquired with the digital microscope (220x) of the (Dü) pear Britanische Herbstbirne showing wrinkles of the pictorial film (a), consequent loss of color (b-d) and micro-cracks (e). Widespread non-fluorescent tiny dots on the (GV) pear Fusone di Lombardia under UV light (f).

4.2 Pulsed Thermography

The micro-detachments of the external pictorial film of the objects were evaluated by analyzing the temperature evolution recorded by the thermal camera. To highlight their localization, an algorithm based on the fourth standardized central moment (kurtosis) was used (Fig. 3). Thermograms processing based on high-order statistics rely on the consideration that the temperature evolution in time of each pixel can be seen as a probability mass function, i.e. statistical distribution. In contrast to low-order statistics, high-order static such as skewness (order 3) and kurtosis (order 4) can provide information about asymmetry and degree of peakedness of a distribution with respect to the normal distribution. Kurtosis describes how a distribution is more peaked or flat with respect to the normal distribution. The entire sequence of thermograms is compressed in a single image which shows the kurtosis value of each pixel cooling curve over time. The difference between defected and non-defected areas are usually well highlighted in kurtograms [33-37].

PT has been shown to be a highly predictive technique able to prevent or to limit the loss of pictorial film in multi-material and multi-layer artifacts such as pomological models. Moreover, in this specific case, it allowed us to quickly distinguish the exemplars produced by more accurate manufacture in the choice of the durability of the materials – such as that of Garnier Valletti, from more perishable and less accurate manufacture – such as that of Dürfeld.

4.3 High Resolution Digital Radiography

Hi-Res DXR has allowed inspecting 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, as clearly visible in the grayscale X-ray image in which the lighter areas correspond to the less radiopaque materials, contrarily to the traditional visualization [Fig. 2]. The latter element would be validated in the literature [38]. In addition, the peduncle is totally radio-transparent 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 inner constitution: this in fact depends on the different quantity of melted mixture 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. This is clearly evident, for example, in the case of the (GV) model representing the Rome Beauty Apple: the X-ray image (in inverted grayscale) (Fig. 7) shows how to achieve the desired weight the model was left almost empty but with very thick and uneven walls.

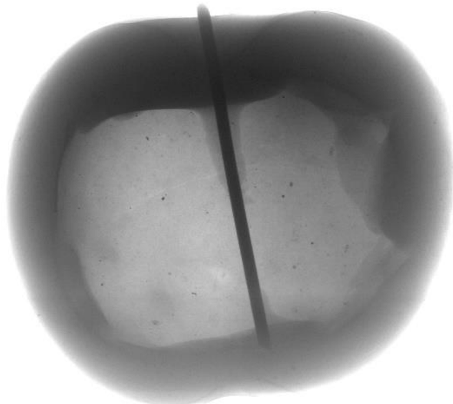

Figure 7: RX 2D image (in inverted grayscale) of (GV) apple Rome Beauty.

4.4 X-ray Fluorescence and FORS spectroscopy

XRF spectra were acquired on both Britanische Herbstbirne (Dü) pear and Rome Beauty (GV) apple. Three points were selected on each fruit: one for the most yellow parts of the skin, one for the red parts and one corresponding to scrapings on the surface, where the core of the samples was uncovered. Results are summarized in Figg. 8-9 respectively via comparison of XRF spectra for the different measuring points.

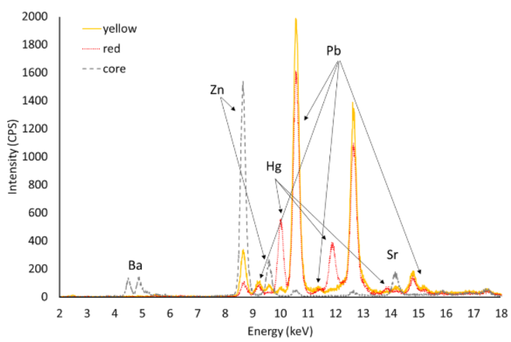

Figure 8: XRF spectra of the considered areas on (Dü) pear Britanische Herbstbirne.

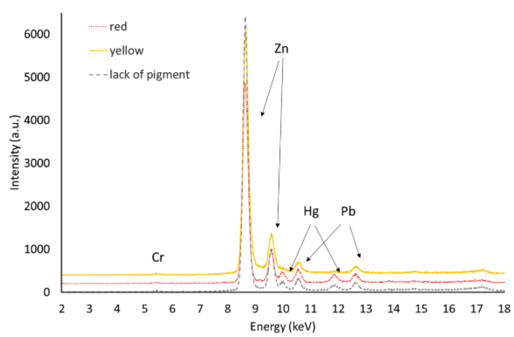

Figure 9: XRF spectra of the considered areas on (GV) apple Rome Beauty. Values on the y-axis have been shifted for sake of clarity.

It should be noted that, for the Britanische pear, the lack of the pigment layer is surely larger than the X-Ray beam. For this reason, the spectra shown in Fig. 8 allow to clearly discriminate the elements from the internal part with respect to the colored layer. In this situation, the elements linked to the inner part of the fruit are barium, zinc and strontium, with small traces of calcium and lead. It should not surprise that calcium is detected in traces, being in a mixture with heavy elements (such as barium) and in a low detection efficiency energy region. Indeed, the presence of a calcium based compound in the core seems to be suggested by the pronounced presence of the signal of strontium, its chemical vicarious typically present for calcium based minerals, like gypsum. Barium and zinc are instead typical elements of white pigments probably mixed with gypsum, while lead traces could also derive from the surrounding red/yellow pigments. Yellow areas are in fact characterized by a strong presence of lead signals, together with lower zinc peaks. The yellow pigment is then a lead based one, while the reddish areas show in addition the presence of mercury (due to vermillion) and traces of iron, probably from an earth or an ochre; both pigments are confirmed by the observation of FORS data (Fig. 10).

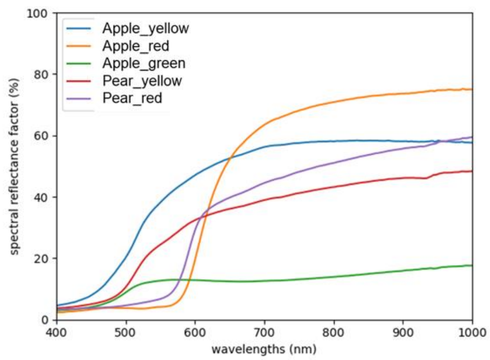

Figure 10: FORS spectra of the considered areas on (GV) apple Rome Beauty and (Dü) pear Britanische Herbstbirne.

Different is the case of the apple: here, the surface scraping is smaller than the X-Ray beam and colored areas cannot be excluded from the analyses. Still, some interesting considerations can be done. Zinc seems to derive from the substrate, or from Zinc based yellow pigment, while red zones also exhibit the presence of mercury, i.e. vermillion. From the FORS spectrum it is possible to hypothesize the presence of both vermillion and an organic red pigment such as lake.

In addition, a small peak of chromium - with minimum traces of iron, cobalt and calcium - were detected, thus suggesting the use of a modern yellow/green pigment. The observation of reflectance data would suggest otherwise the mixture between a yellow pigment and a blue rather than a green pigment.

The comparison between the two fruits shows a clear difference between the materials of the core, testified by the total absence of barium in the (GV) apple. Also the yellow pigments identified are different: zinc based yellow for the apple, and lead based yellow for the (Dü) pear.

4.5 FT-IR reflection spectroscopy

FT-IR reflection spectra acquired on the Rome Beauty (GV) apple represent an interesting example of the information that can be collected in a non-invasive way about the materials of the examined artefacts. In particular, two areas of the fruit were analyzed, one corresponding to the intact skin and the other to the scratch in the surface revealing the underlying material.

In the medium IR region (4000 – 400 cm^{-1}), the intact skin showed the typical signals due to beeswax at 2955, 2920, 2850, 1735, 1464, 1167, 728 and 720 cm^{-1}, as shown by the comparison with a reference beeswax sample (Fig. 11). In addition, a wide component is observed from 1700 to 1600 cm^{-1}, possibly associated with thermal alteration products of wax itself [39]. On the other hand, the spectrum obtained on the inner material through the scratch in the surface, even if it has a low signal/noise ratio, leads to identify gypsum thanks to the band centered at 1150 cm^{-1}. An organic component is also present, as demonstrated by the signals due to C-H stretching at 2920 and 2850 cm^{-1}, but the two wide bands around 1600 and 1400 cm-1 suggest just a possible mixture of different substances whether they are original or altered.

In the near-IR region (7000 – 4000 cm^{-1}), the intact skin gave a response suggesting the co-presence of beeswax and a natural resin like dammar, probably used in the layers just below the surface. The evidence of natural resin is demonstrated by bands at about 4060, 4160, 4250, 4340, 4630, 4810, 5190, 5730 and 5850 cm^{-1} (see the comparison with the spectrum of the dammar resin in Fig. 12 and reference [40]).

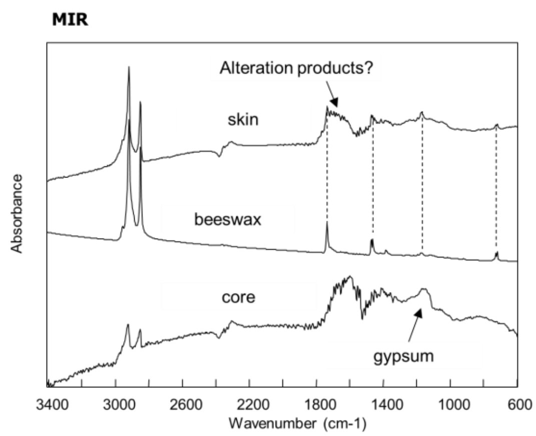

Figure 11: FT-IR spectra of the considered areas on (GV) apple Rome Beauty in the medium IR region.

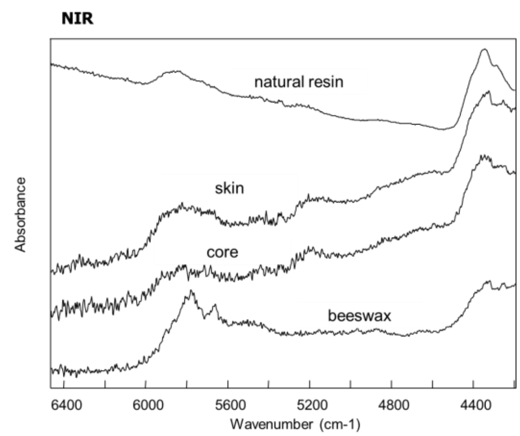

Figure 12: FT-IR spectra of the considered areas on (GV) apple Rome Beauty in the near-IR region.

5 CONCLUSION

With 3D CH modeling as standard practice, high-realistic digital renderings can be passed on to future generations for historical documentation, cross-comparison, monitoring of shape, color, and ageing deterioration, computer-aided restoration, augmented reality museum exhibitions, etc. [41]. 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 the first step towards the complete digitization of this extraordinary collection and demonstrates how the multidisciplinary combination of compositional, stratigraphic and photogrammetric data is extremely powerful in showing the manufacturing complexity of the artworks examined in this research project.

The main limitation relies on the difficulties that normally go along with the basic 2D digitization of an entire collection of artworks. If we consider other bands of investigation in addition to the visible and at the same time moving to the 3D multiband digitization of a copious collection such as the Garnier Valletti, the challenge is particularly demanding for the acquisition, processing and post-processing steps. Since our goals are the analytical diagnostics, documentation and preservation of these artifacts, high quality radiometrically and geometrically correct 3D models are required. In this context, the additional effort is aimed at the highest quality 3D acquisition for as many artifacts as resources and time allow, while collecting, generating and including rich metadata and annotations throughout the workflow.

Finally, several developments and advances will derive from this preliminary phase: first, a systematic and accurate multi-temporal spectrocolorimetric survey and microclimatic campaign are planned to verify the onset of any chromatic alterations and/or morphological deformations. Successively, an extensive Hi-Res DXR documentation will be carried out to highlight intriguing and unusual constituent details used by the artist for the creation of the different fruits and cultivars - even if weakly radiopaque - such as the original achenes in the strawberry models or the original grape seeds inside the resin berries. Lastly, the PT conducted on selected artworks will provide a priority scale of the most fragile models to be the first to undergo immediate restoration.

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