Digital Imaging Techniques in Archaeometry: The Case of an Ancient Crucifixion Icon

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Abstract. An ancient Crucifixion icon has been studied using imaging techniques integrated with appropriated visualizations. Relevant parameters and suitable algorithms have been selected in a proper sequence to segment the studied images into meaningful elements functional to the attribution of the icon through analysis of the employed materials and techniques. The cross-referencing of the results allowed to identify three main phases in the realization of the painting, to describe their extension, character and determine the possible authors as: Cretan/Ionian painters, '500-' 600 (1st phase); Hristofor Žefarović, Western Balkans or Vienna, 1730-1753 (2nd phase); Placido Fabris / Michelangelo Barbini, Venice, mid 19th c. (3rd phase).

Keywords: Digital Image Post Processing, Imaging Techniques, Technical-Technological Analysis, Hristofor Žefarović, Painting Techniques.

1 Introduction

This paper illustrates the application of an appositely elaborated ontology-based knowledge model (Stoyanova, 2014) (Stoyanova, 2015) (Stoyanova & Lukić, 2015) (Stoyanova & Pavlova, 2017), (Stoyanova, Stoyanov & Pavlova, 2018) dedicated to digitization of Byzantine and post Byzantine painting and functional to archaeometric and conservation purposes. It is intended to assist authentication, attribution and dating, reasoning through defined semantic data collected from digital multimodal & multidimensional images which describe the physical and chemical characteristics of the studied objects.

In the present case, with the help of particular digital visualizations an ancient Crucifixion icon has been studied by optical microscopy, macro photography in VIS/raking light, ultraviolet fluorescence, infrared reflectography and X-ray. Technically relevant parameters and suitable algorithms have been selected in a proper sequence to segment the studied images into meaningful elements functional to the attribution of the icon

through analysis of the employed materials and techniques (Stoyanova, Stoyanov & Pavlova, 2020).

The introduction into the state-of-the-art and the description of the critical points that hinder the authentication and attribution of the painting is followed by a section which presents the methodological approach and workflow phases of the digital reconstruction and analysis. In the exposition, the outcomes of the spectral measurings are discussed considering historic, art-historic and iconographic aspects, technical information derived from painting treatises of the epoch and from leading research and restoration centers' databases. The conclusive part summarizes the main phases in the realization of the painting and advances hypothesis about their authors.

Application of ontology-based knowledge models aimed to provide logical representation of any particular domain of interest (Jakus, Milutinović, Omerović & Tomažič, 2013), (Cruz & Xiao, 2003), (Brewster & O'Hara, 2007) evolved in recent years from conventionally defined standards for meta-, para-, and provenance information[1] to semantic technologies such as expressed through Web Ontology Language (OWL) (Antoniou & Van Harmelen, 2004). However, as regards the field of cultural heritage, in these new computational artifacts potential of reasoning through defined semantic facts is often ignored or limited to recognition (Durand, Derivoux, Forestier &Wemmert, 2007), (Maillot, 2005). The existing interactive platforms for digitization of CH objects as the CIDOC Conceptual Reference Model (CRM)[2] only structure biographical and provenance information related to a physical object (Gosden& Marshall 1999) giving museums and archives the possibility to publish and link their existing databases, but do not help much the technical - scientific exploration of the items[3]. From the other side, accessible technical databases (OPPRA, e.g.: Odat, 2014) do not provide the information needed for our concrete purpose.

2 The Artifact

The object of this case study is an ancient panel painting (Fig.1) depicting the Crucifixion[4], about whose place of origin, date and vicissitudes there is any information. The whole representation is denoted by profound dichotomy between the iconographic composition, on the one hand, and the technical realization of the painting and its ornamentation – on the other. For example, at the foot of the cross, in front of the Virgin, we do not find Longinus, as traditional, but a figure that would be compactable with that of John the Theologian, however, of such feminine traits as to confuse him with Mary

[1] Examples of XML schema-based standards are LIDO (Coburn, Light, McKenna, Stein & Vitzthum, 2010) and MIDAS Heritage (English Heritage, 2012).

[2] CIDOC-CRM, designed as standard to archive biographical heritage information, is the most prominent and widely used ontology within the cultural heritage community (Le Boeuf, Doerr, Ore &Stead, 2018).

[3] Among these are, for example, the Europeana (2022) (Fernie, Gaverilis, & Angeli, 2013) or the Louvre collection (2022).

[4] The icon, actually in the Ferdinando Mazzei collection (Rome), has been purchased few years ago at an auction in Rome.

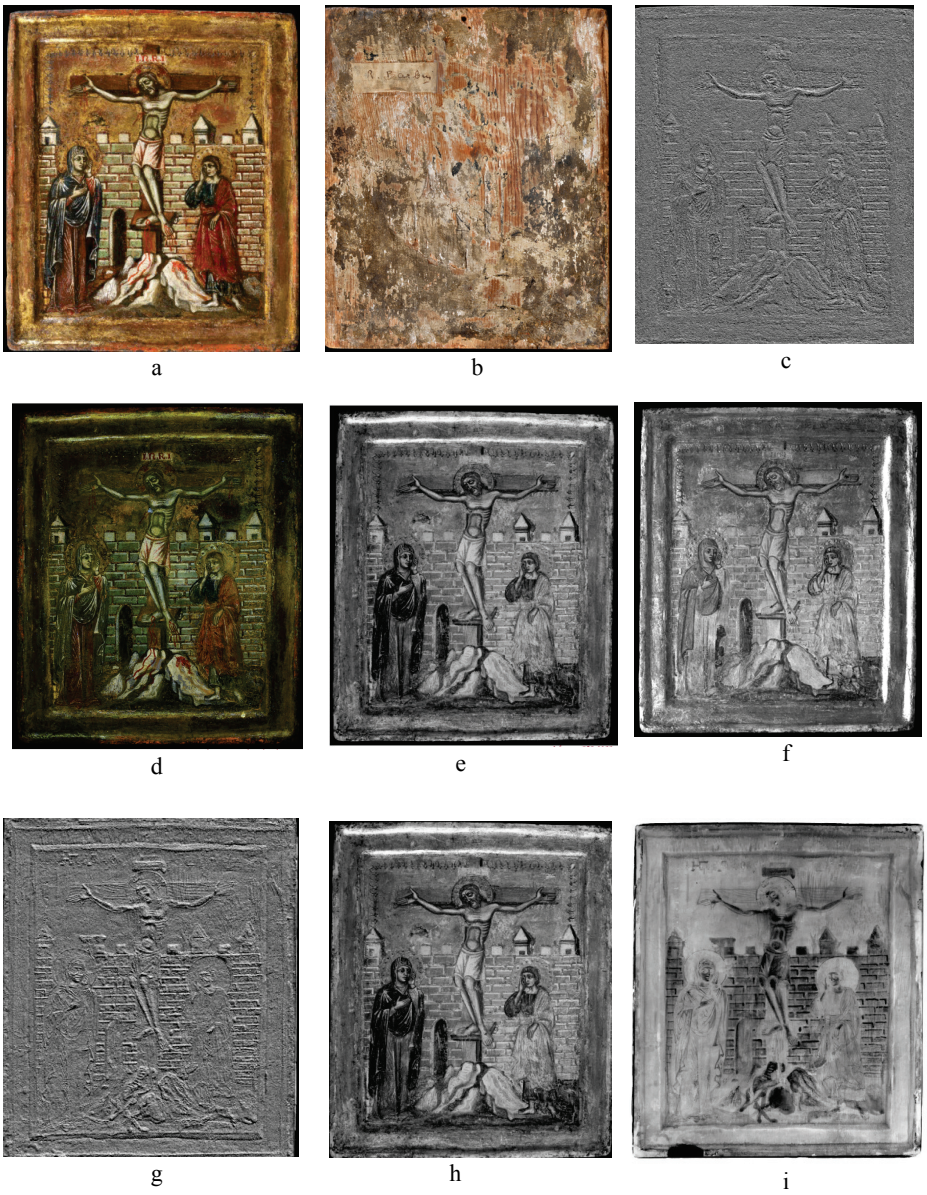

Fig.1.The Crucifixion icon in: a) VIS b) backside, c) VIS monochrome shadowed, d) UVf, e) IR at 950-1100 nm, f) IRr at 1650-1800 nm, g) XR shadowed, h) XR, i) XR color inversion

Magdalene. That this may not be authentic springs from the relief of the pictorial layer in raking light. Besides, from the naked eye observation is visible that the wooden support should be much older than the style of painting, indicative for the religious art of

the reformed Catholic Church (17th – 18th centuries)[5] does presume. Other perplexities arise from the fact that under Golgotha one does not see the usual for Orthodox iconography, module with the skull of Adam, the rivers of paradise and the woods of which the cross was built[6]. Embarrassing are as well the flattened geometric and underlined in relief shapes of the stones that, with a sort of hyperrealism, depict the wall of Jerusalem in the background. And not least, the only preserved inscription on the painting, JNRJ (Jesus Nazarenus Rex Judaeorum) is in Latin, while on the back side we can see the typical cross dating formula in Greek, as used by post Byzantine iconographers (Fig.1.b).

For to solve the doubts about the origin and age of the icon scattered from the stylistic, iconographical and technical anomalies and peculiarities, it was decided to integrate the historical-artistic study with a complex non-destructive technical-technological investigation, based on spectral analysis (UV, IR and XR), on particular visualization techniques and comparisons with the technical treatises of the epoch.

The results allowed to identify the remains of a much older image painted in tempera and consonant with the Byzantine iconography of the Crucifixion. The radiography brought to light an inscription (partially preserved on the sides of the cross at the top, invisible at normal light) that names the depicted scene Σταυρωσις (Crucifixion in Greek), while in the halo of Christ reappeared the typical Byzantine *tituli* α and ω (Fig. 1.h). These discoveries put in doubt the originality of the overlying *stucco* decoration around the central field and on the punched aureoles.

3 Methodological Approach

The diagnostic campaign conducted on the icon has been limited to spectral analysis by imaging techniques: photo documentation of the support, of the painting and the gilding in VIS/raking light, examination in UV fluorescence, IRr at 950-100 & 1650-1800 nm, and XR. In the course of the case study was collected and put in use a considerable amount of inhomogeneous data (referential art historic material included[7]). All information necessary to the study (analogue pictures, texts, tables etc.) has been digitized. Contemporary, with external devices & software have been generated the digital images

[5] At that time, throughout all the Latin area the wooden supports had long since been replaced from textile fabrics and the egg tempera - from oil painting, whose invention mid 15th c. is attributed to the great Flemish painter Jan van Eyck.

[6] These elements not rarely are encountered even in Italian Renaissance art, i.e.: The master of san Francesco, *Processional cross, double sided,* 1275 ca. Perugia, National Gallery of Umbria; Bonaventura Berlinghieri?, The *way to the Calvary, Crucifixion and Deposition*, Uffizi diptych, 1250 ca; Landini Jacopo detto Jacopo Del Casentino (1297/1349), *Crucifixion,* 1340,Uffizi, Florence; Andrea Mantegna, *Pala of San Zeno with Crucifixion*,1457-1459, Louvre; Antonello da Messina, *Crucifixion* (oil on linden wood, cm 59,7×42,5) 1475, Koninklijk Museum voor Schöne Künsten, Anvers.

[7] Of particular utility for the attribution of the painting has been the documentation collected in occasion of the STSM "Spectral investigation of Serbian Baroque icons" carried out in Galerija Matica Srpska November 2014 funded by the COST COSCH Action TD1201(Stoyanova 2015)

of the icon in VIS/raking light, UVf, IRr and XR. The raw data have been subjected to digital processing following the guidelines developed by (Stoyanova, Stoyanov & Pavlova, 2018). The general workflow is illustrated at Fig. 2.

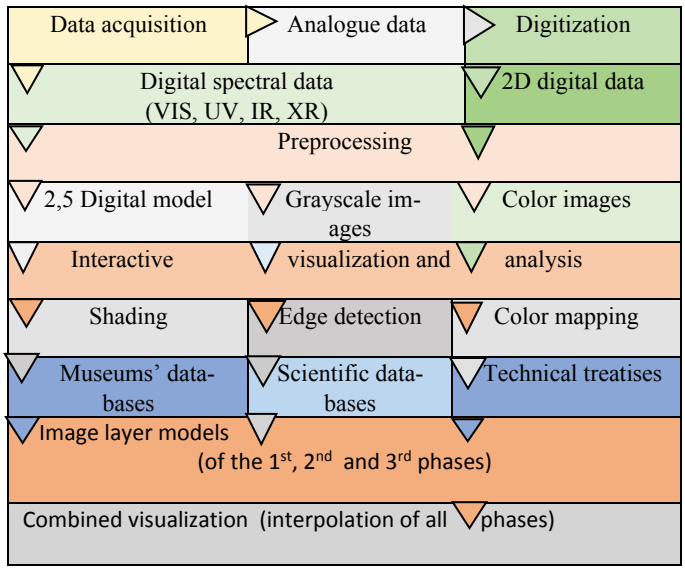

Fig. 2. Workflow diagram

Large files have been reduced and transformed to formats that allow to visualize them contemporary by an internal image viewer. All images have been rendered more legible by denoising, histogram adaptation, selection of the color palette and color inversion, by monochromatic filtering of the visible light and chromatic transformation of halftone images, morphological filtration, edge detection, opportune highlighting or shading of the surface relief (Stoyanova, Stoyanov & Pavlova, 2018). This last, for example, comparable to raking light photography in its capacity to emphasize details, has the advantage of producing shadings from any angle anytime (Phong, 1975). Besides the "moveable virtual light source", the "color mapping", "layer-structure", "transparency" and "edge filter" functionalities have been of great efficacy for enhancing the visibility of the processed images, particularly regarding their intensity, color, density, homogeneity; the presence of dark or clear areas and lines which are of primary importance for the evaluation of the chemo-physical properties of the artifact.

The protocol for cross-referencing followed best practices for nondestructive investigation of paintings resulting from assessment of big data collected in the last decennials and updated on the possibilities of the actually used techniques (Stoyanova, Maximova, Mazina, & Provorova, 2017). Concretely in this case, the experiments aimed to study the reaction of gesso, paint and varnish layers together as well as separately to UV, IR and XR radiation. To the purpose to permit a combined contemporary visualization of the various spectral profiles of the analyzed painting and of their digital transformations, they were reported to the same scale and arranged in a palimpsest (Fig.

1); high resolution details were “mapped” on the background of the entire image in VIS. Using the coordinates of each image, corresponding information about determined matching points of all them could be searched and found contemporary, without loss of data as it could happen in case of overlapping. The issues were further correlated with the materials and techniques for icon paining described in medieval treatises as well as with issues of laboratory analyses of analogue cases, with external sources (scientific databases, museum’s collections etc.).

4 The Investigation by Imaging Techniques Integrated with Technical Visualizations

4.1 The Investigations under Radiation Induced by UV Fluorescence

The entire surface of the painting has been subjected to radiation induced UV fluorescence. The reflectography (Fig.1.d) showed diffuse fluorescence on the maphorion of the Virgin, her tunic, the lower parts of the mantle of Magdalene and the faces of the three figures. This renders the colors misty and opaque and is a sign that the protective layer there is very new and, probably, lies on layers of old paints. The major intensity of reflection was noted on the wound of Christ, on his loincloth, on some folds of the Virgin mantle, on the white rocks at the foot of the cross, on the crossbar of the cross with the inscription JINRJ and on the Jerusalem wall, especially on some of its delineations in relief: a sign that there the paint is relatively new and thinner than the rest. Traces of partial removal of the original protection appeared on the pinnacle to the left of the Cross, whose round shape has been modified in an earlier restoration. Retouching on partially removed varnish revealed the numerous patches ranging from red to yellow on the red coat of Magdalene, and from dark blue to green – on her tunic.

Increased absorption intensity, due to local loss of gilding and to the properties of the underlying *bolus,* was observed along the profiles of the frame with pastille decoration as well between the left arm of Christ and the pinnacles. The pronounced UV density of the pigments used to paint the stones under the cross showed that these are younger and less affected by aging in comparison to the oldest areas which, to the contrary, appear more dull. Finally, thanks to the characteristic UV fluorescence, it has been possible to identify some of the used pigments without taking samples. Among them of particular archaeological importance are the whites. Lead white (*biacca,* (2PbCO3 * PB (OH)2)) has been attested in the original figures, while zinc white - on the rocks at the foot of the cross, on the JNRJ inscription and in the accents on the maphorion of the Virgin (right shoulder). The lack of UV luminescence and the characteristic black flashiness of the gilding *bolus* and of the shadows at the foot of the cross suggested presence of ocher.

4.2 The Investigation in the IR Register

The underlying layers were studied by infrared shooting at 950-1100 nm and infrared reflectography, conducted with a high-resolution scanning system with InGaAs detector, capable of recording infrared radiation between 1650 and 1800 nm). Infrared reflectography (Fig.1.e-f) helped to identify the extent of the various modifications to which the original painting has been subjected over the centuries, and to define their character. These touch-ups match especially the design of the anatomical parts and the cross. IRr also highlighted a widespread crackle (in shape of cells, in the central and lower part of the table), and fragments of very articulated drawing - in the mantle of Magdalene, for example, made by brush with carbon containing substance and visible as black lines. Under the inscription JNRJ appeared another, difficult to read, however compatible with the typical for the Greek - Byzantine Crucifixions «βαζιλιας». Under the canopy of the pinnacle to the right of the cross took shape a small figure of a person raising a cross (perhaps the converted to Christ soldier Longinus).

Regarding the chemical composition of pigments, judging from their reflection to infrared rays it was established that the tunic of Magdalene has been painted with indigo (Déribéré, 1954), (Gibbson, 1978) as well as the piece of the Virgin's mantle which comes down from her left arm. The rest of this mantle, as visible also from the X-ray, has undergone remakes: in IRr at 1650-1680 it appears dark gray, reaction that is compactable with that of the blue of Prussia or of the artificial lapis lazuli. This chronologically places the intervention in the third phase because the white, with which it is lightened, is not *biacca* and is transparent to X rays (Stoyanova, 2022).

The blood painted at the base of the cross results thoroughly transparent to IR rays: considered its flashiness in VIS, UV and RX, this means that most likely it is obtained from madder. The strong fluorescence of the pigments used for the mantle of Magdalene and the tunic of the Virgin is compactable with the characteristics of madder, crimson and cinnabar, as well as with these of yellows mixed with *biacca*. The IRr reaction of the modifications visible at the foot of the cross (originally painted with *biacca*) and on the inscription JNRJ indicated the use of zinc white (ZnO).

The thick brush shading along the arms of Christ, on the neck and eyes of Magdalene, and in the folds of her and those of the Virgin robes is performed with substances that strongly absorb in the infrared, therefore containing coal (soot or Chinese ink). Ambiguous reading and need for deepening represent the clear areas on the trunk of the cross, at the bottom (very probably painted with organic substances on *imprimatur* based on *biacca*), and the composition of metals used for the gilding and its preparation which, in addition to traditional ochre (compositions containing Fe), for the reaction to infrared rays seems to contain also cinnabar.

4.3 The Investigation in the XR Register

The radiographic analysis of the Crucifixion (Fig.1.g-h) could not give a definitive answer to all the questions posed due to the domination of areas painted on white *imprimatur* such as the faces of the three figures and the wall of Jerusalem. However, it

allowed to visualize the internal structure of the painting and to define three main executive phases in its creation (Stoyanova, 2022) thanks to the identification of some materials of archaeological importance. No traces of lining with fabric are visible on the X-ray. Natural dyes (madder or crimson, coal or soot black), respectively lacquers based on such, are visible as black spots on the delineations and shadows of the Mother of God tunic and in the preliminary drawing in black. The areas containing heavy elements such as Pb or Hg (the white areas of the original and the ancient name of the scene in Greek, written with cinnabar), strongly absorb the radiation and go back on the rest as light blotches. Pigments such as smalt, ultramarine and indigo (the latter is hypothesized on the tunic of Magdalene and on the maphorion of the Virgin), which consist of light elements, are penetrated by the X rays without great weakening, producing on the radiography gray areas. The mantle of Magdalene and the tunic of the Virgin, fluorescent in IR, in XR are dark, which means that they are painted with organic dyes (madder or crimson). The background gilded on *bolus* reveals a chemical composition with low percentage of Fe which is completely compatible with the recipes for its preparation going back to the Byzantine period. The areas covered with metal leaf, however, are barely noticeable due to their very low thickness (of a few micrometers) or due to their chemical composition (Stoyanova, Maximova, Mazina, & Provorova, 2017).

Besides helping to orient in the chemical composition of pigments and dyes of archaeometric value, the X-ray investigation showed numerous black dots on the background that are not due to grinders but can be explained solely by the property of preparations based on gypsum or clay - unlike those based on oil or emulsions - to form in the *levcas* during brush application foam and air bubbles that later turn to craters on the surface.

Radiography also helped to build an idea of what the composition was like in phase 1 basing on the preliminary design, visible in areas not covered by *imprimatur* as white lines (for the accumulation in the handwriting of heavy material). It does not match the design of the second version visible in IRr as black lines, especially with regard to the loincloth of Christ (originally tied in a knot), the flaps of the robes of the Virgin and Magdalene, the silhouettes of the cross and the extremities of all the three figures and, above all, the skull of Adam with the heavenly rivers and driftwood, revealed by the XR.

5 The Visible and Invisible Crucifixion: Digital Reconstruction and Attribution

The cross-referencing of the results obtained in the course of the complex stylistic, iconographic, technical-technological and digital spectral investigation allowed the identification - without sample collection - of some of the pigments employed and of original parts under paints, thus providing substantial clues for the reconstruction of the various transformations of the original icon. The definition of their extent and date was possible mainly taking into account the differences that distinguish the Orthodox tradition from the Latin as regards the plastic construction of the figures, the type of per-

spective, the painting technique, and the use of specific materials. Thanks to the abundance of data of archaeometric value, a highly plausible periodization of the various interventions could be advanced according to which the original icon was created in post Byzantine style, with inscriptions in Greek on the verse and with the master's signature on the back. In the second phase were added the pastille ornaments (hiding the Greek name of the scene), the frames around the central field and the relief halos. On this occasion the thong of Christ was modified and in the background was introduced the now visible Jerusalem wall, with relief underlining of the stones. In the third phase, together with the touch-ups of the faces and hands with oil, the module with the skull of Adam was hidden and the Greek inscription on the cross replaced with JNRJ. Also the maphorion of the Virgin was repainted, hiding the original, detailed design of the folds and their graphic ornamentation visible in XR.

The divergence between the graphic design - as documented in the preliminary drawing - and the overlying layers of painting, as well as the iconographic and aesthetic changes threw more light on the cultural identity of the painters and suggested to identify them with Cretan/Ionian painters, '500-' 600 (1st phase); Hristofor Žefarović, Western Balkans or Vienna, 1730-1753 (2nd phase); Placido Fabris/Michelangelo Barbini, Venice, mid 19th c. (3rd phase) (Stoyanova, 2022). The conceptual reconstruction of the now invisible phases could be visualized using the XR image as base for the earliest phase, and the IR reflectography – for the second phase (Stoyanova, Stoyanov & Pavlova, 2020). However, peculiarities that determine the character and quality of the painting (the exact coloring, the type of modeling, the transparency, brightness and dominance of the chromatic surfaces, the fineness of the brushstrokes and the exact course of preliminary drawings and delineations) are only occasionally recognizable and cannot be reconstructed for the entire painting. Both in terms of aesthetic *ductus* and exact compositions of the three versions still remains a considerable gaming space.

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