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New Information Provided by Multidisciplinary and Combined Studies, Including Radiography, XRD and XRF, of the triptych the Last Judgement from National Museum in Gdańsk: Rogier van der Weyden and Hans Memling co-authorship

ABSTRACT

Examination of the Gdańsk triptych *Last Judgment* carried out by the Faculty of Art. Conservation of the Academy of Fine Arts in Warsaw and CHARISMA Group researchers included XRD/XRF, multispectral reflectography MNIR and other methods. They have shown that the work, a typical example of 15th-century Flemish art, was probably begun by Rogier van der Weyden (design, drawings and some underpainting, and completed by Hans Memling. Dendrochronology tests have confirmed that the support from Baltic oak might have been ready for painting in 1460, i.e. 4 years before the death of Weyden. The *Last Judgment's* unique expression is due to its Northern Renaissance features.

Keywords: multi-criteria research, non-destructive tests of artworks, 15th-century Flemish painting, Rogier van der Weyden, Hans Memling, synergy of sciences in artwork analysis

*The fact that any image relies on physical means to manifest itself,
and that means are not an end, does not excuse us
from the considering how the material used relates to the image.*

Cesare Brandi, *Theory of restoration*

General informations

The central scene of the triptych represents the *Last Judgement* and, from the viewer's perspective, is flanked by *Heaven* on the left and *Hell* on the right. Portraits of the commissioners, Angelo Tani and Caterina Tanagli, are represented on the backside of the wings. We have no data related to the commission. The painting, currently housed in the collection of the National Museum in Gdańsk, is painted in tempera and oil technique on an oak wood support. The central section of the triptych is 242 cm by and 180.8 cm (height x width), the wings both measure 242 cm by 90 cm.

The earliest historical reference, that can be used to date the artwork, mentions its capture by Gdańsk pirates in 1473 and the ensuing lawsuit against the Hanseatic League. Authorship of the masterpiece has been reattributed many times. The masterpiece was first attributed to the van Eyck brothers (Hubert – born about 1366, died 18th September 1426, Jan born about 1390 in Maaseik, died July 9th 1441 in Bruges). It later attributed to Rogier van der Weyden (1399/1400 Tournai, June 1464 in Brussels) and other Flemish masters. In 1843, the Triptych in 1843 was attributed to Hans Memling (born about 1435–1440 in Seligenstadt, died August 1494 in Bruges) by the art historian, Professor Heinrich Hotho – who was a philosopher and pioneering art historian from the Friedrich-Wilhelms (now Humboldt) University in Berlin. His attribution was made based on humanistic interpretations. Hans Memling was first recorded in history in January 1465, when he appeared in Bruges. Many authors suggested that he was a pupil of Rogier van der Weyden [Ziembra 2011].

Below is report from a current multidisciplinary case showing how multidisciplinary scientific analysis can fail to properly to understand painters' techniques and authorship.

Recognition of the *Last Judgement*

The Triptych was painted in accordance with the strict guild rules that dictated the artistic practice in the Low Countries, during in the second half of the 15th century. A dendrochronological examination of the support indicates that the support is constructed from oak boards. The central section is made up of six vertical boards with a total width of 180 cm. Dendrochronology has often contributed to solving important art-historical questions and controversies [Woll et al. 2008, Ważny 2011]. It is completely independent of other chronological indicators. If the wood used by the author of the triptych can be dated, this date can be used to confirm or exclude attribution. If the support had a fell-date after van der Weyden's death, then his authorship would be automatically excluded.

Dendrochronological examination of the oak wood support was carried out in 2003¹. Fell dates were determined by comparing the tree-ring series of the boards with a set of European oak chronologies. This also provided a potential origin for the wood.

¹ Dendrochronological analysis was performed in 2003 in the National Museum in Gdańsk by the Institute for the Study, Conservation and Restoration of Cultural Heritage of the Nicolaus Copernicus University in Toruń. After removing the panel from the frame the cross sectional area of wood was care-

Taking the dendrochronological factors into account, in conjunction with the date of Rogier van der Weyden's death in June 1464, the results of the dendrochronological analysis, and consideration of the earliest possible production date, places the construction of the painting support toward the end of 1460. Incidentally, this then does not preclude Rogier van der Weyden's participation in the creation of the masterwork the *Last Judgement*.

Results of preliminary non-invasive research

Above conclusions were supported by the subsequent non-invasive research carried out to identify the materials used to paint the *Last Judgement*, reported below. New information and data were provided by a thorough preliminary non-invasive investigation of the painting². The painting was examined and documented using visible light (VIS), ultraviolet radiation inducing fluorescence (UVF), X-radiography, XRF/XRD and infrared reflectography (IRR). These studies revealed some of the exceptional details used to create the altarpiece. The various phases of construction could be compared with other studies carried out on paintings [Faries 1994]. The present results suggest that indeed Rogier van der Weyden could indeed have contributed significantly to the design and construction of the painting.

The initial composition of the image appears to be very different to that depicted in the paint. These changes in composition were revealed in the IRR images. The IRR images of the initial layout and design were compared with those from another *Last Judgement* by Rogier van der Weyden (The Hospices/*Hôtel-Dieu* in Beaune, France) painted c. 1443–1452.

fully cleaned and prepared for testing. The ring widths of all six boards were measured with an accuracy of 0.05 mm. See more: Szmelter I., and Ważny T., *Interdisciplinary approach to the identification and authorship of "The Last Judgement" triptych from the National Museum in Gdańsk* [in:] Wood Heritage; Research and Conservation in 21st century, ICOM-CC papers, NIMOZ Publisher, Warsaw 2013, pp. 62–63, 173–174. Online: [//nimoz.pl/pobierz/718.html](http://nimoz.pl/pobierz/718.html). accessed on: 20.11.2015 *Interdisciplinary approach to the identification and authorship of The Last Judgement triptych from the National Museum in Gdańsk*, file:///C:/Users/iwona.szmelter/Downloads/Drewno_zabytkowe%20(2).pdf.

² The research was undertaken by the Faculty of Conservation and Restoration of Works of Art of the Academy of Fine Arts in Warsaw and analysed by the primary author and Anna Fortuna from the National Museum in Gdańsk. See more: *Całościowe zebranie i przygotowanie do dalszych analiz informacji oraz wyników badań rozpoznawczych tryptyku Sąd Ostateczny z Muzeum Narodowego w Gdańsku przypisywanego Hansowi Memlingowi, uzyskane w latach 2010–2013 w wyniku następujących badań analitycznych: UV, VIS, IR 1200 nm mid-FTIR, near-FTIR, SERS oraz XRD/XRF, MNIR wielospektralna reflektografia w podczerwieni*, <http://mng.gda.pl/wp-content/uploads/2014/10/Badania-S%C4%85du-Ostatecznego-pdf.pdf> [access: 20.09.2015].



Fig. 1. Central composition of the *Last Judgements* – comparison of the infrared reflectography (IRR) images by a) the polyptych of Rogier van der Weyden in Beaune (circa 1443–1452) (IRR acquired in 1953, courtesy ARCHLAB-C2RMF, Paris); b) the triptych by Hans Memling (~1460–1471), IRR image acquired at 1000–1200 nm (Roman Stasiuk, AFA, Warsaw, 2010); c) the triptych by Hans Memling (~1460–1471), scanning multispectral IRR image acquired at 2265 nm (Mattia Patti, courtesy CHARISMA-MOLAB, 2013). Digital mosaic photo Archive of Faculty of Conservation, AFA, Warsaw

The comparison shows remarkable similarities. The masterful development of the design and underlayers of paint appear closely related. Furthermore, the early compositional design and details are similar to other typically detailed underdrawings in other works by van der Weyden [Ainsworth 1994].

The analytical information provided by the combined use of different techniques

The initial documentation of the painting was supplemented by the research carried out by the Faculty of Conservation-Restoration of Works of Art, Academy of Fine Art in Warsaw in 2010 and then by the MOLAB team. The team travelled twice to Gdańsk to study the painting. The first visit took place in January–February 2012, and the second in

May–June 2013³. The MOLAB team performed in-situ analysis of the painting materials using a variety of techniques described below.

A systematic study of the painting materials and technique was undertaken in two consecutive strategic phases. The first phase of the diagnostic campaign consisted of an in-situ analytical survey of the triptych, using non-invasive analytical equipment provided by MOLAB. The second phase comprised of targeted sampling of representative areas, in order to answer specific questions that arose during the non-invasive investigation, and related mostly to the stratigraphy of the paint layers. The in-situ investigations were based on multipoint analyses by Fourier Transform near and mid-infrared reflectance spectroscopy (near-FTIR and mid-FTIR, respectively), ultraviolet-visible (UV-vis) reflectance and fluorescence spectroscopy and measurements of luminescence lifetimes (time-correlated single-photon counting – TCSPC). More than 350 point analyses were performed on the wings and on the central panel of the triptych. Scanning Electron Microscopy (SEM), equipped with an energy dispersive spectrometer (EDS) and reflectance mid-FTIR micro-spectroscopy were both used to study micro-samples and establish the stratigraphy of the painting.

This research also benefited from the fortunate opportunity to compare the results with those obtained in a previous MOLAB study of another important painting painted by Hans Memling and his assistants, *Christ with singing and music-making angels* (dated ca. 1487–1490, painted in the last years of Memling's life). This comparison was carried out during the treatment of the panel at the Royal Museum of Fine Arts in Antwerp [Romani et al. 2010]. The investigation of the painting surface also revealed an almost unique technological aspect of the painting. The portrait of the saved men, found on the scales of the wings of Archangel Michael, was painted initially on a separate tin plate support, which was subsequently glued, as an insert, on to the original surface. It is considered to be a portrait of Tommaso Portinari, who replaced Angelo Tani (the donor of triptych) as head of the Medici bank in Bruges in 1471. The production of a donor portrait on a tin support was also carried out by Rogier van der Weyden in one other work, the *Seven Sacraments*, now found in the Royal Museum for Fine Arts in Antwerp. Here eleven of the portraits are painted on a tin support and then added to the panel [Steyaert 2012]. The characterisation of the artist's palette, determination of pigments and organic lakes, and the analysis of the organic components of binders and varnishes, through the stratigraphic and mid-FTIR analysis, aided in the present study of this painting technique.

X-ray fluorescence (XRF) and X-ray diffraction measurements (XRD)

The X-ray measurements were performed directly on the panels by means of two mobile instruments developed by the Laboratory of Molecular and Structural Archaeo-

³ The MOLAB team travelled to the National Museum in Gdańsk in 2012 and 2013. With the exception of the mid-FTIR reflectance spectrometer (Alpha-R, Bruker Optics), a detailed description of the MOLAB instruments and their operational configuration is given in the literature [Miliani et al. 2010].

logy⁴. These techniques are particularly suitable for the study of works of art as they are totally non-invasive [Gianoncelli et al. 2008, Duran et al. 2009]. XRF gives information on the elemental composition of the pigments – qualitatively and/or semi-quantitatively, and on the superimposition of layers. However, XRF analyses cannot detect light elements like carbon, oxygen, sodium and magnesium. X-ray diffraction allows identification of the crystalline phases in pigments and of their degradation products, as well as provide other information such as the size of the crystals, by observing the shape and the texture of the diffraction peaks. However, it is not appropriate for the identification of amorphous materials such as smalt or hybrid pigments such as copper resins, acetates or lake pigments.

The spatial resolution of the XRF-XRD instrument is 4 per 3 mm². It allows for the identification of the different crystalline phases in each color. It requires careful alignment: two laser pointers intersect at the analyzing position where the X-ray beam impinges the surface of the sample. The instrument was built with an air-cooled X-ray tube from the IFG Company in Berlin with a copper anode and a maximum power of 30 W. This X-ray source is equipped with a polycapillary semi-lens and a 0.5 mm vertical slit that provides a 4 x 0.5 mm² quasi-parallel X-ray beam. By working in reflection mode, with an angle of about 10° between the incoming X-rays and the surface of the object, the beam impinging on the painting has an area of 4 x 3 mm². A large photostimulable imaging plate is used to record the diffractograms over a period of approximately 20 minutes, before being scanned to obtain the diffraction image. The software FIT2D allows the observation of the diffraction patterns and their transformation into standard 2θ XRD diagrams; the Bruker-AXS EVA software is used to identify the crystalline phases from the diagrams.

XRF is combined with XRD and usually performed in this configuration but the detection of copper is limited by the strong Rayleigh diffusion of the copper X-rays from the source. We can incidentally use a 750 µm-thick Al filter to eliminate the incoming Cu-K lines, and measure Cu-concentrations with a good level of accuracy. A silicon drift detector from Amptek is used to detect the XRF signal.

The thickness of materials analyzed by this instrument is small and it corresponds usually to the upper layer of paint matter on the painting. This is due to the strong absorption of X-rays used for XRD measurements (8.05 keV) by the pigments. Taking into account the angle between the incident X-ray beam and the object surface (10°), we estimate that XRD is performed on a 25 µm thick layer of matter constituted of low Z elements like an earth constituted by aluminosilicates, and less than 10 µm for a paint layer with heavy elements, such as a lead white layer.

Another instrument was utilized to reveal X-ray fluorescence mapping [Viguerie et al. 2010]. This is a homemade system, equipped with a Moxtek tube with a palladium anode and a Silicon Drift Detector from Amptek, with an active area of 25 mm². Micrometric motors allow displacements in X and Y directions on an area up to 20 x 20 cm². This prototype gives measurements that are complementary to the XRD/XRF instrument: this

⁴ X-ray fluorescence and X-ray diffraction measurements were performed directly on the panels by means of the two mobile instruments. The team of the Laboratory of Molecular and Structural Archaeology realized analyses on the painting in the framework of the CHARISMA European project and its MOLAB activity.

system has a smaller beam impact on the surface of about 1 mm in diameter and, with its Pd anode, is more adapted to analyze materials containing copper compared to the XRD-XRF system. All the XRF spectra were processed with PyMcasoftware. (Fig. II)

The primary aim of this research was to describe the colors and the technique used by authors from the identification of the list of pigments used on the palette of the artist. We can also find relevant impurities to identify material sources and give new insights on the trade of pigments, and understand the physical properties of the paint matter to explain the artist's gesture, for example the use of glazes.

Table 1. Pigments identified by XRD

Vermillion	Cinnabar: HgS
Red/brown	Red earth: hematite Fe_2O_3
White	Lead white: hydrocerussite 2PbCO_3 , $\text{Pb}(\text{OH})_2$ and cerussite PbCO_3 , with calcite CaCO_3
Yellow	Lead tin oxide type I: 2PbOSnO_2 (lead tin yellow)
Ultramarine	Lazurite: $(\text{Na}, \text{Ca})_8(\text{AlSiO}_4)_6(\text{S}, \text{SO}_4, \text{Cl})_x$ (from lapis lazuli)
Blue	Azurite: $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$
Gold	Gold: Au

XRD-measurements were used to identify the pigments (Tab. 1). Lead white, constituted by a mixture of hydrocerussite and cerussite, was found in many analyses, sometimes even to shade the colors. We observed a high quantity of hydrocerussite in all the points of measurements. We cannot, at this stage of the study, demonstrate if several qualities of lead white were used. [Welcomme et al. 2007]. The other revealed pigments are calcite for the preparation layer, cinnabar, for the vermilion color, lead tin yellow, lazurite for ultramarine, azurite, gold and some earths with quartz impurities and carbon black, pure, mixed or superimposed. The mineral pigments used for the ground were identified using mid-FTIR, XRF, XRD, and SEM-EDS, carried out both in-situ and on cross-sections. Both calcite (CaCO_3) and two types of lead white (basic lead carbonate in the form of cerussite, PbCO_3 , and hydrocerussite, $2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$) were found in the ground layers. This is different to the ground of *Christ with singing and music-making Angels* [Van der Snickt et al. 2011], which also contained gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

In the 'orange' part of the rainbow, lead tin yellow and vermilion were mixed. Lead tin yellow type I was also used in the areas with more brilliant tones of yellow, as well as other orange hues, such as in the mantle of the Angel for example (Fig. III). Two blue pigments were used: ultramarine and azurite. The mineral lazurite, characteristic of lapis lazuli or ultramarine, is present only for the blue mantle of the Virgin and for the blue gems of St. Michael. We observe azurite in all other blue areas. More interestingly, there is only lazurite in the gem of St. Michael whereas the blue mantle of the Virgin Mary contains both lazurite and azurite. This can be linked to the high cost of the ultramarine pigment: the final cost of the painting depended upon the materials employed and it was probably not possible for the painter to use a large quantity of ultramarine. Cost may also have been a factor in the author's last layer of glaze, as they did not use ultramarine for painting the reflection of the Virgin's blue mantle on the sphere below the feet of

Christ. The image was found to only contain azurite. It is interesting to note this, as the author may not have found it necessary to use the highly symbolic pigment commonly chosen for the mantle of the Virgin on the sphere, because it corresponds to the mantle's reflection on the metallic surface and not the mantle itself. The painted image of the real mantle could have been more valued for its symbolism, and hence its pigments, but its image in a reflection seems to have a lower value.

Examination of the XRF spectra corresponding to the areas rich in ultramarine shows its presence is linked to a relatively important concentration of potassium, which is not a chemical element constitutive of the structure of lazurite. Only a few sources of lapis lazuli exist in the world and the finest lapis was considered to originate from Afghanistan. Recent works have shown that this source can indeed be characterized by a relatively important concentration of potassium. Through X-ray diffraction we observed a little amount of diopside, a pyroxene, which might be another impurity associated to the source of the pigment. X-ray fluorescence spectra show that azurite is associated with the presence of a little amount of barium, as an impurity. This impurity can again be linked to the origin of the raw materials but we have no other evidence of its geological source. The same azurite was used for the preparation of purple colors, probably mixed with a lake pigment and/or an earth pigment to obtain the expected tint.

For the red pigments, cinnabar was identified in all red points, except in the red mantle of St. Peter, on the left panel. This mantle was probably painted using a red lake pigment. The main dyestuff was identified as madder lake by its UV-Vis emission and absorption spectra [Szmelter et al. 2014].

The investigation of the painting surface also revealed an almost unique technological aspect of the painting. The portrait of the Redeemer, found on the scales of the wings of Archangel Michael, was painted initially on a separate tin plate support, which was subsequently glued, as an insert, on to the original surface. It is considered to be a portrait of Tommaso Portinari, who replaced Angelo Tani (the donor of triptych) as head of the Medici bank in Bruges in 1471. The production of a donor portrait on a tin support was also carried out by Rogier van der Weyden in one other work, the *Seven Sacraments*, now found in the Royal Museum for Fine Arts in Antwerp. Here eleven of the portraits are painted on a tin support and then added to the panel [Steyaert 2012] (Fig. V). Concerning more particularly the head of Portinari painted on a tin foil, intense tin X-ray lines are detected by X-ray fluorescence, but we did not observe metallic tin by X-ray diffraction, shows an XRF mapping of this area, with 60 x 70 pixels and a 1 mm step between each point of measurement. The acquisition time was 1 second per pixel (Fig. VI). The shape of the tin foil is easily observed on the Sn-K mapping. Concerning Sn-L mapping, the absorption of the X-rays through the paint layer of the complexion, rich in lead white, strongly modified its distribution. Different hues were obtained by adding more vermilion (mapping of Hg) and we can also see that the pigment used for the shadows is visible on the Pb-M mapping because it absorbs X-rays of low energy. In the area corresponding to the hair, earth pigments were used and are less absorbing for these X-rays between 3 and 4 keV. The X-ray diffraction measurements show the presence of romarchite SnO and cassiterite SnO₂ which are both known to be degradation products of metallic tin. It was shown in other studies that the formation of romarchite as a corrosion product is a required step in the oxidation of pure metallic tin to the final

most stable phase, the cassiterite. These results can be compared with another study we carried out by X-ray diffraction, in collaboration with Koen Janssens and his group at Antwerp University. The *Triptych of the seven sacraments* was painted by Rogier van der Weyden and is actually on display in the Royal Museum of Fine Arts in Antwerp. Likewise, the presence of tin under the colored layer was detected: in this particular case, metallic tin and cassiterite were observed. The two cases show that the metallic tin foil, which was used as a support on the painting, was oxidized, probably first due to the contact with the paint layers and their binders, and later by the action of the oxygen from the atmosphere.

The study of the complexion areas was also done on other faces, as shown in figure VII. The green area of the painting contains copper corresponding to an amorphous green pigment. Green pigments are established to be copper based, but an accurate identification of the mineral content was not possible due to the intrinsic difficulty in discriminating between the compounds typically used. This was aggravated by the presence of a coating varnish. Iron and Calcium are characteristic of the darker areas, corresponding to the adding of an earth, like an Umber pigment. Vermillion was used for the flesh tones and we can see on the Pb-L map that more lead white was spread in the light areas of the complexion, relatively to in the shadows. That means a thin layer of dark paint matter was not spread on a homogenous pink film to depict the shadows on the face. The lights and shadows were obtained by a subtle work of juxtaposition of dark and light paint matters.

In conclusion, the analytical information was provided by a combined use of different techniques to enhanced our knowledge of the artwork,

New information provided by Scanning Multispectral Infrared Reflectography

The new images obtained using scanning multispectral infrared reflectography MNIR allowed a further, more careful study of the underdrawing. The IRR results generally confirmed the hypothesis of three stages of design in the central composition and team/ or double authorship. The multispectral IRR Scanner used was a prototype instrument developed by the Istituto Nazionale di Ottica (INO), Florence, Italy – funded by the Italian National Research Council. This instrument was provided as part of the MOLAB transnational access program [Daffara et al. 2010]. This technique represents a powerful tool for the investigation of paintings, allowing for the detection of underdrawings, and *pentimenti* underneath the paint layers (Fig. VIII).

With respect to the wide-band conventional method, the multispectral option improves the ability to detect features hidden by the IR opaque paint layers by selecting the most effective NIR bands and also provides multispectral images with a spatial resolution less than 1 mm². The MNIR (wide-band IR imaging in the NIR-MIR-FIR) results on the Gdańsk triptych are extraordinary. In the upper left and upper right side of the central panel, the first phase of the composition was detected. This area shows a change in composition that was unclear prior to this investigation. The drawing initially depicted

angels with Arma Christi. The underdrawing is composed of delicate brushstrokes in an abundance of detail. During the painting phase the design changed and, in place of angels, the Apostles were painted. The form of these Apostles is similar to figures in other paintings by Rogier van der Weyden.

The underdrawing of the *Last Judgement* from Gdańsk shows the precise hand of a master. A dilute liquid medium applied with a fine brush was used to lay-out the composition. The executed lines are as distinct as handwriting. Analysis of the graphology confirms that one hand executed the design phase of the composition. Characteristic ‘T’ lines, hatches and ‘dots’ present at the end of the brushstrokes are consistent throughout the composition. A number of freehand changes were clear in the IRR images, mainly in the design of the Apostles. Here the faces and bodies were reworked. Furthermore, the drawn image is less dramatic than the painted version, especially in the wing of the triptych depicting Hell.

The next phase of the painting practice was to produce a modelling giving a naturalistic three-dimensional form to the composition in preparation for the paint layers. This was carried out by applying hatching for the halftones and light shadows and outlining the contours of the forms. The deeper shadows were more closely hatched, and in places cross-hatched to provide more emphasis. In some areas were partially whitened to enhance light effects. Corrections were added in the next stage, prior to the paint application. These were carried out in another medium, probably black chalk.

At this stage of the current multidisciplinary research project it was still unclear whether the draughtsman and the painter are one and the same for the Gdańsk *Last Judgement*. In Flemish artistic practise the compositional design and underdrawing were usually made by the principal artist who headed the workshop, especially for the main elements of the composition, while assistants were delegated to complete other parts of the painting. However, if Rogier van der Weyden executed the underdrawing prior to his death, could the commission have been continued by Hans Memling? Or was the painting phase a collaborative work?

The MNIR investigation also showed that the portraits of the donors on the reverse of the wings of the triptych were painted without an underdrawing. Observations using bandwidths between 800–2265 nm did not reveal the presence of a carbon containing medium. It seems that the portraits of Caterina Tanagli and Angelo Tani were executed in a typical proto-Renaissance *alla prima* style quite different than the underpaintings in all panels and figures of donors too (Fig. IX and X). The stylistic analysis confirms a modern appearance of paint layers in the face-portraits of donors. Authors, together with the CHARISMA-MOLAB team present the results of project in the final book “Science and Art” as a pilot project for multicriterial studies⁵.

Analogical suggestions about early modern paintings from the Low Countries, especially devoted to the Flemish Masters, are in current exhibition “Memling- Rinascimento flamingo” in Scuderie del Quirinale curated by Til Holger Borchert, provides a thesis

⁵ Szmelter I., Cartechini L., Romani A., Pezzati L., *Multi-criterial Studies of the Masterpiece ‘The Last Judgement’ attributed to Hans Memling, at the National Museum of Gdańsk (2010–2013)* [in:] A. Sgamellotti, B. Brunetti, C. Miliani (eds.), *Science and Art. The painted Surface*, Cambridge 2014, pp. 230–251. On line: http://mng.gda.pl/wp-content/uploads/2014/08/Multicriterial-Studies-of-the-The-Last-Judgement_at-the-NM.pdf [access: 20.09.2015].

about proto-Renaissance style in Flemish paintings in the second half of 15th century in the light of humanistic studies⁶. With multi-disciplinary research and current technological developments, broader studies in archives are a challenge to traditional art-historical methodologies. Our research results in particular, the high-resolution images open ways to observe and further investigate of artworks that traditional studies cannot offer. The historical, stylistic and technical aspects are all taken into account in order to better understand the characteristics of these painters and highlight the innovative solutions contributed by their individual artistic practice.

Conclusion

The answers to some important questions concerning the technique and authorship of the *Last Judgement* triptych from National Museum in Gdańsk were obtained through the multi-disciplinary research by Warsaw's Faculty of Conservation and the CHARISMA-MOLAB team (2010–2013), and provides much progress in our knowledge in respect to the earlier studies. The obtained results confirmed that the triptych was painted using techniques and materials typical of the Flemish style, dating back to the second half of the 15th century. The MNIR images show several types of the designs, as well as the different materials used in the initial lay-out of the composition. The initial design appears to relate to the style of other known works by Rogier van der Weyden, such as the Beaune *Last Judgment*, a polyptych painted c. 1446–1452 and other his works. The previous hypothesis of the *Last Judgement* authorship by Hans Memling, created by Hotho in 1843, was not based on research and the results of instrumental analysis which are available to us now. Results presented in this article testify to the existence of hidden layers – drawings and several paint layers by Rogier van der Weyden as his original design, especially in part of Apostols in the central panel, which has been repeatedly amended hand over his previous polyptych of Beaune. The artist worked on his composition in his characteristic way but probably his sudden death in June 1464 prevented the completion of the work in his workshop in Brussels. His successor could be Hans Memling, who appeared on the pages of history half a year later, the first time in January 1465, when he appeared in Bruges, where he took a job as a painter. This example serves as a good commentary relating to the need of re-interpreting the epoch; today we often look at a work of art primarily from the point of view of individual authorship, but in the second half of the 15th century and even during the Renaissance popular prime contractors for large artworks were workshops and teams of professionals from different fields, who acted under the guidance of a master. Thus, the conclusion of results from a multitude of combined research, including MNIR, radiography, X-ray diffraction and X-ray fluorescence studies of the *Last Judgement* from National Museum in Gdańsk, confirms the Rogier van der Weyden and Hans Memling co-authorship.

⁶ Borchert T.H., *Memling, Rinascimento fiamingo*, SKIRA, Scuderie del Quirinale, Rome 2014.

References

- Ainsworth M.W., 1994, *Hans Memling as a Draughtman* [in:] D. de Vos (ed.), *Hans Memling Essays*, Stedelijke Musea Brugge & Fonds Mercator Paribas, Brugge
- Daffara C., Pampaloni E., Pezzati L., Barucci M., Fontana R., 2010, *Scanning Multispectral IR Reflectography SMIRR: An Advanced Tool for Art Diagnostics*, "Accounts of Chemical Research", Vol. 43, pp. 847–856.
- Duran A., Perez-Rodriguez J.L., Espejo T., Franquelo M.L., Castaing J., Walter P., 2009, *Characterization of illuminated manuscript by laboratory-made portable XRD and micro-XRD systems*, "Analytical and Bioanalytical Chemistry", 395, pp. 1997–2004.
- Faries M., 1994, *The Underdrawing of Memling Last Judgment Altarpiece in Gdańsk* [in:] H. Verstraete, R. van Schoute, M. Smeyers, A. Dubois (eds.), *Memling Studies*, Proceedings of the International Colloquium (Bruges, 10–12 November 1994).
- Flik J., Olszewska-Świątek J., 2005, *Tryptyk "Sąd Ostateczny" Hansa Memlinga z Muzeum Narodowego w Gdańsku – technologia i technika malarska (Triptych 'The Last Judgement' by Hans Memling from National Museum in Gdańsk – technology and paintings technics)*, Toruń, passim.
- Gianoncelli A., Ortega L., Castaing J., Dooryhée E., Salomon J., Hodeau J.-L., Walter P., Bordet P., 2008, *A portable instrument for in-situ determination of the chemical and phase compositions of Cultural Heritage objects*, "X-ray Spectrometry", 37, pp. 418–423.
- Miles D.H., 2005, *New developments in the interpretation of dendrochronology as applied to oak building timbers*, University of Oxford, unpubl. PhD thesis, 386 pp.
- Miliani C., Rosi F., Brunetti B.G., Sgamellotti A., 2010, *In Situ Non-invasive Study of Artworks: the MOLAB Multi-technique Approach*, "Accounts of Chemical Research", Vol. 43, pp. 728–738.
- Romani A., Clementi C., Miliani C., Favaro G., 2010, *Fluorescence Spectroscopy: A Powerful Technique for the Non-invasive Characterization of Artwork*, "Accounts of Chemical Research", Vol. 43, pp. 837–846.
- Steyaert G., 2012, *The 'Seven Sacraments' Some Technical Aspects Observed During Restoration* [in:] L. Cambell (ed.), *Rogier van der Weyden in Context*, Paris–Leuven, pp. 124–127.
- Szmelter I., 2014, *Wyniki wielokryterialnych badań Sądu Ostatecznego z Muzeum Narodowego w Gdańsku. Nowe odczytanie tryptyku jako dzieła Rogiera van der Weydena i Hansa Memlinga / Results of Multi-Criteria Research on the Last Judgment from the National Museum in Gdańsk. New Attribution of the Triptych to Rogier van der Weyden and Hans Memling*, "Muzealnictwo", Vol. 55, pp. 37–60, http://nimoz.pl/upload/wydawnictwa/Muzealnictwo/Muzealnictwo55/Muzealnictwo_nr_55_2014.pdf, accessed on: 21.11.2015
- Van der Snickt G., Miliani C., Janssens K., Brunetti B.G., Romani A., Rosi F., Walter P., Castaing J., De Nolf W., Klaassen L., Labarquee I., and Wittermannf R., 2011, *Material analyses of 'Christ with singing and music-making Angels', a late 15th-C panel painting attributed to Hans Memling and assistants: Part I. non-invasive in situ investigations*, "Journal of Analytical Atomic Spectrometry", 26, p. 2216.
- Viguerie L. de, Walter P., Laval E., Mottin B., Solé V.A., 2010, *Revealing the sfumato Technique of Leonardo da Vinci by X-Ray Fluorescence Spectroscopy*, "Angewandte Chemie", 49, pp. 6125–6128.
- Ważny T., 1990, *Aufbau und Anwendung der Dendrochronologie für Eichenholz in Polen*, Diss. Universität Hamburg, Hamburg, 213 pp.

- Ważny T., 2011, *Secrets of a Rembrandt School Still Life: A Baltic oak panel and its many layers* [in:] A.C. Weislogel, *The New and Unknown World: Art, Exploration and Trade in the Dutch Golden Age*, Herbert F. Johnson Museum of Art, Cornell University, Ithaca, NY, pp. 22–30.
- Welcomme E., Walter P., Bleuet P., Hodeau J.-L., Dooryhée E., Martinetto P., Menu M., 2007, *Classification of lead white pigments using synchrotron radiation micro X-ray diffraction*, “Applied Physics A”, 89, pp. 825–832.
- Woll A., Mass J., Bisulca Ch., Cushman M., Griggs C., Ważny T., Ocon N., 2008, *The unique history of “The Armorer’s Shop”. An application of the confocal X-Ray fluorescence microscopy*, “Studies in Conservation”, 53, pp. 93–109.
- Ziemia A., 2011, *Sztuka Burgundii i Niderlandów 1380–1500, Niderlandzkie malarstwo tablicowe 1430–1500 (The Art of Burgundy and Netherlands 1380–1500, Dutch Panel Painting 1430–1500)*, University of Warsaw, Warsaw, Vol. II, pp. 97–119, 283–286.