SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 5, No. 3, (2019), pp. 55-68
Open Access. Online & Print

DOI:10.5281/zenodo.3340112

VISUALISING UNDERPAINTED LAYERS VIA SPECTROSCOPIC TECHNIQUES: A BRIEF REVIEW OF CASE STUDIES

Bratitsi Maria[1], Liritzis Ioannis[1], Alexopoulou Athena[2], Makris Dimitrios[3]

[1]University of the Aegean, Lab of Archaeometry and Laboratory of Environmental Archaeology & Preventive Conservation, 1 Demokratias Str, Rhodes 85132, Greece
[2]University of West Attica, Dept of Conservation of Antiquities and Fine Arts, Athens , Lab of NDT Methods, Campus 1 Aghiou Spiridonos Str., 12243 Greece
[3]University of West Attica, Dept of Interior Architecture, Campus 1 Aghiou Spiridonos Str., 12243 Athens, Greece

Received: 25/03/2019
Accepted: 17/07/2019
Corresponding author: Liritzis Ioannis (liritzis@rhodes.aegean.gr)

ABSTRACT

Paintings, mostly due to deteriorations, are sometimes repainted, concealing in underlayers important features, dates, names and other information. Conservators are facing dilemmas as to whether to preserve these interventions and retrieve valuable hidden information, but in the last decades the evolution of spectroscopic techniques has contributed to such uncertainties.
The current brief review explains the intentional repaint and presents the techniques used around the world to visualize the underpainting layers, and how these techniques have developed from a simple X-Ray radiography and an infrared (IR) photography to mobile devices with great imaging capabilities. Case studies include Byzantine icons and oil paintings.

KEYWORDS: repainting, multispectral imaging, X-ray radiation, byzantine icons.

1. INTRODUCTION

Painting has always been a form of expression since early human dawn. From the first Palaeolithic cave drawings until today, spectacular painted images represent past cultures and the history of mankind in general (Aubert et al., 2014; Karapanagiotis et al., 2008; Valladas, 2004). Over the years, these paintings could have been repainted for several reasons, resulting to hiding important elements, such as dates or signatures of significant artists, leading conservators to make important decisions on whether to keep the overpainted layers (Sister Danillia et al., 2002). In recent years, non-destructive imaging techniques at wavelengths beyond the visible can solve such issues attempting to display the underlying layers without, removing the overpainted one. Characteristic cases are the oil paintings, portable icons with egg tempera technique and wall paintings, frescoes or al secco.

This paper deals with the ways hidden painted layers might be revealed, using techniques like Synchrotron Radiation Based XRF and macro-XRF or Confocal 3D Micro-XRF, after presenting the agents of deteriorations according to the material constructions of each painting techniques and the rationale of making these overpaintings.

2. PAINTING LAYERS

Painting initial started with a plain imprint on the rocks of the caves [1] and evolved into organized art defining each cultural period.

Since the remote past people painted on the walls of their caves where they lived, with colours from natural mineral oxides of iron and magnesium, white clay and black from charcoal and burnt bones. Subsequently, however, various organic ingredients indications according to analyses, such as fat and blood, were probably used as colours binder, while the walls were covered by clay used as a substrate (Curtis, 2006; Guthrie, 2006).

As the evolution of the techniques occurs several materials were used as painting supports (Gunnar, 2007), such as various types of stone (marble or shale, mainly used in Italy in the 16th and 17th centuries and in Flanders), clay (painting decoration in ceramics), paper (in manuscript decorations), metals, glasses, skins and plastics. But the most widely used and refer only to painting are wall paintings, oil paintings on canvas and portable icons.

2.1 THE CONTRUCTION MATERIALS

Wall paintings construction materials as shown in Fig.1c are the masonry, mortar and painting surface which is made by using fresco1 or al secco2 technique, on which archaeometric analysis and conservation practices have been applied (Mora and Mora, 2007; Liritzis and Polychroniadou, 2007; Gehad, et al., 2015; El_Rifai et al., 2013; Al-Emam Ehab et al 2015; Bader et al., 2014). An oil painting on canvas (Fig.1b), consists of a textile support stretched on a frame, covered with a ground layer painted mainly with oil colours, while in some cases a layer of varnish is over coated. In a portable icon (Fig. 1a), the wooden support, in some cases reinforced by canvas (extremely durable plain-woven fabric), is covered by a ground layer to become smooth. This in turn is efficient of accepting the painted layer with egg tempera technique, protected by a transparent varnish. In several cases the painting layer is gilded by a sheet of gold or silver (Dionysiou Hieromonk of the Fourna, 1909; Kontoglou, 1993), after a clay bole[3] was applied over the gesso.

All the above cases of different painting techniques, consist of a stable support which is covered by a smooth and slick layer of ground layer, made by a filling material and a binder, which will finally accept the colour. Thus, we have three or four levels as shown in Fig. 1, were 1a refers to portable icons with egg tempera technique, 1b to oil paintings and 1c to wall paintings.

2.2 AGENTS OF DETERIORATION

The materials used to construct a painted surface, as well as, the environment in which it is made, exposed and stored, has a significant effect on its conservation status. The construction materials from which painted surfaces are composed are different and have their own decay process and rate, but they are all interrelated and can act catalytically to one another.

The agents of deterioration in a wall painting are the presence of moisture in a monument, were it leads to the decline of the mortar and its removal of the masonry, the growth of microorganisms and crystallization of salts. At the same time, the bonds between sand and pigment granules and its binder are weakened causing crumble to the mortar and the paint layer.

---

[1] Fresco is made by water colours applied to the mortar before it gets dry

[2] Al secco consist of colours mixed with wax, egg or another binder applied in dry mortar

[3] Bole is a clay mixed with an adhesive in order to have a good cushion under the gold leaf making it shine and durable as it compresses it on the ground layer.

Figure 1. Painting artwork construction materials for (a) portable icons with egg tempera technique on wooden panel, (b) oil paintings on canvas and (c) wall paintings i.e. fresco or secco.

Local moisture leakage can separate the layers of mortar and surface paint and create internal blanks and blisters. At the same time the salt crystallization on the surface and inside the murals causes their deterioration and aesthetic corruption.

Canvas in oil paintings is a very sensitive support, is easily torn and even a tiny bump can cause ground layers peeling or cracking as much as other mechanical damage. In the areas were different pieces of fabric are stapled together, there may be variations in moisture and temperature behaviour due to differences in thickness, weave or fibre direction. If the weaving is sparse and the preparation layer is thick, micro-cracks are caused along the threads which eventually peel off and leave small holes in the artefact.

Wood has a variable structure and properties and exhibits anisotropy and hygroscopicity, resulting constantly contractions and expansions that affect both the ground and the painted layer and sometimes even the varnish. Its degradation problem due to fungi and insects, consist on loses and damages (Salama et al., 2016; Enas Abo El Enen Amin, 2017, 2018; Abdel-Kareem, 2010).

The knots, the various cracks and all woods imperfections that exist before using it as a portable icons support, causes pressures and movements that affect all the other layers of the artefact. Metal nails used to join pieces of wood, or traverse, causes mechanical stresses and cracks. Several problems in preparation layer are caused by the incompatibility between wood and gesso. The proper quantity of Dyes binder, as well as, the ground layers glue is very important. Loss of painting surface occurs in places where there is also substrate loss, such as cracks, holes, knots, etc.

The damage to the varnish layer is mainly due to the accumulation of dust and pollutants, the decomposition of natural resins and oils, the presence of moisture, and restoration by people without knowledge and experience since an important factor of deterioration is human intervention. Varnish removal with unsuitable chemicals can cause unpleasant results, such as alkaline solutions (soaps, ammonia, etc.), saponification of the binder and chromatic alteration of certain dyes. Strongly active materials lead to losses, cracks, flaking and colour changes.

All the above damages result obscuring of painted surfaces in details and the original colours over the years, with losses and major deterioration. That is why, often, painters overpainted mostly the faces of the figures and in some cases even painted a new layer over an old one, differentiating the depiction. As a result, extensive interventions are applied, offering a great strength of importance, but at the same time introduce restoration problems.

3. OVERPAINTINGS

Overpainting is usually made for covering up damages, dressing naked bodies or modernizing clothing [2], while in some cases, conspicuous counterfeiting with the addition of signatures could increase value. Besides, some interventions can be made by the painter himself, either altering something in the composition or as arbitrary repaint of the older work.

Wall-paintings and portable icons, were utilitarian artefacts of worship; thus, whenever they were damaged and no longer easily distinguishable, they were overpainted. In some cases, entire paintings repainted older iconographies (Fig. 2) as the owner requested, or because different eras imposed variant standards.

Figure 2. Icon that has been repainted all over. The underlying layer depicts St. Nicholas and the overpainted Saint Stephen (personal photo archive: Bratitsi, probably a 19th century icon, private owner.

Also, many letters, dates and signatures were rewritten in order to change the text (Fig. 3) or because it was ready to be erased.

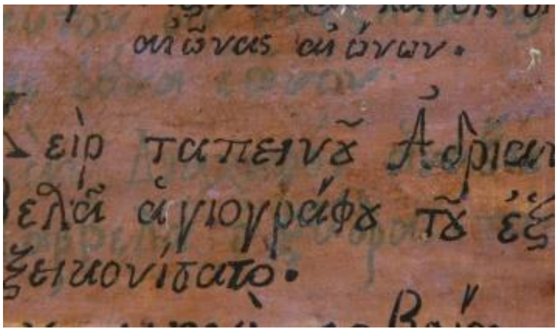


Figure 3. Reshaping the inscription of an icon, that contains donors, hagiographer and date of construction. (personal photo archive: Bratitsi, detail of a 19th cent. icon of St Nicholas from ''St Nicholas'' church at Paradisi Rhodes)

Overpainting are usually not limited to the damaged area but are expanded to unify the illustration (Fig. 4).

Figure 4. An overpainted fresco. (personal photo archive: Bratitsi, a 19th century portable icon from ''Ag. Marina'' church, Paradisi Rhodes)

Great interventions also occur in the gilded areas, as the gold leaf easily gets obscured and loses its shine, in many cases with bronze, even covering golden leaves of an excellent quality (Fig. 5).

Figure 5. Subsequent gold leaf cover with brass on a table. (personal photo archive: Bratitsi, detail of a 20th cent. oil painting of St. John, from the church of ''Presentation of Mary'' at Niochori, Rhodes

In many cases the old varnish (Fig. 6) still remains between the paint layers, but in some others is removed accidently[4].

Figure 6 the first piece shows the later intervention, the second the old varnish and the third the cleaned underlying layer. (personal photo archive: Bratitsi, part of a 19th cent. Iconostasis from church ''the presentation of Mary'' at Koskinou, Rhodes)

Past work on paintings conservation is known, but with different character than today [3], thus by

[4] In many churches it has prevailed to clean the icons and frescoes with cologne or nama and because they both contain ethanol, many times the old varnish was removed, often removing and destroying part of the colors and especially the golden leaf.

the meaning[5] of repairness or performing interventions in order to cover the damage, such as Fig. 7, where in order to place the image in a temple, a piece of another image was added and painted over in order to unify the hole icon. At any rate, conservation was performed by hagiographers, wood sculptors and various craftsmen (Brandi, 1977).

Figure 7. Icon where they have added part of another icon in order to reach the desired width to fit into the newest templum and was repainted. (personal photo archive: Bratitsi, detail from a 19th cent. icon of St John from ''St Dimitrios church at Paradisi, Rhodes)

The most important icon, as it relates to the first depiction of Christ Pantocrator dated to the 6th century, from the Monastery of St. Catherine of Sinai, painted by the encaustic method, was at some time overpainted (Fig. 8) and that intervention was removed by conservator Tasos Margaritof (Margaritof, 1999). One of the well-known cases of an extraordinary overpaint, was in Spain, the case of Ecco Hommo by Elias Garcia Martinez a 19th century fresco. The art piece was ruined by an old lady's ''restoration'', Cecilia Giménez, resulting many profits due to publicity of bad art critics reaction [4], so she sued the church demanding a large amount of money [5](Fig.9).

Figure 8 Christ in Sinai. The icon before and after the removal of the overpainting

(a) (b) (c)

Figure 9 a) Initial fresco, b) fresco with deteriorations, c) overpainted fresco

Overpainting, however, is part of art's long history providing greater significance and at the same time huge problems to conservators [6]. But if the overpainted layer remains how is it possible to visualize the underlayer. The answer comes from the technology of analysis and digitization, even mobile for greater ease and refers to the entire depth of the subject, i.e. the methods refer to 1D and 2D, moreover 3D.

4. METHODS FOR IMAGING UNDERPAINTED LAYERS

In the field of Cultural Heritage research there are two terms which are used to express all procedures applied for material characterisation, construction technique identification and dating. Archaeometry which includes the characterization and the dating of mainly archaeological material such as bones, stone or pottery, and the visual art diagnosis which refers to the study of cultural heritage artifacts which present simple color decoration or paint layers

[5] "Definition of a Profession". *International Council of Museums - Committee for Conservation*. Retrieved 18 August 2012.

stratigraphy like paintings. This emerged as a need for understanding the interaction mechanisms between construction materials, deterioration phenomena and consequently the investigation and treatment of them, which differ according to the material and the technique used. By following a series of non-destructive and analytical techniques, a set of information can be gathered, processed and become an important tool for art-conservators.

Methods of analysis are available for the study and recording of works of art, acting complementary and offering a considerable amount of information. This leads to safe conclusions about its structure and damage that is not visible to the naked eye. Moreover, qualitative and quantitative analysis of construction materials leads one to choose the conservation methodology to be followed.

Non-destructive testing and imaging techniques at various wavelengths are a valuable tool in the research and conservation of works of art since the decade of 1930, while nowadays they have been operating in three dimensions, thus multiplying the possibilities (Moropoulou et al., 2013). Especially in multi-painted layers like the above mentioned. This is a continued effort and regarding icons only a few cases involving underlying layers of painted works have been observed, while many cases of underdrawings have been examined. This is probably due to the fact that an underlying paint layer is very difficult to be observed without a proper equipment.

Techniques used for overpainted works of art being mention below are: Synchrotron Radiation Based XRF and macro-XRF and Confocal 3D Micro-XRF. (Janssens et al., 2017; Evans et al., 2019).

In fact, in irradiated art surfaces the wavelength range is divided into areas where one can see the surface of a work of art or penetrate in depth revealing the hidden secrets. Wavelengths for deeper areas are x-rays and infrared radiation because they penetrate the varnish. In the case of IR the ranges include the areas from deep red at 760nm to the limits of microwaves but only a restrict region of it ranging from 760nm to 2500nm can be used in the art diagnosis. IR is an invisible radiation, characterized by its great penetration ability. Its usefulness in scientific applications of diagnosis of artworks is based on the fact that some materials reflect infrared radiation while some others allow it to pass through their mass. On the other hand, X-rays are electromagnetic waves in wavelength between 10 nm and 0.01 nm and are produced when high-speed electrons fall into matter. Below the techniques of XRR, and IRR with versions applied to paintings are reviewed in some case studies.

4.1 X-RAY RADIATION

The oldest method refers to X-ray radiation, from the late 19th century. X-Ray Radiography (XRR) is the first technique that can collect information from the internal parts of a painting in a non-destructive way and is now available in many conservation workshops (Gavrilov et al., 2014).

This tends to be replaced by digital radiography with less exposure to radiation and direct data without test exposures and records on film, but since these problems relate to medicine rather than cultural heritage, they are opposed to the high cost of equipment and the possibility of lateral analysis due to the size of the grain (Oliviera et al., 2013).

X-ray does not provide elemental analysis, nor does interpret underlying paint layers in cases of heavy metals painting such as lead or mercury, or in cases of overlapped by thicker layers with highly absorbent elements such as zinc. Very important is the ground layer on which the painting surface is deposited, as its components may act prohibitively for the display of the color elements (such as zinc ground layers) (Noble et al., 2012; Alfred et al., 2013, van der Loeff et al., 2012). In order to reduce this difficulty of paint reading on such ground layers, various tests were made digitally with algorithms, corresponding to those involving to the removal of the weave from the canvas support of paintings (Johnson et al. 2010) and the characteristics of wooden panels (Padfield et al., 2002). Besides XRR, many other ways of X-ray analysis began to refer and be used in cultural heritage, such as strati-radiography (Van Asperen de Boer. 1976) where the film is placed directly on the painting, whereby the X-ray tube moves during the exposure, leaving a blurring substrate. Electron emission radiography is very helpful in reducing XRR's problems (Bridgman et al., 1958). Important and particularly useful for icons painted on both sides is stereo-X-ray (Van Asperen de Boer, 1976) where two x-rays are taken from different locations and combined into a stereographic image. Energy radiography is an imaging technique that can significantly enhance the contrast of the images and possibly the elemental imaging, as not only photons, but their energy also, is recorded. The K-edge dichromography is achieved by using primary radiation of different energies (Baldelli et al., 2006) where the beams of the selected energy are collected by Bragg diffraction. A very specific X-ray source, which emits a monochromatic beam, has been very recently described, while efforts have been made to combine the K-edge with synchrotron radioactive source (Schalm et al., 2011).

However, all these methods are non-portable, difficult to use and at an early stage.

Zemlicka et al. (2012) constructed a mobile instrument, by using a Timepix detector to perform X-Ray energy resolved without lateral scanning and managed to separate the energy diffusion of individual X-ray photons, so they were able to separate the painted layer from the support (Zemlicka et al., 2012). Subsequently, Schalm et al., (Schalm et al., 2006) constructed another instrument that provide radiographs with higher colour contribution than ground layer and support by using a W-anode X-Ray tube with an energy dispersive detector.

X-Ray Fluorescence was also used initially to identify pigments (the fluorescent radiation emitting an X-ray specimen contains quantitative and qualitative information) but very recently the use of Macro-XRF appeared for the visualization of underlying painted layers. The shots are obtained by scanning two lateral dimensions with a focused primary beam in reflection geometry. Scanning micro-XRF with a micrometre ray of analysis is a technique also widely used to explore cultural heritage objects since 1990, but with several technical problems (Janssens et al., 2000). However, all of these scanners required several seconds of space per pixel, limiting their application to very small details.

In the last decade, the novel-based-X-Ray Fluorescence synchrotron imaging method was developed for studies in overpainted paintings such as ''Patch of Grass'' by Vincent Van Gogh. This particular painting was transferred and investigated in Deutsches Elektronen-Synchrotron (DESY, Hamburg, Germany) in 2007 by Dik et al., were a concentrated monochromatic beam, depicted an underlie painting of a head (Dik et al., 2008). At DESY other painting studies were followed such as in 2009 at the painting ''the laughing Rembrandt'' by Rembrandt van Rijn (Dik et al., 2010) and in ''Pauline im Weißen Kleid'' by Philipp Otto Runge (Alfeld et al., 2011) and a study of a hidden underpainting in Vincent van Gogh's ''Flower Still Life with Meadow Flowers and Roses'' (Van der Loeff et al., 2012; Alfeld et al., 2013). At the National Synchrotron Lighting Laboratory (NSLS, Brookhaven National Laboratory, NY, USA) the underlying painting from the portrait of a Rembrandt's ''An Old Man'' became visible (Alfeld et al., 2013), as well as in Melbourne, Australia, with the Australian Synchrotron an overpainted painting by Arthur Streeton (Howard et al., 2012). Of course, all the above case studies involve transferring the paintings to the synchrotron sources laboratories and that is not always achievable.

Alfeld el al., (2013) manage to build a scanner consisting of 4 detectors recording fluorescent radiation from X-ray sources with a highly sensitive result. The mobile scanner was used to complement the previous results obtained in Vincent van Gogh's ''Flower Still Life with Meadow Flowers and Roses'' by Synchrotron (Alfeld et al., 2011, 2013). This study showed that moving instruments can achieve a sensitivity comparable to synchrotron-based scanners. The MA-XRF revealed details of an underlying portrait of a Goya's portrait of ''Don Ramón Satué'' of (Bull et al., 2011). However, the addition of minium (red lead, Pb_3O_4) between many pigments or white paint with red organic lakes is not directly visible. The limitation of MA-XRF is that the in mobile detectors the fluorescence radiation is of low energy and is absorbed by the dye.

Confocal XRF (Monico et al., 2011) allows the in-depth analysis with elemental contrast. The visual field of the detector is achieved by the insertion of a borosilicate monocapillary optic to focus the incident beam and a borosilicate polycapillary lens to collect the fluorescent x-rays. It presents several limitations, but is (one of the few) non-destructive movable method and will be used a lot in the future. The hold time of several tens of seconds requires long scans (about half an hour) for a single depth of profile, but is possible to obtain virtual 2D cross-sections or even 3D data cubes (Kanngießer et al., 2013) as was confirmed at a black drawing cat visualized behind a Vincent Van Gogh's paintings ''Daubigny's Garden'' (Nakanoa et al., 2016).

4.2 INFRARED RADIATION (IRR)

Infrared radiation in cultural heritage has been used since the early 20th century, but since 1960 infrared reflection has begun to project in-depth layers. It is accompanied by simultaneous heat emission. It is easier to use than X-ray and does not constitute a health hazard. Also, the availability of the detectors is now wide and of course extends to multi-spectral and hyper-spectral imaging (Alexopoulou 2013; Alexopoulou 2018). Here, all the case studies refer to underdrawing and not to underpainted layers.

The first application was IR-photography and concerns photons of infrared radiation with a sensitivity of 700-900 nm which is recorded as reflected by the painting. Its limitation refer to the transparency of 900nm and the possibility of observing underdrawings in many pigments. (Mairinger 2004). Subsequently, IR photography has been replaced by Si CCD or CMOS cameras sensitive from 700 to 1100 nm. (Walmsley et al. 1992, Gargano, et al., 2007, Alexopoulou 2004, 2005).

Recently, Falco (2009) described a process of modifying a commercial digital camera 8 Mpixel in IR, tested in a work by Lorenzo Lotto, however, he has received many criticisms (Stork and Kossolapov, 2011). For observing underlayers, a useful tool is Short Wave IR, i.e. at 1000-2400 nm. Van Asperen de Boer invented IR-reflectography, by replacing the film recording the IR radiation with an IR camera at first (van Asperen de Boer, 1966) and later a vidicon tube with target PbS sensitive up to 1900 nm (van Asperen de Boer, 1974). Underdrawings can be better examined in paintings before 16th-century, as they contain highly reflective grounds with black carbon-based underdrawings that absorb infrared strongly.

Vidicon analogue tubes present a satisfactory image resolution coupled with high penetration depth (Alexopoulou, 2010) but they record many geometrical distortions while not displaying the same photometric response across the surface. Many attempts have been made to avoid such errors but were finally replaced by cameras with a solid state array of PtSi (with a sensitivity of 1000-5000nm) initially, which required liquid nitrogen cooling (Delaney et al, 1993 and Walmsley et al., 1993) until very recently InGaAs (sensitive to radiation between 900 and 1700 nm), which don't need a cooling system and is more efficient (Alexopoulou, 2018) . In order to achieve longer wavelengths, HgCdTe and InSb can be used, but these devices are considerably more expensive and need also cooling (Saunders et al. 2006).

IRR at higher wavelengths presents an overall lower contrast and can also provide additional information as the absorption and reflection characteristic of many dyes is different in SWIR and MIR. However, along with the reflectogram, a highly thermographic result is also observed.

Multispectral imaging has quite recently appeared offering a number of views recorded at different wavelengths. However, the data is quite limited. (Francisco et al., 2001). At a later stage, hyperspectral imaging applied to the analysis of Goya paintings in the Museum of Zaragoza (Spain), (Daniela et al., 2015).

Optical Coherence Tomography uses near infrared radiation of 700-1500nm allowing a 3D imaging of layers (Targowski and Iwanicka, 2011). It is applied at a safe distance from the object, without any contact and depicts the first successive layers of an object in both qualitative and quantitative terms (for example, it provides information about the thickness of the varnish of an image). With the help of the OCT, Targowski et al (Targowski and Iwanicka, 2011) found strong signs of a forgery signature in the Portrait of an Unknown Woman that was created in the late 19th century by an unknown artist.

5. DISCUSSION

The study of overpaintings in recent years has begun to progress rapidly as imaging techniques have recently been involved into art, and efforts have been made in order to study the image behind an image. The following table (Table 1) presents the case studies that have been studied above.

Until recently the only techniques that could examine underlayers were XRR and IRR, but with many difficulties such as in thicker layers or carbon based pigments, although nowadays are being used in many conservation studios allowing faster and detailed acquisition.

The exploitation of the fluorescence radiation that emitted by the painting during X-Ray irradiation instead of the absorption was of great importance, as it allows a contrast not being achieved by any other technique. Confocal XRF is the only so far in situ technique being able to investigate underlayered paintings.

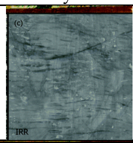
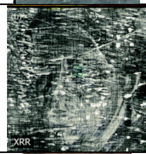
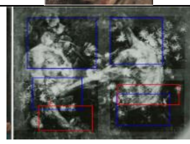
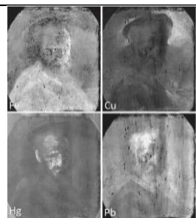
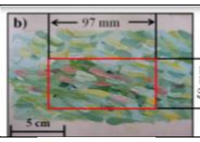
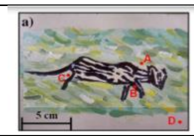
On the other hand multispectral IRR allows the selection of different wavelengths providing great results on the identification of pigments.

All the case studies are oil paintings in canvas and each one has been examined many times with different equipment, so that they can compare all the methods but mainly because they can act complementary to one another. Surely several other techniques are available for paintings in-depth study, such as terahertz imaging or NMR, but are not yet applied to study overpaintings, since X-Ray and IR are both long established and therefore more common and prone to supply in a conservation laboratory.

6. CONCLUSION

An overpainted work of art conceals many secrets that give importance to its history and make it unique and irreplaceable. Removing an overpainted layer is not always feasible or advisable in many cases and of course, by removing it, we miss important elements. It is apparent from the current review that all the case studies of visualizing underlying painting layers relate to oil paintings mostly in canvas. The study in egg-tempera or wall paintings is only limited to a few attempts, as such overpainted images are difficult to be found.

Table I. All the case studies that have been examined concerning overpaintings.

Case studies	Type	Over painted layer	Underlying painted layer	method
Patch of Grass Vincent Van Gogh 1887	Oil painting in canvas			IRR
Patch of Grass Vincent Van Gogh 1887	Oil painting in canvas			XRR
Patch of Grass Vincent Van Gogh 1887	Oil painting in canvas			Synchrotron Radiation Based X-ray Fluorescence DESY, Hamburg, Germany Dik et al. (2008)
Flower Still Life with Meadow Flowers and Roses' Vincent van Gogh 1974	Oil painting in canvas			Synchrotron Radiation Based X-ray Fluorescence DESY, Hamburg, Germany Alfeld et al. (2013) Van der Loeff et al. (2012)
Old Man in Military Costume Rembrandt van Rijn, 1630	Oil painting on panel			Synchrotron Radiation Based X-ray Fluorescence DESY, Hamburg, Germany Dik et al. (2010)
An Old Man Rembrandt van Rijn 1630	Oil painting in canvas			XRR
An Old Man Rembrandt van Rijn 1630	Oil painting in canvas			IRR
An Old Man Rembrandt van Rijn 1630	Oil painting in canvas			synchrotron-based scanning macro-XRF NSLS, NY, USA Alfeld et al. (2013)
self-portrait Sir Arthur Streeton 1923	Oil painting in canvas			X-ray fluorescence microscopy using synchrotron radiation Melbourne, Australia Howard et al. (2012)
Daubigny's Garden Vincent Van Gogh 1890	Oil painting in canvas			Confocal 3D micro-XRF Nakanoa et al. (2016)
Portrait of a Woman. Edgar Degas 1937	Oil painting in canvas	 a		XRF fluorescence microscopy elemental maps Thurrowgood et al. (2016)

All the case studies refer to particular techniques and instruments, although the above techniques can act conjointly and complementary. The paintings of great painters such as Vincent Van Gogh and Edgar Degas are a few case studies but significant examples of underpaintings being examined the last decades revealing hidden depiction under correspondingly amazing creations which are forbidden to be removed and destroyed.

ACKNOWLEDGEMENTS

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Strengthening Human Resources Research Potential via Doctorate Research" (MIS-5000432), implemented by the State Scholarships Foundation (IKY). This work forms part of MB's PhD.

FOOTNOTES

1. https://whc.unesco.org/en/list/310
2. https://www.theguardian.com/artanddesign/jonathanjonesblog/2016/jul/25/renaissance-art-nudity-cover-up-sistine-chapel-leonardo-censorship
3. https://www.britannica.com/art/art-conservation-and-restoration
4. https://www.businessinsider.com/woman-who-restored-fresco-of-jesus-wants-money-2012-9
5. https://www.independent.co.uk/arts-entertainment/art/news/elderly-woman-destroys-19th-century-spanish-fresco-by-elias-garcia-martinez-in-botched-restoration-8073267.html
6. http://journals.openedition.org/ceroart/4765

REFERENCES

Alexopoulou, A., Koutsouris, A., Konstantios, D., Mariolopoulou, P., Gerakari, K., Xatzistylianou, A., Psalti, E. (2005) Non-Destructive documentation of 12 post Byzantine icons of the Loverdo's collection, *Proceedings of ART'05 8th International Conference on Non Destructive Investigations and Microanalysis for the Diagnostics and Conservation of the Cultural and Environmental Heritage,* Lecce 15-19 May, Univ. of Lecce Italian Society of Non Destructive Testing Monitoring DiagnosticsPubl., Italy.

Alexopoulou, A., Kaminari, A. (2010) Study and documentation of an icon of "Saint George" by Angelos using infrared reflectography" Icons by the hand of Angelos. The Painting Method of a fifteenth-century Cretan Painter, *Benaki Museum*, Athens, pp. 151-161.

Alexopoulou, A. (2004) Comparative study of 12 icons of the Loverdos' Collection. In the CD-ROM DiARTgnos is: Study of European religious painting, *Byzantine and Christian Museum*, Edited by University of Westminster.

Alexopoulou, A., Moutsatsou, A., Kaminari, A. (2018) Hyperspectral imaging studies on Greek monuments, archaeological objects and paintings on different substrates: Achievements and limitations. *1st International Conference on "Transdisciplinary Multispectral Modelling and Cooperation for the Preservation of Cultural Heritage" [TMM_CH]* October 18 -21, 2018, Athens, Greece, Proceedings: *J. Communications in Computer and Information Science*, Springer, Vol. 962 [ISBN 978-3-030-12959-0], pp. 443-461.

Alexopoulou, A., Kaminari, A., Panagopoulos, A. and Poehlmann, E. (2013) Multispectral documentation and image processing analysis of the papyrus of Tomb II at Daphne, Greece. *Journal of Archaeological Science, Elsevier Pub.*, Vol. 40 (2), pp. 1242-1249.

Al-Emam, E., El-Gohary, E, M., Abd El Hady, M. (2015) The paint layers of mural paintings at Abydos temples - Egypt : a closer look at the materials used. *Mediterranean Archaeology & Archaeometry*, Vol.15, No.3, pp. 113-121.

Alfeld, M., Janssens, K., Appel, K., Thijsse, B., Dik, J. (2011) A portrait by Philip Otto Runge? Visualizing modifications to the painting using synchrotron-based scanning X-ray Fluorescence elemental Imaging, *Zeitschrift fur Kunsttechnologie und Konservierung*, Vol. 25, pp. 157-163.

Alfeld, M., Janssens, K., Dik, J., De Nolf, W., Van der Snickt, G. (2011) Optimization of mobile scanning macro-XRF systems for the in situ investigation of historical paintings. *Journal of Analytical Atomic Spectrometry*, Vol. 25, 26, pp. 899-909.

Alfeld, M., Van der Snickt, G., Vanmeert, F., Janssens, K., Dik, J., Appel, K., Van der Loeff, L., Chavannes, M., Meedendorp, T., Hendriks, E. (2013) Scanning XRF investigation of a Flower Still Life and its underlying composition from the collection of the Kroller-Muller-Museum, *Applied Physics A: Mater. Sci. Process,* Vol. 111, pp. 165-175.

Aubert, M., Brumm, A., Ramli, M., Sutikna, T., Saptomo, E. W., Hakim, B., Morwood, M. J.. Van den Bergh, G. D., Kinsley, L., Dosseto, A. (2014) Pleistocene cave art from Sulawesi, Indonesia, *Nature*, Vol.514, pp. 223–227.

Basem, G., Aly Foad, M., Marey, H. (2015) Identification of the byzantine encaustic mural painting in Egypt. *Mediterranean Archaeology & Archaeometry*, Vol.15, No.2, pp. 243-256.

Bader, N.A., and Rashedy, W.B. (2014) Analytical study of paint layer in mural painting of Krabia School (19th c.), Cairo, Egypt. *Mediterranean Archaeology and Archaeometry,* Vol. 14, No 2, pp. 349-366.

Baldelli, P., Bonizzoni, L., Gambaccini, M., Gargano, M., Ludwig, L., Milazzo, M., Pasetti, L., Petrucci, F., Prino, F., Ramello, L., Scotti, M. (2006) Application of the K-edge X-ray technique to map pigments of art paintings: preliminary results, *Nuovo Cimento,* Vol. 29, pp. 663-672.

Binda, L., Saisi, A., Tiraboschi, C., Valle, S., Colla, C. and Forde, M. C. (2003) Application of sonic and radar tests on the piers and walls of the Cathedral of Noto, *Construction and Building Materials*, Vol. 17, pp. 613–627.

Brandi, C. (1977) Teoria del restauro; Rome: Edizioni di Storia e Letteratura, 1963: reprint, Turin: G. Einaudi.

Bridgman, C.F., Keck, S., Sherwood, H.F. (1958) The radiography of panel paintings by electron emission, *Studies in Conserv*ation, Vol.3 pp. 175-182.

Bronk, H., Rohrs, S., Bjeoumikhov, A., Langhoff, N., Schmalz, J., Wedell, R., Gorny, H.E., Herold, A., Waldschlager, U., (2001) ArtTAX—a new mobile spectrometer for energy- dispersive micro X-ray fluorescence spectrometry on art and archaeological objects. *Fresenius Journal of Analytical Chem*istry, Vol.371, pp. 307-316.

Bull, D., Krekeler, A., Alfeld, M., Dik, J., Janssens, K. (2011) An intrusive portrait by Goya, *Burlington Magazine*, Vol. 153, pp. 668-673.

Cabal Rodriguez, A.E., Pernia, D.L., Schalm, O., Van Espen, P.J.M. (2012) Possibilities of energy-resolved X-ray radiography for the investigation of paintings. *Analytical and Bioanalytical Chemistry,* Vol.402, pp. 1471-1480.

Cosentino, P. and Martorana, R. (2001) The resistivity grid applied to wall structures: first results. *Proceedings of the 7th Meeting of the Environmental and Engineering Geophysical Society, European Section*, Birmingham, U.K.

Curtis, G. (2006) *The Cave Painters: Probing the Mysteries of the World's First Artists*, New York, Anchor Books

Daniela, F., Mouniera, A., Pérez-Aranteguib, J., Pardosb, C., Prieto-Taboadac, N., Fdez-Ortiz de Vallejueloc, S., Castroc, K. (2015) Hyperspectral imaging applied to the analysis of Goya paintings in the Museum of Zaragoza (Spain), *Science Direct, ,Elsevier,* Vol. 126, pp. 113-120.

Delaney, J.K., Metzger, C., Walmsley, E., Fletcher, C., (1993) Examination of the visibility of underdrawing lines as a function of wavelength, in: J. Bridgland (Ed.), ICOM 10th Triennial Meeting, ICOM Committee for conservation, Washington D.C., USA, pp. 15-19.

Dik, J., Janssens, K., Van Der Snickt, G., Van der Loeff, L., Rickers, K., Cotte, M. (2008) Visualization of a Lost Painting by Vincent van Gogh Using Synchrotron Radiation Based X-ray Fluorescence Elemental Mapping. *Analytical Chem*istry, Vol. 80, pp. 6436-6442.

El-Rifai, I., Hagar, E., Hend, M., Bebars, Y. & Ide-Ektessabi, A. (2013) Artwork digitization and investigation a case study of the loom weaver oil painting by Hosni el-Bannani. *Mediterranean Archaeology and Archaeometry*, Vol. 13, No 2, pp. 21-29.

Enas Abo El Enen Amin (2018) Technical investigation and conservation of a tapestry textile from the Egyptian textile Museum, Cairo. *Scientific Culture*, Vol. 4, No 3, pp. 35-46 DOI: 10.5281/zenodo.1409804.

Enas Abo El Enen Amin (2017) Study and treatment of selected decorated shawl in applied art museum, Cairo, Egypt. *Scientific Culture*, Vol. 3, No 3, pp. 1-11. DOI: 10.5281/zenodo.813010.

Evans, E. H, Pisonero, J., Clare, M., Smith, M. and Taylor, R. N. (2019) Atomic spectrometry update: review of advances in atomic spectrometry and related techniques, *Journal of Analytical Atomic Spectrom*etry, Vol. 34, pp.803-822.

Falco, C.M. (2009) Invited article: high resolution digital camera for infrared reflectography, *Review of Scientific Instrum*ents, Vol. 80, 071301.

Francisco, D.C., Imai, H., Rosen, M., Berns, R.S. (2001) Multi-spectral imaging of van Gogh's Self-portrait at the National Gallery of Art, Washington, *Proceedings of the IS&T's 2001 PICS Conference*, pp.185-189.

Fukunaga, K., Picollo, M. (2010) Terahertz spectroscopy applied to the analysis of artists' materials. *Applied Physics A, Mater. Sci. Process.*, Vol. 100, pp. 591-597.

Gavrilov, D., Maev, R. Gr. and Almond, D.P. (2014) A review of imaging methods in analysis of works of art: Thermographic imaging method in art analysis *Canadian Journal of Phys*ics, Vol. 92, pp. 341–364. dx.doi.org/10.1139/cjp-2013-0128).

Gargano, M., Ludwig, N., Poldi, G., (2007) A new methodology for comparing IR reflectographic systems, *Infrared Physics and Technology*, Vol. 49, pp. 249-253.

Guthrie, R. Dale. (2006) *The Nature of Prehistoric Art*. Chicago: University of Chicago Press.

Heydenreich, G. (2007) *Lucas Cranach the Elder: Painting materials, techniques and workshop practice*, Amsterdam University Press.

Hieromonk Dionysius of Fourna (1909) *Interpretation of Byzantine painting art*, under A. Papadopoulou Kerameos, Petroupolis (in Greek).

Hocquet, F.P., del Castillo, H.C., Xicotencatl, A.C., Bourgeois, C., Oger, C., Marchal, A., Clar, M., Rakkaa, S., Micha, E., Strivay, D. (2011) Elemental 2D imaging of paintings with a mobile EDXRF system. *Analytical and Bioanalytical Chemistry*, Vol. 399, pp. 3109-3116.

Howard, D.L., de Jonge, M.D., Lau, D., Hay, D., Varcoe-Cocks, M., Ryan, R., Kirkham, C.G., Moorhead, G., Paterson, D., Thurrowgood, D., (2012) High-definition X-ray fluorescence elemental mapping of paintings, *Analytical Chemistry*, Vol. 84, pp. 3278-3286.

Janssens, K., Adams, F. (2000) Application in art and archaeology. In: K.H.A. Janssens, F.C.V. Adams, A. Rindby (Eds.), Microscopic X-ray Fluorescence Analysis, Wiley, Chichester, pp. 291-314.

Anssens, K, Van der Snickt, G., Vanmeert, F., Legrand, S., Nuyts, G., Alfred, M., Monico, L., Anaf, W., De Nolf, W., Vermeulen, M., Verbeeck, J., De Wael, K., (2017) Non-Invasive and Non-Destructive Examination of Artistic Pigments, Paints and Paintings by Means of X-Ray Methods. Part of volume ''Analytical Chemistry for Cultural Heritage", Springer, 10.1007/978-3-319-52804-5_3.

Johnson, D.H., Johnson, C.R., Erdmann, R.G. (2013) Weave analysis of paintings on canvas from radiographs, *Signal Process.*, Vol.93, pp. 527-540.

Johnson, D.H, Johnson, C.R, Hendriks, E. (2010) Signal processing and analyzing works of art, Proc. SPIE 7798, *Applications of Digital image processing* XXXIII, 77980G doi.org./10.1117/12.862994.

Kareem, A.O., Alfaisal, R. (2010) Treatment conservation and restoration of the Bedouin dyed textiles in the Museum of Jordanian Heritage, *Mediterranean Archaeology and Archaeometry*, Vol 10, No 1, pp. 25-36.

Karapanagiotis, I., Wei, S., Sister Daniilia, Minopoulou, E., Mantzouris, D., Rosenberg, E., Stassinopoulos, S. (2008) Analytical Investigation of the Painting Techniques in Icons of the Cretan School of Iconography, *9th International Conference on NDT of Art*, Jerusalem Israel, 25-30 May 2008.

Kanngießer, B., Malzer, W., Reiche, I. (2013) A new 3D micro X-Ray fluorescence analysis set-up-First archaeometric applications, *Beam Interactions with Materials and Atoms,* Vol. 211(2), pp. 259-264.

Kontoglou F (1993) *Expression of Orthodox Iconography*, 2nd edition, volume A (technological and pictorial), publications ASTIR, Athens, (in Greek).

Krug, K., Dik, J., Den Leeuw, M., Whitson, A., Tortora, J., Coan, P., Nemoz, C., Bravin, A., (2006) Visualization of pigment distributions in paintings using synchrotron K-edge imag*ing, Applied Physics A: Mater. Sci. Process.,* Vol. 83, pp. 247-251.

Liritzis,I. and Polychroniadou,E. (2007) Optical and analytical techniques applied to the Amfissa Cathedral mural paintings made by the Greek artist Spyros Papaloukas (1892-1957). *Revue d' Archaeometrie (Archaeosciences)*, Vol. 31, 97-112.

Mairinger, F. (2004) UV-, IR- and X-ray imaging, in: Janssens, K., Van Grieken, R., (Eds.), *Non-destructive Microanalysis of Cultural Heritage Materials, Elsevier,* Amsterdam, pp. 15-72.

Mantler, M., Schreiner, M., Weber, F., Ebner, R., Mairinger, F. (1992) An X-ray spectrometer for pixel analysis of art objects, *Advances in X-ray Analysis,* Vol. 35, pp. 987-993.

Margaritof, T., (1999) The Problems of Conservating Icons in the Past and Today. *Proceedings of the International Meeting of the Icons' Working Group,* Athens, Greece (in Greek) pp. 23-26.

Mass, J.L., Bisulca, C. (2010) Revealed a lost illustration by N.C. Wyeth, Antiques and Fine Art Summer/Autumn, pp. 222-223.

Methot, L. (2005) *The Development of an X-Y Stepper for Application in X-ray* Fluorescence A*nalysis of Paintings and Other Two Dimensional Objects,* Department of Physics, University at Albany, State University of New York, Albany.

Monico, L., Van der Snickt, G., Janssens, K., De Nolf, W., Miliani, C., Verbeeck, J., Tian, H., Tan, H.Y., Dik, J., Radepont, M., Cotte, M. (2011) Degradation process of lead chromate in paintings by Vincent van Gogh studied by means of synchrotron X-ray, *Analytical Chemistry*., Vol.83, pp. 1214-1223.

Mora, P., Mora, L., Philippot, P. (1984) *Conservation of Wall Paintings*, England, Butterworths.

Moropoulou, A., Labropoulos, K., Delegou, E., Karoglou, M., Bakolas, A. (2013) Non-destructive techniques as a tool for the protection of built cultural heritage, *Construction and Building Materials*, Vol.48, pp. 1222–1239.

Nakano, K., Tabea, A., Shimoyamab, S., Tsujia, K. (2016) Visualizing a black cat drawing hidden inside the painting by confocal micro-XRF analysis, *Microchemical Journal, Vol.* 126, pp. 496–500.

Noble, P., Van Loon, A., Alfeld, M., Janssens, K., Dik, J. (2012) Rembrandt and/or Studio, Saul and David, c.1655: visualising the curtain using cross-section analyses and X-ray fluorescence imaging, *Techne,* Vol. 35, pp. 36-45.

Oliveira, D., Calza, C., Rocha, H.S., Nascimento, J.R. and Lopes, R.T. (2013) Application of Digital Radiography in the Analysis of Cultural Heritage, *International Nuclear Atlantic Conference*, Recife, PE, Brazil, 24-29 November, - INAC https://pdfs.semanticscholar.org/21ce/35e99f94dd660f38a7c1ca62213422cab065.pdf.

Padfield, J., Saunders, D., Cupitt, J., Atkinson, R. (2002) Improvements in the acquisition and processing of X-ray images of paintings, *National Gallery Technical Bulletin,* Vol. 23, pp. 62-75.

Picollo, M., Fukunaga, K., Labaune, J. (2014) Obtaining non-invasive stratigraphic details of panel paintings using terahertz time domain spectroscopy imaging system, *Journal of Cultural Haritage,* Vol. 16, pp. 73-80.

Salama, K.K., Ali, M.F., Moussa, A.M. (2016) Deterioration factors facing mural paintings in el Sakakeny palace (problems and solutions). *Scientific Culture*, Vol. 2, No 3, pp. 5-9 DOI: 10.5281/zenodo.44897.

Saunders, D., Billinge, R., Cupitt, J., Atkinson, N., Liang, H. (2006) A new camera for high- resolution infrared imaging of works of art, *Studies in Conservation*., Vol. 51, pp. 277-290.

Schalm, O., Cabal, A., Van Espen, P., Laquiere, N., Storme, P. (2011) Improved radiographic methods for the investigation of paintings using laboratory and synchrotron X-ray sources, *Journal of Analytical Atomic Spectrom*etry, Vol 26, pp. 1068-1077.

Schreiner, M., Mantler, M., Weber, F., Ebner, R., Mairinger, F. (1992) A new instrument for the energy dispersive X-ray fluorescence analysis of objects of art and archaeology, *Adances in X-ray Anaysis,* Vol.35, pp. 1157-1163.

Scott, D.A. (2001) The application of scanning X-ray fluorescence microanalysis in the examination of cultural materials, *Archaeometry,* Vol. 43, pp. 475-482.

Sfarra, S., Theodorakeas, P., Ibarra-Castanedo, C., Avdelidis, N.P., Paoletti, A., Paoletti, D., Hrissagis, K., Bendada, A., Koui, M., Maldague, X., (2012) Evaluation ofdefects in panel paintings using infrared, optical and ultrasonic techniques, *Insight,* Vol. 54, pp. 21 -27.

Stork, D.G., Kossolapov, A.J. (2011) X-ray image analysis of Lorenzo Lotto's Husband and Wife, Proc. SPIE 7869 78690L.

Sister Daniilia, Bikiaris, D., Burgio, L., Gavala, P., Clark, R. and Chryssoulakis, Y. (2002) An extensive non-destructive and micro-spectroscopic study of two post-Byzantine overpainted icons of the 16th century *Journal of Raman Spectrosc*opy, Vol. 33, pp. 807–814 DOI: 10.1002/jrs.907.

Targowski, P., Iwanicka, M. (2012) Optical Coherence Tomography: its role in the non-invasive structural examination and conservation of cultural heritage objects—a review, *Applied Physics A,* Vol. 106, pp265-277.

Thurrowgood, D., Paterson, D., De Jonge, M., Kirkham, R., Thurrowgood, S., Howard, D. (2016) A Hidden Portrait by Edgar Degas, *Scientific Reports,* Vol.6, 29594, DOI: 10.1038/srep29594.

Trentelman, K., Bouchard, M., Ganio, M., Namowicz, C., Patterson, C.S., Walton, M., (2010) The examination of works of art using in situ XRF line and area scans, *X-Ray Spectrometry,* Vol.39, pp. 159-166.

Tserevelakis, G. J., Vrouvaki, I., Siozos, P., Melessanaki, K., Hatzigiannakis, K., Fotakis, C., Zacharakis, G. Photoacoustic imaging reveals hidden underdrawings in paintings, *Scientific Reports,* Vol 7, 747 DOI:10.1038/s41598-017-00873-7.

Van Asperen de Boer, J.R.J. (1974) A note on the use of an improved infrared vidicon for reflectography of paintings, *Studies in Conservation*, Vol. 19, pp. 97-99.

Van Asperen de Boer, J.R.J. (1966) Infrared reflectograms of panel paintings, *Studies in Conservation,*Vol. 11, pp. 45-46.

Valladas, H. (2003) Direct radiocarbon dating of prehistoric cave paintings by accelerator mass spectrometry. *Measurement Science and Technology*, Vol.14 (9), pp. 1487–1492. doi:10.1088/0957-0233/14/9/301.

Van Asperen de Boer, J.RJ. (1976) An introduction to the scientific examination of paintings. In: J.P. Filedt Kok, J.RJ. van Asperen de Boer (Eds.), Scientific Examination of Early Netherlandish Painting, Fibula-Van Dishoek, Bussum, The Netherlands, pp. 1-40.

Van der Loeff, L.S., Alfeld, M., Meedendorp, T., Dik, J., Hendriks, E., Van der Snickt, G., Janssens, K., Chavannes, M. (2012) Rehabilitation of a Flower Still Life in the Kroller-Muller Museum and a lost Antwerp painting by Van Gogh. In: L. van Tilborgh, D. van Halsema, J. House, G. Weisberg (Eds.), Van Gogh Studies 4: New Findings, WBOOKS, Zwolle, pp. 33-53.

Walker, A. (2012) *The Emperor and the World: Exotic Elements and the Imaging of Middle Byzantine Imperial Power, Ninth to Thirteenth Centuries C.E.* New York, Cambridge University Press.

Walmsley, E., Fletcher, C., Delaney, J. (1992) Evaluation of system performance of near-infrared imaging devices, *Studies in Conservation.,* Vol. 37, pp. 120-131.

Walmsley, E., Metzger, C., Delaney, J.K., Fletcher, C. (1993) Evaluation of platinium silicide cameras for the use in infrared reflectography, in: J. Bridgland (Ed.), ICOM 10th Triennial Meeting, ICOM Committee for conservation, Washington D.C., USA, pp. 57-62.

Zemlicka, J., Jakubek, J., Krejci, F., Hradil, D., Hradilova, J., Mislerova, H. (2012) Mobile system for in-situ imaging of cultural objects, *J. Instrum.,* Vol. 7, C01108, pp. 1-7.