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NON-DESTRUCTIVE INVESTIGATION OF PAINTINGS ON DIFFERENT SUBSTRATES. METHODOLOGY, ACHIEVEMENTS & LIMITATIONS

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ABSTRACT

Today, non-destructive testing includes diagnostic methods that provide significant information for art historians, archaeologists, conservators and researchers. The quick in situ application, the absence of expensive consumables, the inspection of entire surfaces and the ability for mapping make these methods attractive to users. Additionally, they provide the advantage of examining large areas of work of art, supporting a multidisciplinary approach, documentation, analysis and protection of visual arts' works. The case studies presented here involve the application of methodology on paintings on wood, canvas and paper substrate, while the constraints and particular requirements that different structures and special conditions dictate are discussed. Through these case studies the authors intend to highlight that the application of modern non-destructive methods and in particular versatile and renowned imaging techniques in the visible, ultraviolet and near infrared regions of the spectrum, offer many possibilities to the end user, making the revelation of the painting technique and the characterization of the materials feasible, while supporting the decision making for conservation.

Keywords:
Non-destructive testing, spectral imaging, conservation, icons, easel paintings, paper support.

1. INTRODUCTION

Non-destructive testing with an emphasis on spectral imaging in ultraviolet and near infrared regions of the spectrum are the spearhead of diagnostic methods, constituting a valuable tool at the service of art historians, scholars, conservators and researchers [Fischer and Kakoulli, 2006]. Being non-invasive techniques, they are attractive because of the quick in situ application, the absence of expensive consumables, the inspection of the entire surface of the object and the mapping ability, offering the advantage of examining large areas of an object giving both spatial and spectral information and thus supporting a multidisciplinary approach, documentation, analysis and protection of visual arts' works. Spectral imaging collects images of an object in a series of spectral windows differentiated from each other only regarding the spectral channels they operate. They were initially applied qualitatively, for band-to-band comparison, in order to identify areas of different material composition, preparatory sketches, degradation of materials, interventions and previous conservation treatments, and quantitatively to improve precision in color measurement. Later, when development of the equipment provided increased number of bands and speed of acquisition, spectral imaging was additionally used to extract qualitative spectral reflectance information for pigment identification. The instrumentation can operate in UV, visible, NIR reflectance mode and in UV induced visible fluorescence mode. Multispectral and hyperspectral imaging are in increasing demand in the field of art conservation, art history and archaeology judging by the number of recent reviews on the subject from the conservation and archaeology community [Fischer and Kakoulli, 2006; Liang, 2012; Dyer et al, 2013; Daniel et al, 2016]. A latest trend in the non-destructive research is the coupling of hyperspectral imaging with motorized XRF scanning easels. In such cases, mapping data are collected by XRF at the same time and from the same area as images by the hyperspectral camera, thus reducing the overall examination time of the artefact compared to when the methods are applied separately [Kleynhans et al, 2021; Gabrieli et al, 2021]. However, this could be exploited only by museums that already possess such instrumentation and cannot be easily supported by cultural heritage institutes due to the high budget, the requirement of specialized equipment and the conditions of maximum accuracy.

2. APPLICATION OF NON-DESTRUCTIVE TESTING/ METHODOLOGY

The case studies presented here refer to paintings on wooden substrate, like religious portable icons and folk art paintings, paintings on canvas and paintings on paper support. The applied methodology is described with special emphasis on the specific characteristics and optical properties of the material, while the constraints and particular requirements that different structures and special conditions dictate are also discussed [Kaminari et al, 2013; Moutsatsou and Alexopoulou, 2014].

Through these case studies the authors want to show that the application of modern non-destructive versatile and renowned imaging methods offer many possibilities to the end user by making feasible the revelation of the painting technique, including the drawing detection, the characterization of the materials and their technique of application. Furthermore, they can bring to light damage, alterations and changes the materials may have suffered over time. The findings are very important in highlighting the artistic value of the artwork, as well as in providing essential information for art historians and conservators who are involved in tasks of conservation and restoration.

2.1 A SYSTEMATIC APPROACH

As a practical guide, a general methodology flow chart can be proposed to assist researchers. This flow chart includes relevant parameters, evidence and procedures in order to understand all the conditions associated with the artwork, answer questions about what is happening and explain them with scientific proof.

The flow chart describes the different stages of the physicochemical methodology and the way by which the different methods must be combined, in order to achieve sound results. As it can be eas-

ily understood, non-destructive testing (NDT) is the first step of the methodology and in some cases it is enough to solve documentation problems. [1] (fig.1)

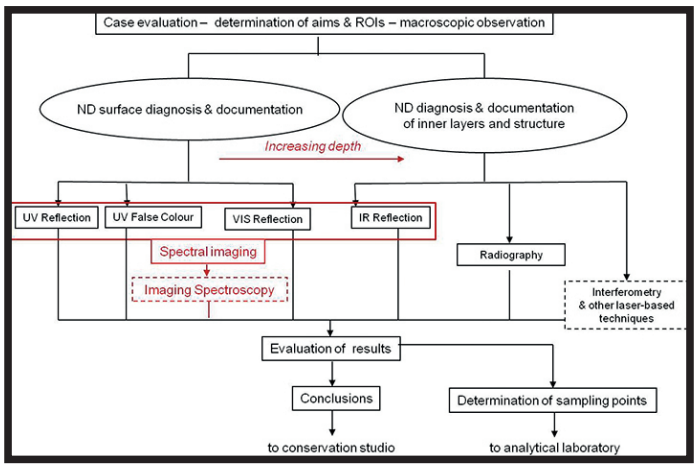

Figure 1:NDT flow chart of paintings. (Moutsatsou A., 2013)

Non-destructive documentation includes not only multispectral and hyperspectral imaging, but also the individual imaging and photographic techniques that have been applied for years for the examination of works of art, such as ultra-violet induced visible fluorescence color photography (UVFC), ultraviolet reflectance photography (UVR), visible photography, infrared reflectography (IR-Ref), false color infrared imaging (FCIR).

Before conservation treatment, all the historical and preliminary data concerning the condition, the materials, the technique and the structure of a painting must be complemented, combined, correlated and confirmed by the physicochemical data in order to achieve a holistic, systematic and scientific documentation of the icon. Application of one or more methods of physical analysis, which are not incorporated in a methodical study project with specific goals, may prove to be weak and might sometimes lead to erratic conclusions.

Nowadays, the abundance of scientific tools provided by advanced technology has widened the field of application of physical methods in the diagnosis of art, minimized the negative effects of their use and contributed to the creation of user-friendly equipment, so that the required information can be collected in situ, in a fast, direct and reliable way.

More precisely non-destructive testing is used in a systematic approach of paintings for:

- Detecting the current condition (flaking, losses or damages of the internal or superficial painting layers and the support/substrate)
- Detecting interventions or/and alterations on the original work
- Detecting initial drawings, underdrawings, sketches etc.
- Detecting “pentimenti”, meaning hesitations or changes in the compo-sition during the creation of the painting
- Studying the internal structure of paint layers, their chemical composition, sequence and optical propeties
- Studying painting technique, meaning the particular way the materials have been used, the brushstrokes, the high lights, the glazing etc.
- Revealing over-paintings, inpaintings or other similar elements of the paint layers
- Reading of faded or covered inscriptions, signatures, texts, dates and lost iconongraphic elements, which might reveal the date and origin of the work, as well as to document which practies were in actual use in various periods in the history of art (or in certain places and school of painting). This will eventually help in the indirect dating based on the combination of physicochemical data with historical data.

The categories of paintings presented below were selected to present the different conditions and requirements, which must be met depending on the structure of each artefact even though the same methods were applied. For example, regarding the transparency of the support, a different setup is required for imaging papers, where light must be excluded in cases where it affects the optical effect due to the high transparency of the material, while in cases of wooden supports, which are solid, this is not a factor for concern.

2.2 PAINTINGS ON WOODEN SUPPORT

Panel paintings or paintings on wooden support, are usually found in the form of icons in Greece, either as part of the Templon within the church or as portable religious artefacts. The results of many case studies examined by the authors showed that by studying the internal structure,

the quality, the thickness and the particular use of color mixture it is possible to approach the painter's work and technique, to confirm bibliographic data or to reject hypotheses. For example, paint layers that reflect great care (the use of pigments of fine grinding and homogeneous granularity, the presence of even paint layers) were combined with the icons' high artistic value, as well as with the use of rare and expensive pigments (lapis lazuli, azurite and yellow orpiment) without, however, being able to determine a specific haghiographer's laboratory.

In the case of the works of Theophilos, one of the most important naïve painters of Greece, little can be found about the techniques and the materials he used, some of them having been passed down orally as part of his personal myth. He mostly painted Greek characters in the context of traditional folklore life and history [Koutsouris et al, 2018]. The study of five of his creations owned by the Museum of Modern Greek Culture was crucial in providing information about his artistic talent. The purpose of this research was to apply an internationally accepted scientific procedure for drawing safe conclusions about the stratigraphy of Theophilos' works, the painting techniques and materials he used and their condition. This information in turn would clarify issues related to Theophilos' technique and artistic approach, thus facilitating researchers in interpreting his works and conservators to assess their condition.

The non-destructive imaging methods applied were UVFC, visible photography, IR-Ref, FCIR and hyperspectral imaging in order to examine the existence of varnish layer, the color layers, the pigments and find whether Theophilos used sketches for his paintings.

The UVFC photography showed that all of the artist's paintings were covered with a thick white-bluish fluorescent varnish layer. The images showed the way the varnish was laid on every single surface, revealing that on one of the paintings, The brave general Theodorakis Grivas, Theophilos had left the surrounding margins without varnish deliberately (fig.2). This provided the crucial information of the artistic awareness of Theophilos and the way he employed materials to enhance the end result. Given that Theophilos was considered a naïve painter and most of the public considers his painting to be simple and populist, it is now shown that he was fully aware of what he was doing. Furthermore, FCIR, apart from discerning different pigments, assisted in locating areas where the artist had used bronzine, a metallic paint that resembles gold, which by the ages was discolored.

Hyperspectral imaging and IR-Ref showed that in two of Theophilos' paintings there was no under drawing, indicating that the artist has applied the colors on the panel improvising, yet following a clear vision in his mind, as the color brushstrokes are very specific and

Figure 2: Theophilos, The brave general Theodorakis Grivas, after 1929, tempera on wood, 62.7x23.5cm, Athens, Museum of Modern Greek Culture (no.2808) – detail. (a) visible light photography, (b) ultraviolet induced visible fluorescence photography. (Alexopoulou A. and Kaminari A., 2016)

do not overlap for correction. In two other paintings, sketching was revealed, with intense and complex sketch lines (fig.3). From the above it is evident that the painting, in order to study the transmitted infrared radiation (TIR).

Using the aforementioned setup, one of the most important cases of under

Figure 3: Theophilos, Erotokritos and Aretousa, after 1929, tempera on cardboard pasted on masonite, 61x36cm, Athens, Museum of Modern Greek Culture (no.3097) – detail: (a) visible photography, (b) infrared image (1000nm). (Alexopoulou A. and Kaminari A., 2016)

Theophilos does not seem to be interested in the rules of the academic painting art, the proportions, the perspective etc. All these elements confirm the aspects of the art historians that Theophilos had a spontaneous painting based on simplicity in details and spaces.

2.3 PAINTINGS ON CANVAS

Paintings on canvas are another important category of works of art for which

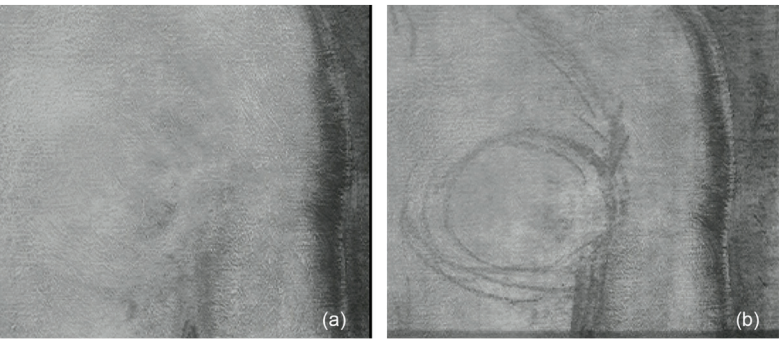

Figure 4: George Frederic Watts, Psyche, oil on canvas, 190x60cm, Athens, National Gallery –Alexandros Soutzos Museum (P.258) – detail 1: (a) imaging of the transmitted IR radiation, (b) imaging of the transmitted IR radiation. (Moutsatsou A., 2011)

non-destructive testing can be very illuminating. Several paintings belonging to the collection of the National Gallery - Alexandros Soutzos Museum, Athens, Greece were examined with modern multispectral imaging systems. The results presented here came about during the imaging operation of the infrared reflection (IRR) in the 950-1150nm wavelength region, but one of the light sources was placed in the back side of

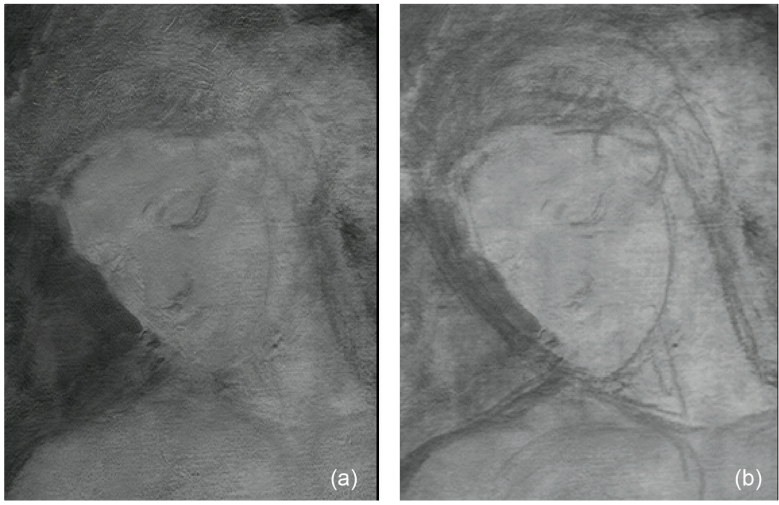

Figure 5: George Frederic Watts, Psyche, oil on canvas, 190x60cm, Athens, National Gallery – Alexandros Soutzos Museum (P.258) – detail 2: (a) imaging of the transmitted IR radiation, (b) imaging of the transmitted IR radiation. (Moutsatsou A., 2011)

drawing revelation was done and it regarded the painting of G.F. Watts entitled Psyche. The sketch can be clearly seen in the images of the transmitted IR radiation (fig.4b and fig.5b), while in the corresponding images of the reflected radiation (fig.4a and fig.5a), in the same spectral region this was not possible. This information has proved to be invaluable to the art historians, as the detailed, spontaneous and high quality under drawing that was revealed by this method, contributed to a better understanding of the artist's works and techniques.

The painting On the terrace or Athenian Night of the Greek painter Iakovos Rizos is one of the favorite paintings of the visitors to the National Gallery. Using naked eye and transmitted visible radiation, one

can locate several areas with craquelure of seemingly limited depth (fig.6a). However, by employing transmitted infrared radiation, the extent of the craquelure proved to be deeper than first thought (fig.6b). In this case, the application of the method helped conservators to acknowledge the severity of the problem and take the necessary steps for a more drastic conservation treatment/intervention. The recording of more than 170 multispectral images provided extended information about the under drawing and pentimenti. Furthermore, the application of transmitted IR radiation successfully documents the craquelure's depth and thus the state of preservation of the paint and preparation layers, whereas the reflected and transmitted VIS radiation and the reflected IR radiation depict a less critical impression of the problem.

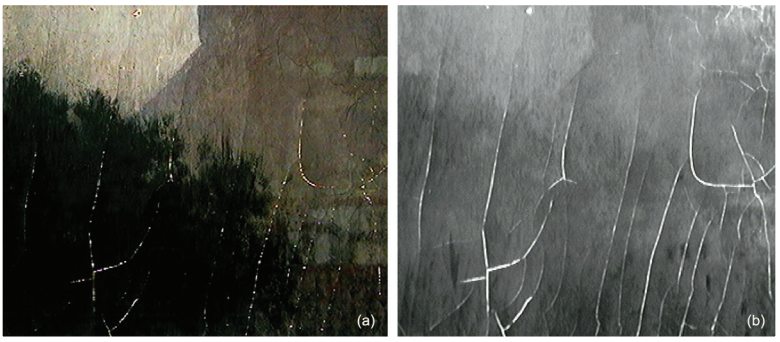

Figure 6: Iakovos Rizos, On the terrace, oil on canvas, 111x167cm, Athens, National Gallery – Alexandros Soutzos Museum (P.1108) – detail: (a) imaging of the transmitted IR radiation, (b) imaging of the transmitted VIS radiation. (Moutsatsou A., 2010)

2.4 PAINTINGS ON PAPER SUPPORT

As far as paintings on paper are concerned, the materials and techniques used for their creation principally determine the condition of the work, as well as the decision making in conservation treatment and preservation planning. Paintings on paper involve a great variety of drawing and painting materials. The condition of the painting layers or the painting media depends on the behavior of the paper support, but also on the presence of ground, preparation or priming layer, that act as a barrier between the painting materials and the paper support.

Non-destructive testing can provide data about the materials used, as well as indications about the chemical changes that evolve during ageing or/and the interaction of the materials. It can also characterize certain types of damage, like foxing, mould damage, tidelines, rust stains, etc. [Bicchieri et al, 2001; Pedersoli Júnior et al, 2000; Dupont, 1996].

Non-destructive testing can also provide indications on the stage of deterioration of the support, often associated with the use of certain drawing and painting media (watercolour, pastel, oil colour, etc.) and binding medium (such as gum, egg, oil or glue). It is known that the use of iron gall inks or metal-based pigments impose the deterioration of the support, while the intensity and the extent of the phenomena are associated with the preservation conditions through time [Banik, 1989; Reissland, 2001; Havermans et al, 2003].

On a bifacial tempera painting of plants in a 17th century medicinal codex, non-destructive testing indicated the use of a metal-based pigment, like verdigris,

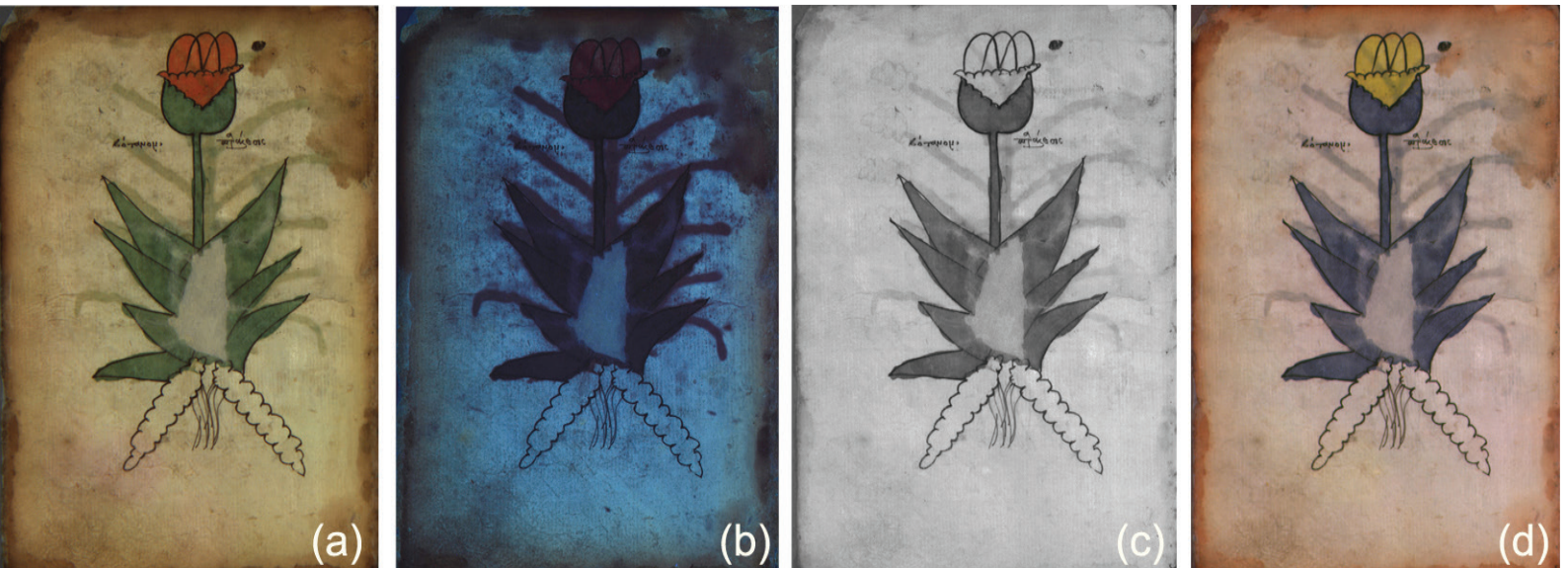

Figure 7: Unknown, Paintings of plants, 17th century, tempera on paper, 21x32cm, General State Archives of Greece, Collection of G. Vlachogiannis, Medical Codex – detail: (a) visible light photography, (b) ultraviolet induced visible fluorescence photography, (c) infrared image (900nm), (d) false color infrared image. (Banou P. and Kaminari A., 2016)

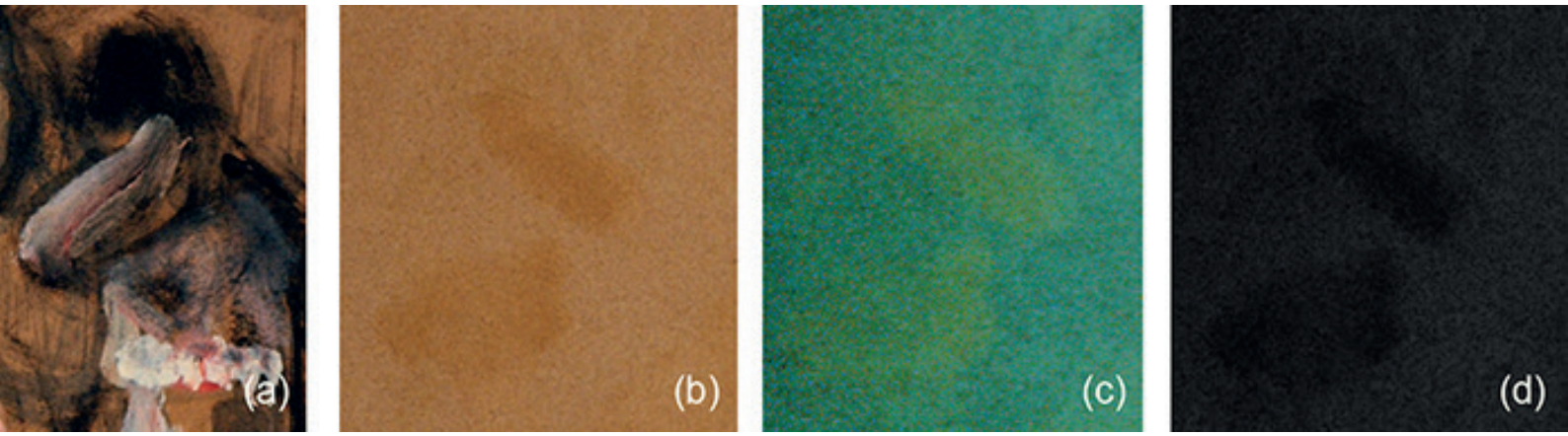

Figure 8: Nikolaos Gyzis, The sewing studio, 19th century, oil sketch on paper, 20x18cm, Athens, National Gallery – Alexandros Soutzos Museum (P.3434) – detail: (a) visible light photography recto, (b) visible light photography verso, (c) UVFC verso, (d) UVR verso. (Alexopoulou A., Kaminari A., Moutsatsou A., Banou P. , 2009)

which explains the deterioration of the support and the resulted loss (fig.7). It also indicated the use of red cinnabar. The intense whitish fluorescence on the surface of the paper indicates the application of a sizing or priming layer, as there are no additives or fillers to the paper pulp in that era to justify intense fluorescence [Dabrowski, 2009]. The fluorescence on the limits of the wet and dry interface of the tidelines indicate the oxidation of cellulose, while the extent of water damage is clearly defined. The data provided set limitations in conservation treatment, but also defined the conditions for storage and exhibition so as to ensure preservation of the work through time.

Research has also indicated that oil binders in oil colors affect the condition of the paper support [Banou et al, 2016]. On oil paintings on paper, non-destructive testing can record the areas of oil absorption and diffusion, map the areas of paper with diverse oil concentration and provide indications for the state of deterioration, data significant for condition assessment [Banou et al, 2017].

On the oil study The sewing studio by N. Gyzis the discoloration on the verso side of the work has been attributed to the absorption of the oil binder due to the yellow fluorescence recorded in UVFC photography (fig.8c), while the variation of oil concentration on paper is evident in UVR photography (fig.8d). The images indicate that the discolored areas are at the initial stages of discoloration.

3. DISCUSSION - CONCLUSIONS

The previous case studies have shown that applying a standard non-destructive testing methodology contributes to approaching the artistic creation, studying the condition and helps in the decision-making for conservation planning of works of art.

However, there are shortcomings and difficulties that must be addressed:

- the difficulty of quantifying image features and the need for more sophisticated processing
- the management of large amounts of imaging data
- the high investment cost in specialized equipment
- the need for qualified and certified staff as, despite the relative simplicity of some methods and the user-friendly tools, obtaining and interpreting the data requires the user's training, experience and deep understanding of the theoretical background of each method.

In the present day of rapid technological progress, the interpretation of art, the tracing of its historical path and consequently the protection of cultural heritage should be expressed through their interdisciplinary approach incorporating nondestructive documentation. Future steps to enhance this approach could include:

- the adoption of rigorous specifications and the establishment of new scientific methodology protocols and standards
- user certification
- the acknowledgment of the increasing importance of the non-destructive methods
- the strive for more comprehensive services and systematic research
- the development of electronic automation technology and appropriate software
- the development of more functional portable equipment for in situ analysis
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NOTES

[1] ROI stands for Region of Interest

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