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► To cite this version:

Ina Reiche, Myriam Eveno, Clément de Mecquenem, Thomas Calligaro, Eric Laval, et al.. The original appearance and beauty of ancient paintings virtually reconstructed. Un patrimoine pour l'avenir une science pour le patrimoine, Mar 2022, Paris, France. hal-03875495

HAL Id: hal-03875495

<https://hal.science/hal-03875495>

Submitted on 28 Nov 2022

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The original appearance and beauty of ancient paintings virtually reconstructed

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Keywords:

Smalt, discolouration, macro-XRF scanning, hyperspectral imaging, virtual reconstruction

Abstract

As part of questions about methods of cultural heritage conservation, transdisciplinary research was performed in order to develop a set of analytical processes allowing us to reconstruct the appearances of historical paintings at different moments in their history. This reconstruction is based on a detailed knowledge of the materiality of the works, their preservation state and the conditions of conservation and storage. These analyses, necessarily non- or micro-invasive for precious artworks, are accompanied by actual and virtual modelling of the evolution of the materials composition of the works. The example of a restored French 16th c. painting illustrates our approach.

I. Introduction

Although generally well exhibited or correctly stored, easel paintings can change over time. As complex works of art, the degradation processes can be variable depending on multiple factors. Therefore, preserving paintings over a long time represents a challenge. When the painting is already weathered, conservation-restoration measures are intended to maintain as much as possible the original material, to restore an appearance as original as possible and to prevent the painting from further degradation. Restoration generally needs a practical intervention into the materiality of the painting. The choice to be made is not always simple and straightforward. Virtually proposing different restoration solutions based on physicochemical analyses and imaging support the conservation decision making. Models need to be developed for determining the original state of the studied painting on the basis of quantified physicochemical markers by comparing them to artificially aged mock-ups. Additionally, these mock-ups allow establishing criteria for the assessment of the state of preservation and identifying factors responsible for the alteration phenomena, and explaining visible changes. The gained knowledge on the conservation state and the alteration mechanisms of the painting allows for creating a virtual reconstruction of the original state of the painting using mathematical tools.

The approach to achieve this goal is necessarily transdisciplinary and is based on analysis and imaging of the painting in its current state. Chemical, physical and mathematical tools are used to study the painting *in situ* or on cross-sections prepared from micro-samples. X-rays analyses and imaging as well as reflectance imaging spectroscopy or hyperspectral imaging (RIS) are carried out. The acquired data are combined and treated by statistical tools. The challenge is to be able to carry out these investigations and reconstructions in the less invasive way avoiding sampling. In a practical way and as the first step in this research, we want to set up an operational, analytical strategy for the study of paints when the question of the original appearance of the painted works is raised.

II. Recent technological development

In the last decade, much progress has been made in the instrumental development of analytical devices adapted to the non-invasive imaging of paintings. Above all, the set-up of macro-X-ray fluorescence imaging (MA-XRF) has to be cited (Alfeld *et al.*, 2013, Ravaut *et al.*, 2016). Besides, micro-analyses at synchrotron sources (Cotte *et al.* 2010, Janssens *et al.* 2010) allowed important progress in combination with combined micro-analyses on cross-sections. To gain non-invasive insights into the paint stratigraphy, confocal micro-XRF was developed and applied to easel paintings (Reiche *et al.*, 2012, Reiche *et al.*, 2016). This technique allows minimizing sampling for cross-section analysis. Last but not least, hyperspectral imaging (RIS) was developed as a precious complementary imaging tool for studying the palette of paintings (Delaney *et al.*, 2020, Alfeld *et al.*, 2013, Pillay *et al.*, 2019). In summary, there are available methods ranging from point analysis to multiscale and multimodal imaging at large scale facilities, in the laboratory and using portable devices, allowing *in situ* studies. These methods need to be applied in the framework of an integrated interdisciplinary approach that fulfils the special requirements and challenges of studying precious easel paintings, and that is adapted to the research questions addressed in each special case.

III. Results of a case study

The steps of the process presented here are illustrated here through the following case study provided by a scientific examination at the C2RMF (E. Ravaud, pers. comm.) of the French painting *Woman (Artemise?) doing a Libation* from an anonymous painter from the Ecole de Fontainebleau, around 1570 (320 x 780 mm², inv. no. RFML.PE.2019.40.1), Louvre Museum, Paris, France (Figure 1).

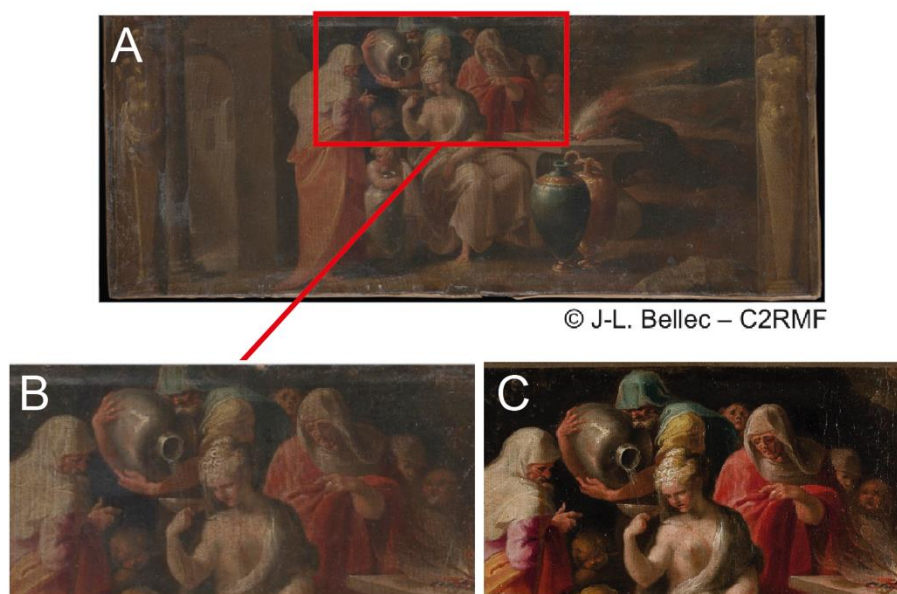


Figure 1 : A) *Woman doing a Libation (Artemise?)* from an anonymous painter from the Ecole de Fontainebleau, around 1570, 320 x 780 mm², inv. no. RFML.PE.2019.40.1, Louvre museum, before restoration, B) Detail of reflected light image before restoration and C) Detail of reflected light image after restoration

We were especially interested in the discolouration of the smalt pigment inducing a colour change of the smalt-based paint layer. Smalt is corresponding to a crushed Cobalt-colored potassium-based blue glass. It turns grey and brown during ageing leading to an irreversible discolouration of the pigment and the paint layer. In this case, a virtual reconstruction of the original appearance is especially appreciable because no restoration treatment allows to turn back to the original aspect.

Figure 2 shows the characteristic chemical maps obtained by MA-XRF for smalt containing paints and the corresponding RIS spectral angle maps obtained from the distribution of defined endmembers.

Interestingly, the chemical maps show that it is possible to divide the smalt containing zones into two types of different smalt compositions or two different ways of using the pigment in the paint. Further work is in progress to clarify this issue and to provide a faithful reconstruction of the original state of the painting (de Mecquenem *et al.* forthcoming).

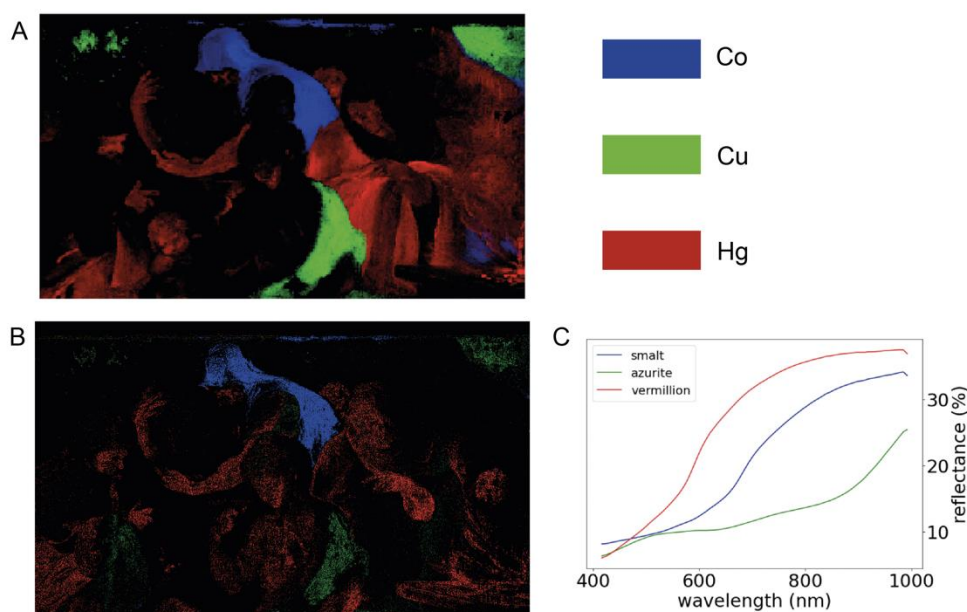


Figure 2: A) MA-XRF maps of Co, Cu and Hg, B) Map showing the pigment distribution obtained from RIS and C) Reflectance spectra of the end members used for the RIS distribution map.

IV. Conclusions and work in progress

Our work shows that the analytical tools are available for *in situ* non-invasive combined and multi-modal imaging of artworks such as easel paintings. The challenge relies on data evaluation, fusion and storage. Although established for isolated methods, progress needs to be made in data fusion to allow for integrated data interpretation and propose dedicated answers in the field of heritage sciences. For the presented case study, work is in progress. The digital tools are available for a colour reconstruction based on combined data of MA-XRF, RIS and colour measurements. It is intended to apply machine learning methods in order to propose different hypotheses of the original appearance (de Mecquenem *et al.* forthcoming). Virtual reconstructions allow for the modelling of different states of the painting by providing new aesthetic projections. These reconstructions can help in a long perspective in the decision-

making during conservation-restoration of paintings, the understanding of painters' techniques and the enrichment of the history of techniques. The history of art will thus benefit from new information and new elements of response to the reconstruction of the genesis and the history of the artworks. Ethical questions may also arise in conservation science, such as how and to what extent can paintings be restored or what are the most important measures for preventive conservation.

Acknowledgements:

We gratefully acknowledge the financial support of the *Fondation des Sciences du Patrimoine* in the framework of the PhD project entitled MARCS (2021-2024).

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