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RESUMEN

Este artículo presenta cómo la historia y trayectoria del Laboratorio del Centre de Recherche et de Restauration des Musées de France (C2RMF) se entrelaza con el desarrollo de la ciencia de la conservación como disciplina durante el siglo XX, sobre todo en términos de tomar ventaja de las mejoras ofrecidas por las ciencias naturales. A través de diferentes ejemplos de proyectos y métodos desarrollados a lo largo de la historia del Laboratorio del C2RMF, el autor muestra los resultados importantes que la introducción de las ciencias naturales en los campos de la historia del arte y la conservación ha logrado. El autor también presenta los actuales desafíos relacionados con la fusión de la disciplina y las nuevas tecnologías de la información, el desarrollo de proyectos pluridisciplinares y la orientación de la disciplina hacia la conservación/restauración del patrimonio cultural.
Palabras clave: *Ciencias de la conservación, C2RMF, Laboratorio, historia, conservación, patrimonio cultural.*

ABSTRACT

This article presents how the history and trajectory of Centre de Recherche et de Restauration des Musées de France (C2RMF) Laboratory is intertwined with the development of Conservation Science as a discipline during the 20th century, especially in terms of taking advantage of the improvements offered by the natural sciences. Through different examples of projects and methods developed throughout the C2RMF Laboratory´s history the author shows the important results that the introduction of Natural Sciences in the fields of art history and conservation has achieved. The author also discusses today´s challenges related to merging the discipline with new information technologies, developing pluri-discipline projects and orienting the discipline towards the conservation/restoration of the cultural heritage.
Key words: *Conservation Science, C2RMF, Laboratory, History, Conservation, Cultural Heritage.*

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NATURAL SCIENCES INSIDE MUSEUMS

The development of the Research Laboratory for the French Museums from its origin and into the future.

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Inside the images, the mark of the artist. Inside the matter, the print of the human hand that manufactured the artifacts, and was able to discover and select in nature the materials useful for his intention. The objects and the works that are exhibited inside museums testify not only of a symbolic thought but also give evidence of technical know-how. Traceology is a neologism used in archaeology for a method to identify the functions of artifact tools by examining the working surfaces and edges. More generally, the study of the different tracks inside matter informs the various scientists, curators, art historians, in charge of the preservation of the objects inside the museums, how to exhibit safely and to transmit to future generations the treasures of the past. Thanks to closely examining the objects at various scales, from the macro to the nano, the way of studying objects has developed tremendously following in the tracks of the progress taking place in analytical sciences. As an example, the widespread use of Scanning Electron Microscopes (SEM) in the 1980's to examine painting cross sections allowed the conservation scientists in the museum laboratories to discriminate precisely the two varieties of lead and tin yellow pigment used during the Renaissance period:[1] one with silica revealing a pigment derived of glass manufacture, the other, without silica, easier to grind and with the same intense hue. Before that, only one pigment was considered. It has become more and more common to examine paintings in a non-destructive way, without any sampling, by using X-rays, especially X-ray fluorescence. This method provides the elemental composition of the matter components. If this information is of major importance, the determination of the corresponding mineral is tricky, sometimes impossible. For instance, if we analyze the white pigment based on lead used from Antiquity until the late modern period at the end of the 19th century, XRF indicates the presence of Pb. So it is concluded that the white pigment is lead white. But lead white has several varieties, mixtures of cerussite (Lead carbonate with the chemical formula $PbCO_3$) and hydrocerussite (lead hydro carbonate, $Pb_3(CO_3)_2(OH)_2$). The development of portable X-ray diffractometers allows characterizing precisely the ratio of the lead components. If this experiment is crucial and needs precise and critical calculations (Rietveld refinement), the determination of the amount of the two lead carbonates opens new possibilities to understand the intention of the artist, the economical context related to the techniques applied to achieve the synthesis of the pigments and finally the physical properties of the paint matter that are of major importance for the conservation/preservation of the paintings.

Since its rise and throughout the 20th century until now Conservation science as a discipline has followed in the tracks of the progress taking place in analytical chemistry, as well as, materials science, called today nanosciences, and also the impact of IT (Information technology) in the management of databases and the input of digital multispectral imaging at various scales. The Centre de Recherche et de Restauration des Musées de France (C2RMF) laboratory during this period followed the development of the discipline taking advantage of the improvements of the natural sciences. Today, the challenges are still numerous: how to merge the discipline with the new information technologies, on one hand, and how to develop our discipline for the conservation/restoration of cultural heritage, on the other.

DEVELOPMENT OF X-RAY RADIOGRAPHY, CREATION OF THE FRENCH MUSEUM RESEARCH LABORATORY

The discovery made by Wilhelm Conrad Röntgen in 1895 of electromagnetic rays which he named X-rays allowed the rapid expansion of

1 Elisabeth Martin and Alain R. Duval. “Les deux variétés de jaune de plomb et d’étain: étude chronologique”, *Studies in Conservation* 35/3, 1990, pp. 117-136.

this imaging method. This great discovery opened new opportunities. At Röntgen's time it was almost magic and also original to see the invisible, something which brought new insights to the heritage kept inside museums. During the same period, the first museum laboratories were created; the Royal museum laboratory in Berlin was the first, in fact as early as 1888, then the British Museum during the First World War and then the Fine Arts museum in Boston in 1929.

In France, during the war 1914-1918, the first examinations of paintings inside a military ambulance were done by medical doctors who were also art lovers. Tests undertaken inside the council hall of the Louvre museum by Dr. Chéron were used as evidence in a communication to the French Academy of science on December 13th 1920. A small section of the painting department of the Louvre museum was after several attempts created officially in 1931. A few years earlier the director of the national museums dedicated a room for the examination of easel paintings through various wavelengths, including X-rays. Two Argentinean medical doctors, Fernando Perez and Carlos Mainini decided to sponsor and develop a laboratory devoted to the already so-called "multispectral imaging" of paintings.

The Mainini Institute was born, located inside the Aisle of Flore. The institute consecrated its activities to the study and examination of paintings and more generally to works of art belonging to the national museums. A photographic studio was associated to the laboratory.

When Dr. Perez passed away in 1935, the Mainini Institute became the Laboratoire d'études scientifiques du musée du Louvre. Jacques Dupont, medical doctor as well as assistant in the painting department of the Louvre Museum, was appointed as the head of the laboratory. The same year, in Brussels, an exhibition portrayed the "recent achievements of the laboratory of the Louvre museum" through a highly varied imagery for the first time: photographs with raking light, under UV fluorescence, and X-ray radiographs. The underside of very famous paintings was unveiled to the public: Jérôme Bosch, Leonardo da Vinci, Chardin or Watteau.

Today the laboratory is equipped with several X-ray studios. The art of the operators is to decide on the optimal conditions for a specific object. For the sculptures made in stone and metal the generator has a higher voltage: 420kV, in order to visualize the inside of the artifacts. One of the goals of the research on museum works is in fact the technical history, how to reveal the ancient know how of the artists and the craftsmen. Thanks to an approach to the matter itself, objects may bring new insights into the conditions of their invention. What kind of materials the artist chose, how he acted, the tools he used, and by that understand what he knew from the matter and its laws, if he was taught or if his genius enabled him to discover.

So X-ray radiography allows us to evidence the fabrication techniques, the assembling technologies, the preservation state and the previous conservation operations. With respect to paintings, the laboratory was famous thanks to the former director, Madeleine Hours, who fascinated the general public during TV shows in which she showed the X-ray radiograph results achieved on paintings. In this domain, the results are sometimes very dramatic. The C2RMF laboratory has today about 100.000 radiographs of paintings which constitute obviously a huge database for new research in art history. Today this extensive documentation is digitalized on one hand for preservation purpose but on the other hand to offer it to the research community thanks to the EROS database. This makes it possible to compare and manipulate images; comparison of X-rays with other images captured by using other wavelengths, easy enlargement of some details, modification of contrasts, and superposition of different images from the same painting.

Elisabeth Ravaud is an architect for the development of painting radiography. Trained as a medical doctor specialized in X-Ray radiography, Ravaud decided to apply her knowledge to painting examination. She was able to write a second PhD in art history this time comprising the different methods for the X-ray examination and a precise and meticulous description of a semiological approach to the various concepts and precepts in the radiographic images.[2] This important work is a real sum taking into account the physical phenomena and how the X-ray image is formed. The major contribution is probably the critical description of the different marks, signs which are explicitly easy to understand, and the signs that are ambiguous and misleading.

A study was undertaken on the famous *Issenheim* altarpiece from the Unterlinden museum in Colmar, which was painted at the beginning of the 16th century by Grünewald. The dimensions of the work (polyptic of several panels each 3.3 m. high and 5.3 m. wide) didn't allow us to bring the altarpiece to the laboratory. The analyses and examinations were undertaken inside the museum. The panels were radiographed during several nights taking into account the safety policy. The panels are painted on both sides which introduces difficulties to interpret the documents because of the superimposition of two images. The radiographs made it possible to determine the wood species as linden tree and the way the different wood planks were assembled.

2 Elisabeth Ravaud. *La radiographie des peintures: apport en histoire de l'art, en histoire des techniques et en conservation-restauration.* Thesis, Paris, Université de Paris 1 Sorbonne, 2011.

The radiographs enabled us to understand the way Grünewald painted. In the Nativity panel, a first sketch was abandoned; the limit of the sky and the far field was achieved with a lead white layer, reserving spaces for the motives in the foreground.

A comprehensive report of the various examinations undertaken on the work was presented at an international conference, and inside an exhibition, both in Colmar and finally published in a book for the general public.[3]

EXPERTISE AND DEVELOPMENT IN CONSERVATION SCIENCE

The Second World War put a stop to the activities of the Institute. Shortly after, in 1946, with the collaboration of the National Optical Institute, the laboratory reopened and Madeleine Hours was nominated shortly after that. In 1950, she was officially appointed as the head of the laboratory. In the mean time she developed research links with the French research institution CNRS and published an annual bulletin in 1956. She associated the laboratory with several exhibitions, especially with the one in 1952 commemorating the 500th birth anniversary of Leonardo da Vinci (1452, April 15th -1519, May 2nd). She took part in exhibitions abroad, escorting Mona Lisa when Leonardo's panel was brought to New York in December 1962.

In 1968, Madeleine Hours was successful in developing her institute in a direction which took into account the academic context and the systemic development of Natural Sciences applied to archaeology and Cultural Heritage (CH). At the time, the pioneers of archaeometry introduced the Human Sciences community to a novel forma of approaching the materiality of CH objects. Thanks to the strong support of André Malraux, the French Cultural minister, she created the Laboratoire de Recherche des Musées de France (LRMF) which was installed inside the Louvre Palace. Two floors were equipped for scientific photography and physico chemical analysis. The team comprised at the time 16 people: curators, chemists, physicists, photographers. A physical branch was also set up with infrared spectrography, X-ray Fluorescence, X-ray diffraction. A Thermoluminescence (TL) system was also conceived for the authentication of ceramics.

Madeleine Hours was thus one of the architects for a laboratory dedicated to the analysis and examination of museum objects. She developed the concept of expertise and authentication, promoting a difficult equilibrium between, on one hand, the duty of the museum curators and, on the other, research and development in materials science applied to

3 F.-R. Martin, M. Menu and S. Ramond. *Grünewald.* Paris, Hazan, 2012.

cultural heritage. This research aimed at understanding the socio-cultural conditions of the creation of objects and also to achieve high performance conservation/preservation of the artefacts inside the museum galleries. The latter provides a service for the museum which comprises the assistance to curators who need material facts for the attribution of their collection. The service also concerns the technical assistance before and during conservation work in order to identify the preservation state of the objects, the characterization of the various constituents and to map the zones where restorers have operated in the past.

RESEARCH AND DEVELOPMENT ON ANALYTICAL TOOLS

1. AGLAE

Shortly before her retirement in 1983, Madeleine Hours convinced the French Ministry of Culture to acquire a middle scale instrument based on a particle accelerator for a non invasive and direct analysis of works of art. At the time, Proton Induced X-ray Emission (PIXE) was the only elemental analytical method for characterizing the surface of objects. It was most likely considered appropriate due to its similarity to X-ray fluorescence, a technique which was widespread in museum laboratories. The project was developed once the Ministry of Culture had approved it. An international conference in Pont-à-Mousson (East of France) brought together during three days in February 1985 some eminent specialists in Ion Beam Analysis (IBA): Georges Amsel from the *Groupe de Physique des Solides* (University Pierre et Marie Curie, Paris 6), William Landford (USA), Klas Malmquist (Sweden), Pier A. Mando (Italy), among others. The results of the conference and the discussions were published in a special issue of the physics magazine *Nuclear Instruments and Methods* Section B.[4] Different aspects of how to achieve an optimized strategy for designing the system and the laboratory were discussed. Finally, it was decided to apply the various IBA techniques.[5] In February 1989, the laboratory was officially inaugurated by the French Ministers of Culture and of Research. From then on, the challenge of the engineer team lead by Joseph Salomon consisted in developing the IBA technique in air. The efforts of the team permitted them to achieve a unique system providing a particle microbeam (proton

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4 G. Amsel *et al.* "Overview of the discussions at the Prémontrés Workshop", *Nuclear Instruments and Methods B14.* 1986, pp. 162-167.

5 For the description of the IBA techniques see: *Ibidem*, pp. 30-37 and T. Calligaro, J.-C. Dran and J. Salomon. "Ion Beam microanalysis", in Janssens and Van Grieken (eds.): *Comprehensive Analytical Chemistry.* New York, Elsevier B.V., 2004, pp. 227-276.

or alpha particle) in air (or in helium at atmospheric pressure). The size of the beam is around 20µm in diameter.

The system based on a tandem accelerator 5SDH-2 from the American company Nuclear Electrostatics Corp. (NEC) is still the only one installed inside a museum and the only one devoted to the characterization of CH artifacts. The accelerator is inside a huge hall which is 35 m long, shielded by 1m concrete walls. A remote control of the machine and the experiments allow the researchers to operate under safe conditions. The team is now inserted in the international community of the IBA researchers participating in different events such as conferences (IBA, PIXE, Microbeams) and review papers. The recent paper written by the Florentine laboratory headed by Prof. P. A. Mando describes the importance of such systems for the study of Cultural Heritage.[6]

Many objects from different French museums such as paintings, drawings, ceramics, glasses, jewels, metals have been characterized thanks to the IBA techniques (PIXE, PIGE, RBS, NRA and also ERDA and IBIL), all performed in the air, at atmospheric pressure.

Today the team is composed of four engineers, each with a specific expertise: Claire Pacheco as the head, Brice Moignard as mechanical engineer, Laurent Pichon as electronic and software engineer, Quentin Lemasson as the local contact and IBA experimentalist.

The present challenge for the team is to complete the automation of the system in order to achieve new kind of experiments based on chemical IBA micro imaging. They succeeded in getting funds for the renewal of AGLAE. This should be a huge advantage not only for the C2RMF laboratory but also for all the colleagues hosted in the C2RMF who want to characterize in depth and in a non-destructive way their CH objects.

AGLAE was also a booster for different European projects such as Eu-Artech and Charisma, giving access to the European colleagues for IBA characterization of museum, historical monument and archaeological objects. Numerous applications have already been carried out and show the increasing interest in IBA characterization of CH works.

2. MOBILE CH LABORATORIES

Another impact of AGLAE is the development of specific methods adapted to the requirements of the museum objects: preciousness, impossibility to sample, heterogeneity and multi composite character. The AGLAE team is involved in the design, the realization and the applications of portable

6 P. A. Mando, M. E. Fedi and N. Grassi. ”The present role of small particle accelerators for the study of Cultural Heritage”, *Eur. Phys. J. Plus* Nº 126, 2011, pp. 41-49.

instruments, such as FORS (Fiber Optic Reflectance Spectrometry), X-ray diffraction combined with X-ray fluorescence (XRD-XRF), micro Raman analysis and 2D XRF imaging.

The interest lies in these instruments being prototypes in development, which are maintained and applied for very specific purposes with accurate achievements, in contrast with how it is mostly done when using commercial systems, which impose particular ways of carrying out the experiments.

Madeleine Hours' institution, the LRMF, promoted in the 1970's an ambulatory laboratory. The concept has recently been developed in the framework of the Eu-Artech and CHARISMA European projects: the Italian MOLAB designed by the Chemistry Department of the University of Perugia and the Italian National Research Center in Florence that carried out many projects all around Europe. More than 12 different analytical methods may be available for a specific project once accepted after the evaluation by a peer review panel.[7] A mobile laboratory has been completed in Cyprus for East Mediterranean projects by STARC from the Cyprus Institute, the STARLAB[8] and a French "Laboratoire Mobile" is now going to be finalized, coordinated by the LRMH, the French Research Laboratory for the Historical Monuments located east of Paris in Champs-sur-Marne,[9] inside which some portable instruments of the C2RMF will be installed if needed: XRD-XRF, FORS.

3. LARGE SCALE FACILITIES FOR CH

Simultaneously, in order to address important questions, the CH laboratories take advantage of the potential of larger facilities like synchrotron or neutron reactors centers. By taking samples from cultural objects, after a comprehensive study of the technical know-how of their production, the conservation scientists are inserted into the users community of the large scale facility centers and contribute to the applications of the powerful methods for determining, at the micrometer scale, the features enabling them to answer specific questions such as determining specific components in mixture, understanding the aging and alteration of the matter, operating micro X-ray tomography in order to visualize the inside of the artifact. The results of the experiments are presented particularly at the International conferences on Synchrotron radiation and neutrons in art

7 http://www.charismaproject.eu/transnational-access/molab.aspx.

8 http://www.cyi.ac.cy/starc/.

9 http://www.lrmh.fr/.

and archaeology (SR2A) organized every two years, the last venue having been Paris, inside the Louvre Museum, during 9-12 September 2014.

PLURI-DISCIPLINARY RESEARCH, THE CASE OF LEONARDO'S *MONA LISA*

The conservation science laboratories are associated with pluri-disciplinary research undertaken through collaborations with different partners from different and complementary disciplines. The C2RMF is thus associated or promotes much research which is aimed to increase expertise in authentication, to build crucial databases and to improve the assistance in conservation/restoration/preservation. That is what it takes to maintain the service at a high level. Hereby service and research are two missions closely tied to a conservation science laboratory.

The analysis of *Mona Lisa* is a good example for emphasizing the necessity of the collaborative project for understanding the complex conditions under which the work of art is created. At the same time working on such a famous painting attracts enthusiastic colleagues not only to work on this particular icon, but also and especially because it enables the improvement of particular methods which should benefit other objects, in this case painted wooden panels and polychrome sculptures. The results of a comprehensive research were published in a book intended to target a wide public.[10] This research, which is still ongoing, was the topic of a conference held at the National Gallery, London, about Leonardo's technical practice as a painter and draughtsman and the proceedings were published recently.[11]

The Mona Lisa project enables us to get a huge and comprehensive multispectral imaging of the painting.

Another achievement of the project was the full understanding of the origin of the original and secret Leonardo's *sfumato*. During his PhD work in physics carried out at the C2RMF, Guillaume Dupuis realized FORS measurements on the face of *Mona Lisa*.

The results allow us to formulate that the *sfumato* is carried out thanks to a thin glaze layer, finely colored with manganese oxide (burnt umber), the thickness of the glaze layer being related to the value and hue of the color and resulting from a delicate application on top of the carnation paint layer by Leonardo.

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10 J. P. Mohen, M. Menu and B. Mottin. *Mona Lisa. Inside the painting.* New York, Harry N. Abrams, Inc., 2006.

11 M. Menu (ed.). *Leonardo da Vinci's technical practice: paintings, drawings and influence.* Paris, Hermann, 2014.

CONCLUSION

The introduction of Natural Sciences in the fields of art history and conservation has already achieved important results. Indeed analytical chemistry and imaging techniques developed by the IT (information technologies) have proved the usefulness of their association. However more efforts should still be undertaken so as to get a definitive merging of the disciplines for building a new art history. Color is also a major challenge of the discipline, going beyond the sole chemical characterization. Of course this characterization is most important for understanding the technical knowhow of the artists and craftsmen from the past, but also for taking into account aging and alteration of the different constituent materials of the objects. Moreover to better understand the intentions of our ancestors, it is important to precise the physical properties of the matter, that is, the qualities sought out by the artists, such as, color, stability, and mechanical properties such as hardness. Such an extensive characterization is also fruitful for conservation and preservation and it fully corresponds to the missions of a CH laboratory. The future of the field will see the close association of experts in different Natural Sciences and IT with curators, art historians, librarians and conservators. Each discipline brings its own procedure for a complete art history and a scientific conservation and preservation of the objects inside museums and other cultural buildings and centers.

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