E-RIHS
EUROPEAN RESEARCH INFRASTRUCTURE
FOR HERITAGE SCIENCE

Scientific strategy

v1.0

The European flagship for the advanced scientific study of tangible cultural and natural heritage

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EUROPEAN RESEARCH INFRASTRUCTURE FOR HERITAGE SCIENCE

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Abstract (for dissemination)	The study and preservation of tangible cultural and natural heritage is a global challenge for science and society at large. The European Research Infrastructure for Heritage Science (E-RIHS) will play a leading role in research on the interpretation, preservation, documentation and management of heritage. As an interdisciplinary infrastructure, E-RIHS will interconnect knowledge and methodologies to address key scientific questions in the field of heritage as a whole. The infrastructure is built on ten core pillars. It will provide a structured and unified input of large-scale instruments, portable devices, physical and digital archives. Its implementation will focus on scientific excellence, interdisciplinarity and cooperation. In doing so, it will offer unprecedented research opportunities to a wide range of interdisciplinary scientific communities.
Keywords	E-RIHS, Scientific Strategy

Disclaimer: This document reflects the state of advancement of the preparatory work at the time of its delivery. As such, its content may be subjected to further evolution.

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EXECUTIVE SUMMARY

The study and preservation of tangible cultural and natural heritage is a global challenge for science and society at large. The European Research Infrastructure for Heritage Science (E-RIHS) will play a leading role in research on the interpretation, preservation, documentation and management of heritage. As an interdisciplinary infrastructure, E-RIHS will interconnect knowledge and methodologies to address key scientific questions in the field of heritage as a whole. The infrastructure is built on ten core pillars. It will provide a structured and unified input of large-scale instruments, portable devices, physical and digital archives. Its implementation will focus on scientific excellence, interdisciplinarity and cooperation. In doing so, it will offer unprecedented research opportunities to a wide range of interdisciplinary scientific communities.

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- E-RIHS PP Consortium. *E-RIHS PP Technical Annex, Call H2020-INFRADEV-2016-2017*. E-RIHS PP document. 2016, coordinated by Luca Pezzati,
- Athanasios Koutoupas et al. *Design, development and implementation of the dissemination and communication strategy*. E-RIHS PP Deliverable 10.1. Projet E-RIHS PP, Nov. 2017. URL: http://www.e-rihs.eu/wp-content/uploads/2018/09/ERIHS_D10.1def.pdf,
- Loïc Bertrand et al. *First version of the E-RIHS Scientific Vision*. E-RIHS PP Deliverable 9.1. Mar. 2018. URL: https://hal.archives-ouvertes.fr/hal-02138538 (visited on 08/28/2019),
- Mary Teehan et al. *Analysis of Innovation Background*. E-RIHS PP Deliverable 9.1. Feb. 2018. URL: http://www.e-rihs.eu/wp-content/uploads/2018/09/D_9_2_INNOVATION_V1_HQ-1.pdf (visited on 05/29/2019),
- Polonca Ropret et al. *Report on education and training needs*. E-RIHS PP Deliverable D7.1. May 2018. URL: http://www.e-rihs.eu/wp-content/uploads/2018/09/D7.1-E-RIHS-education-and-training-strategy.pdf,
- Claire Pacheco et al. *User strategies and access policies*. E-RIHS PP Deliverable D5.1. Jan. 2020,
- João-Manuel Mimoso et al. *E-RIHS Quality Manual and KPIs*. E-RIHS PP Deliverable D2.2. Jan. 2020,
- Holly Wright and Ray Moore. *Data Management Policy*. E-RIHS PP Deliverable D3.3. Jan. 2020,
- *The Catalogue of E-RIHS resources and services*, coordinated in the framework of T6.1 by Carlo Meghini (CNR), unpublished,
- *Cost-benefit analysis and socio-economic impact assessment of E-RIHS*, coordinated in the framework of T6.1 by Speranza Falciano (CNR), prepared by the Centre for Industrial Studies (CSIL), unpublished,
- *The Statutes of the E-RIHS ERIC*, coordinated in the framework of T4.2 by Isabelle Pallot-Frossard (CNRS, C2RMF), unpublished.

In addition, the following deliverables from the IPERION CH project were consulted:

- Marika Spring et al. *Description and plan for three proposed digital research resources*. IPERION HS Deliverable D8.3. Nov. 2016,
- Wim Fremout, Joseph Padfield, and Francesca Rosi. *Description and plan for pilot studies to document and present data gathered within MOLAB and FIXLAB*. IPERION HS Deliverable D8.2. Oct. 2016,
- Marika Spring. *Final report on foresight studies for identification of research priorities*. IPERION HS Deliverable D9.12. Oct. 2016,
- Piotr Targowski. *Final report on impact and innovation actions*. IPERION HS Deliverable D11.9. Oct. 2019,
- Marika Spring et al. *Report on round-table discussions and research reviews of the priority topic working groups*. IPERION HS Deliverable D9.7. Oct. 2019.

The list of main official references is given on page 9 and an extended list of bibliographical references is printed on page 75 onwards.

E-RIHS IN A NUTSHELL

The values of heritage sciences Heritage encompasses unique and fragile irreplaceable resources inherited from the past which people identify, independent of ownership, as a reflection and expression of their constantly evolving knowledge, values, beliefs and traditions. It includes all aspects of the environment resulting from interactions between people and places. As *commons*, heritage contributes to the attractiveness and the development of all cultures worldwide and to the creation of a more peaceful, durable and cohesive society. The European Commission recognises its economic and social value as a resource for economic growth, employment and social cohesion, identifying natural and cultural heritage as vectors to promote dialogue between diverse cultures and generations and as drivers for community regeneration.[1] In strengthening tangible heritage knowledge and interpretation and improving its dissemination and accessibility, E-RIHS has the potential to contribute to the promotion of shared understanding that significantly impacts the social cohesion and well-being of hundred millions of people.

Connecting skills and instruments to study tangible heritage Building on European's and the world heritage, E-RIHS will unify a diverse and fragmented landscape of instruments, institutions and collections to create synergies between complementary fields and allow advanced research of tangible heritage properties. State-of-the-art tools and services will be provided to interdisciplinary teams of users, in order to better contribute to research on heritage interpretation, preservation, documentation and management. These teams gathering social science and humanities scientists, material scientists (physicists, chemists, life scientists), curators, archaeologists, palaeontologists, data scientists and mathematicians, as well as other researchers will jointly develop crosscutting approaches for the study of heritage.

An array of complementary state-of-the-art resources E-RIHS intends to be a leading research institution introducing novel and efficient services, which will be gathered under the umbrella of four research infrastructures, and will each time include the related specialised expertise in the material study of heritage:

- Physical and digital collections such as objects, images, samples and reference materials, analytical data and conservation documentation (ARCHLAB)
- Digital tools and digital research resources concerning heritage and data (DIGILAB)
- Immovable equipment (FIXLAB)
- Portable or transportable instruments and other associated equipment for measurements on site (MOLAB)

Interoperability as a new standard One of the key benefits of E-RIHS will be to provide scientists, scholars and professionals with common access to instruments and data through unified entry points and harmonized procedures. Given the recent emergence of mass data processing, open and participatory science in this field, coupling with training activities is essential.

A critical benefit of E-RIHS will be to provide joint access, data and training through unified entry points and harmonised procedures to scientists, scholars and professionals. Given the recent emergence of the challenges of massive data processing, open and participatory science in this field, coupling with training activities is essential. E-RIHS will foster the development of a structured operational sequence for

[1] European Commission. *A New European Agenda for Culture*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2018) 267 final. May 2018. URL: https://ec.europa.eu/culture/policy/strategic-framework_en.

the interpretation and conservation of tangible heritage, seamlessly integrating data flows and training activities.

A deep impact on knowledge, society and the economy New instruments, protocols and methods have a decisive impact on the tangible study of material heritage, vastly improving our understanding and preservation of heritage objects and sites. E-RIHS will exploit already existing synergies between academia, research centres and cultural institutions while stimulating innovation with profesionnals. Dissemination of research and innovation will impact society and the economy.

Five core simplifications E-RIHS will bring five essential simplifications and improvements, all put in place to ensure the most efficient high quality research in heritage sciences.

1. A **single entry point** to facilities, instruments, collections and skilled professionals
2. An **independent, harmonised and streamlined evaluation** carried out by world-class experts, including for large-scale projects supported by funding agencies or heritage institutions and for exploratory projects
3. An integrated **training facility**, primarily on advanced analysis and open data sciences
4. An operational framework improving **physical interoperability** between instruments
5. An operational framework for **documenting, sharing and reusing standardised data**

A global dimension E-RIHS will further strengthen the position of Europe as a global player in heritage science. In this perspective, the proposal for establishing a Global Research Infrastructure (GRI) based on the E-RIHS partnership was submitted to the G7 Group of Senior Officials on global Research Infrastructures (GSO) in 2015.[2] On these issues, E-RIHS will closely work with the Joint Programming Initiative on Cultural Heritage[3], in developing cooperation policies at global and transnational levels. ICCROM and IAEA will also be relevant partners.

[2] GSO on Global Research Infrastructures. *Progress Report 2015*. Report. G7, Aug. 2015.
[3] JPI-CH, http://jpi-ch.eu/

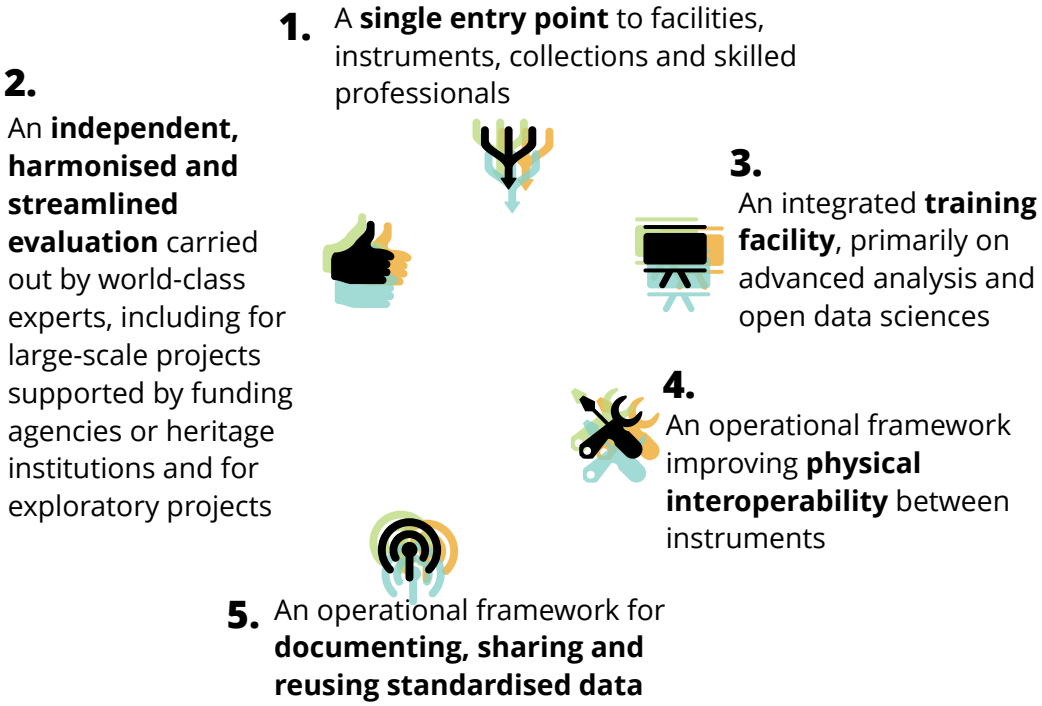

Figure 1.: The five core simplifications of the E-RIHS infrastructure

THE CONTEXT OF E-RIHS IN NUMBERS

84% of European citizens feel that cultural heritage is important to them.[1]

82% of European citizens take pride in historical monuments or sites, works of art or traditions from their region or country.[2]

20 000 000 people attend the European Heritage Days.[3]

In 2013, **52% of EU citizens** visited at least one historical monument or site and 37% a museum or gallery in their respective countries, while 19% visited a historical monument or site in another EU country.[4]

42 672 museums in Europe, including 11,578 Art, Archaeology and History museums, and 4,066 Science, Ethnology and Technology museums.[5]

As of June 2019, EU countries count 409 UNESCO World Heritage properties and Associated Countries to H2020 87, EU hosts **43% of the World Heritage Properties**.

1.5 billion specimens in European Natural History collections, standing for 80 % of the world bio- and geo-diversity.[6]

54 properties on the World Heritage List are currently threatened by natural disasters, excessive urban development, deforestation and logging, and by civil war, political instability and terrorism (e.g.: destruction of major sites in Syria like Palmyra or the ancient city of Aleppo during the Syrian civil war, threats of destruction by terrorist groups in Timbuktu and Gao in Mali).

In the Île-de-France Region of France alone, **92 laboratories** are active in Heritage Sciences with **731 scientists** having some activity in the field.[7]

5 000 scientists studying natural history in the EU.[8]

More than **6 000 000 cultural jobs** in the EU, accounting for nearly 3% of total employment.

Five core simplifications brought by E-RIHS in terms of access, long-term projects, data, physical interoperability and impact.

1 European Commission. *Special Survey on Cultural Heritage*. Eurobarometer 466. Brussels, BE, 2017. URL: http://data.europa.eu/euodp/en/data/dataset/S2150_88_1_466_ENG (visited on 08/28/2019).
2 European Commission, *Special Eurobarometer 466*, see n. 1.
3 European Commission. *Towards an EU strategy for international cultural relations*. Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2016) 477 final. 2014. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=JOIN:2016:29:FIN.
4 European Commission. *Preferences of Europeans towards tourism*. en. Flash Eurobarometer 432. Brussels, BE: European Commission, Mar. 2015. URL: http://data.europa.eu/euodp/data/dataset/S2065_432_ENG (visited on 05/29/2019).
5 Data extracted from the EGMUS database on 01 June 2019. No data for Cyprus, Malta and Slovenia.
6 DiSSCo. *Distributed System of Scientific Collections*. Research Infrastructure Outline. Feb. 2017. URL: https://www.dissco.eu/wp-content/uploads/dissco-outline-feb17.pdf.
7 Data: DIM Matériaux anciens et patrimoniaux, Région Île-de-France, Sept. 2019
8 DiSSCo, see n. 6.

The Scientific Strategy of the E-RIHS ERIC

FOREWORD

The European heritage sciences research landscape is globally recognised for the strength and concentration of its resources and expertise. It consists of an extremely active and culturally diverse network of institutions engaging a wide variety of scientific disciplines, applied to a broad range of cultural and natural heritage, from collections of individual works of art or historic objects to large scale archaeological sites, paleontological assets or historic buildings.

Research groups in the heritage sciences field generally gather scientists coming from diverse research environments, some of them belonging to large facilities or smaller research groups, other working as highly skilled individuals. These interdisciplinary teams are found in universities, research laboratories, heritage institutions such as museums and natural history museums, galleries, libraries and archives, and organisations responsible for the investigation and preservation of built heritage and archaeological sites. European research groups have pioneered the development of instruments and databases of unequalled quality, accessed daily by researchers from all over the world. This ecosystem is rich and creative, multidisciplinary and vibrant.

A better structuring of this research environment is a priority in order to maintain and develop the level of performance of European heritage sciences. By avoiding fragmentation and duplication of effort, a more structured activity would facilitate access by European and third countries research groups to instruments, collections, archives, data and expertise. Such access would be greatly facilitated by setting common standards and shared processes for the production, storage and sharing of data, using state-of-the-art approaches and newly implemented tools.

THE SOCIO-ECONOMIC CONTEXT OF E-RIHS

Heritage contributes deeply to European wealth and cohesion, and to the *joie de vivre* of its citizens, both in its tangible and intangible forms. Cultural and natural heritage plays a central role in European societies as a repository of scientific, cultural, economic, social and societal values. European people attach value to this legacy: around 84% of Europeans think that cultural heritage is important for them,[1] and a similar proportion think it is important for their region, their country and the European Union. Heritage contributes to developing a sense of belonging and promoting dialogue between cultures.[2] It is notably perceived as a way to reinforce European cohesion, a common ground for dialogue and a tool to build peace through cultural and scientific diplomacy.[3] Indeed, 70% of European citizens take pride in a site, work of art or tradition from a European country other than their own, and 82% of them agree that culture can play an important role in developing greater understanding and tolerance in the world, even where there are conflicts or tensions[4] (see also page xv).

By employing 7.8 million people a year, the heritage sector also holds significant economic potential.[5]

[1] European Commission. *Special Survey on Cultural Heritage*. Eurobarometer 466. Brussels, BE, 2017. URL: http://data.europa.eu/euodp/en/data/dataset/S2150_88_1_466_ENG (visited on 08/28/2019).

[2] European Commission, *A New European Agenda for Culture*, see n. 1.

[3] European Commission and High Representative of the Union for Foreign Affairs and Security Policy. *Joint Communication to the Parliament and the Council. Towards an EU strategy for international cultural relations.* Statute JOIN(2016) 29 final. June 2016. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016JC0029&from=EN.

[4] European Commission, *Special Eurobarometer 466*, see n. 1.

[5] Cultural Heritage Counts for Europe Consortium. *Full report*. Report. CHCfE, 2015. URL: https://www.europanostra.org/our-work/policy/cultural-heritage-counts-europe/.

Cultural tourism accounts for 40% of all European tourism, bringing in itself 142.4 billion euros in annual revenue to the European economy.[6] Heritage is also a source of new jobs at different levels of training and in various fields such as heritage restoration, instrumentation, and the dissemination of research results in museums. The Faro Convention calls for "full use of the potential of the cultural heritage as a factor in sustainable economic development".[7] This intrinsic economic and social value of heritage makes it an "irreplaceable repository of knowledge and a valuable resource for economic growth, employment and social cohesion [which] enriches the individual lives of hundreds of millions of people, is a source of inspiration for thinkers and artists, and a driver for cultural and creative industries".[8]

The vulnerability of heritage, as a key component of Europe's society, well-being, and economy, should not be underestimated. It has become a major concern for European decision makers, stakeholders and citizens.[9] Heritage objects and sites are indeed exposed to many risks from which they need to be preserved. Scientific investigation may help to better understand natural decay mechanisms pertaining artefacts as various as paintings, shipwrecks archaeological artefacts, or fossils, as well as their interrelation with their environment. They may bring a response to potentially irreversible damage caused by natural disasters and climate-related phenomena,[10] as well as human activities and conflicts.

The preservation of heritage for future generations is closely related to the question of its transmission. If heritage is positively considered by a vast majority of European citizens, more than one third of the European population is not taking part in any cultural activity.[11] Education, training and research activities have here a crucial role to play in making cultural and natural heritage more accessible and increasing cultural participation is thus an important challenge. The development of new technologies impacts this transmission in fostering new cultural practices, new discoveries and new modalities for their communication.[12]

The above-mentioned challenges require a broad array of local, national and European responses, which are a matter of education and research, as well as diplomacy, environmental policies and political action for the maintenance, restoration, accessibility and exploitation of heritage.

In the framework of the World Meeting on Heritage, Sciences and Technologies organised in Paris in February 2019, the Paris Declaration "Heritage, Sciences and Technologies: an Opportunity for our Societies and the Global Economy" called for action through the mobilisation of knowledge to improve the understanding, preservation and enhancement of cultural and natural heritage in order to promote sustainable development.[13] The signatories invited countries and institutions to include heritage studies in the mis-

[6] European Commission. *Cultural tourism*. Text. July 2016. URL: https://ec.europa.eu/growth/sectors/tourism/offer/cultural_en (visited on 09/20/2019).

[7] Council of Europe. *Framework Convention on the Value of Cultural Heritage for Society*. Treaty 199. 2005. URL: https://www.coe.int/en/web/conventions/full-list/-/conventions/treaty/199 (visited on 08/28/2019).

[8] European Commission. *Towards an integrated approach to cultural heritage for Europe*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee nd the Committee of the Regions COM(2014) 477 final. Brussels, BE: European Commission, July 2014. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0477.

[9] JPI CH. *The Joint Programming Initiative on Cultural Heritage and Global Change: a new challenge for Europe*. Vision Document. June 2010. URL: http://jpi-ch.eu/wp-content/uploads/Vision-Document_17-June-20101.pdf (visited on 05/23/2019).

[10] G7 Academies of Science et al. *Cultural Heritage: building resilience to natural disasters*. Joint statement of G7 Academies of Science. Academies of Science of G7 countries, May 2017. URL: https://www.academie-sciences.fr/pdf/rapport/2017_G7_Cultural_heritage.pdf.

[11] European Commission, *Special Eurobarometer 466*, see n. 1.

[12] JPI CH, *The Joint Programming Initiative on Cultural Heritage and Global Change: a new challenge for Europe*, see n. 9.

[13] French Academy of Sciences and IPANEMA. *Heritage, Sciences and Technologies: An Opportunity For Our Societies And The*

sion statements of research organisations, cultural institutions and funding agencies and interdisciplinary training and recruitment.

EUROPE AT THE FOREFRONT OF HERITAGE SCIENCES

Scientific research on cultural and natural heritage materials is a cornerstone in answering these challenges and tackling their consequences. As stated by the European Commission, "pooling resources in order to apply the latest technologies and stimulate new scientific approaches can greatly improve the understanding, preservation and dissemination of cultural heritage".[14] To address the multiple challenges that cultural and natural heritage are facing, the European Joint Programming Initiative on cultural heritage and global change has thus identified four priorities: developing a reflective society, connecting people with heritage, creating knowledge and safeguarding our cultural heritage resource.[15]

If both tangible and intangible heritage are the common wealth of our societies, E-RIHS addresses research on tangible heritage materials (artefacts, monuments, natural history collections, excavation sites, etc.), keeping in mind that the understanding and "preservation of cultural heritage link materials and their physical condition (tangible) to their cultural significance and meaning (intangible)".[16]

The application of science to the needs of tangible heritage research has a long history. The strength and concentration of the European heritage science research landscape has nowadays global recognition. It consists of an extremely active and culturally diverse network of institutions working in a wide variety of scientific disciplines, applied to a broad range of our heritage, ranging from collections of individual works of art or historic objects to large scale archaeological sites, paleontological assets or historic buildings. Heritage scientists are located in diverse research environments, ranging from entire research institutes (specialised or not) to research groups, or even individuals with unique expertise, located in research laboratories, in heritage institutions such as museums, galleries, libraries and archives, and organisations responsible for built heritage and archaeological sites. European research groups have pioneered the development of instruments and databases of unequalled quality, accessed daily by researchers from all over the world. This ecosystem is rich and creative, multidisciplinary and vibrant. Better structuring of this research environment remains a priority to maintain the competitive advantage of European heritage science through avoiding fragmentation, duplication of effort and isolation of small research groups.

ADDRESSING THE COMPLEXITY OF HERITAGE MATERIAL SYSTEMS

Thousands of objects from the exceptional collections of European museums, galleries, libraries and archives are studied, interpreted and preserved. The British Museum has one of the most impressive collections of objects, gathering more than 8 million items from all over the world. At the end of 2017, 230 research projects were conducted in parallel at the Louvre, which collection includes 450 000 objects and works of art. Imaging techniques such as X-ray microtomography can be applied to small samples of stone, wood, or stained glass to determine their composition and properties, thus providing information on artistic techniques. On the other hand, 2D imaging methods such as X-ray scanning fluorescence or UV

Global Economy. Declaration. Institut de France, Paris, Feb. 2019. URL: http://ipanema.cnrs.fr/IMG/pdf/paris_declaration_15_feb_2019_en_fr_20190214-final2-2.pdf.

[14] European Commission, *Towards an integrated approach to cultural heritage for Europe*, see n. 8.

[15] JPI CH. *Strategic Research Agenda*. Report. 2014. URL: http://jpi-ch.eu/about-us-2/strategic-research-agenda/ (visited on 05/23/2019).

[16] JPI CH, *Strategic Research Agenda*, see n. 15.

photoluminescence provide high-resolution maps of entire sections of chemically complex and altered materials to understand how they are manufactured and how they are altered. Monuments, buildings, archaeological and palaeontological sites can now be scientifically probed using innovative techniques that require complementary skills and knowledge from a range of disciplines. Advanced techniques are used by multidisciplinary teams including physicists, chemists, conservation specialists and art historians. Such a collaboration between natural sciences, humanities, conservation and restoration is necessary to establish diagnoses on materials, to develop new restorative treatments, or else to reduce risks due to heating or mechanical stress.

This interdisciplinary work results in both thousands of studies and large-scale major international projects that gather a large number of laboratories and institutions from all over Europe. Indeed, the study of heritage systems involves numerous specific projects and measurement campaigns, which aim at answering questions on objects (provenance, authenticity, technology of manufacture or artistic technique, trade routes, deterioration mechanisms, etc.). Such analytical programmes are at the heart of the work of heritage science laboratories. A relatively recent new development is the emergence of large collaborative projects (funded by ERC, the EU framework programmes, national and regional programmes) such as the Horizon2020 Nanorestart and Nanocathedral programmes,[17] and of national or regional networks and funding programmes supporting clusters of coordinated research projects under specific strategic themes.[18] These programmes incidentally came across the need to better articulate *object-driven* and *problem-driven* research. For instance the Nanorestart programme[19] couples the development of innovative materials for conservation with testing on artworks by conservators in the course of the project, and training of the end-user community. Such a programme could have thoroughly benefited of a significantly facilitated and coordinated access to advanced instrumentation for analytical characterisation and instrumental development in its course.

Scientific questions raised in heritage science are particularly complex. Indeed, heritage materials are not model materials for which the analytical parameters are known *a priori*. Considered from the point of view of the material constituents, heritage objects and sites are intrinsically *heterogeneous*. In addition, they have been subject to *ageing*, use and deterioration under diverse and unknown conditions over many

[17] European Commission. *NANOmaterials for the REStoration of works of ART (NanoRestart)*. Cordis Entry. 2019. URL: https://cordis.europa.eu/project/rcn/196839/factsheet/en (visited on 09/05/2019); European Commission. *Nanomaterials for conservation of European architectural heritage developed by research on characteristic lithotypes (Nano-Cathedral)*. Cordis Entry. 2019. URL: https://cordis.europa.eu/project/rcn/196845/factsheet/en (visited on 09/05/2019).

[18] Examples of such national and regional networks and funding programmes are:

- The Dutch programmes MOLART – *Molecular Aspects of Ageing in Art* (1995–2001), *De Mayerne* (2002–2006), *Science4Arts* (2012–2018) and the NICAS – Netherlands Institute for Conservation, Art and Science funded by the *Science for Arts of the Netherlands* initiative of the Dutch research funding agency since 2014,
- The French programmes PNRCC – *Programme national de recherche sur la connaissance et la conservation des matériaux du patrimoine culturel*, and following initiatives in particular the PATRIMA Labex (2011–2019), the Fondation des Sciences du Patrimoine, and the key research sector *DIM Matériaux anciens et patrimoniaux* (Île-de-France Region, 2017–2020),
- The *Science and Heritage* programme, funded by the Arts and Humanities Research Council and the Engineering and Physical Sciences Research Council in the UK (2007-–2012).
- The TechnoHeritage Network (*Red de Ciencia y Tecnología para la Conservación del Patrimonio Cultural*), created in 2010 to coordinate and integrate activities in the Heritage Science domain carried out within CSIC, universities, cultural institutions and industries, with support up to 2019 by the Spanish Science Ministries MICINN and MINEICO. The Interdisciplinary Thematic Platform *Patrimonio Abierto: Investigación y Sociedad*, PTI-PAIS [Open Heritage: Research and Society], has been recently approved by the Spanish National Research Council (CSIC). The mission of the platform is the study and conservation of material cultural heritage through advanced and interdisciplinary scientific and technical research and in collaboration with heritage institutions, cultural industries and public and private stakeholders.

[19] European Commission, *NANOmaterials for the REStoration of works of ART (NanoRestart)*, see n. 17.

years, decades or even millennia. Heritage materials are fragile and their integrity must be preserved. Safety must be guaranteed throughout the analysis process, from sampling to adapted analysis protocols, using a well-defined, consistent, risk management process to minimise the potential for loss or damage. As a consequence, experiments on heritage materials cannot be easily reproduced, especially when valuable artefacts are studied. The scientific study of heritage materials is therefore especially challenging.

THE CREATION OF E-RIHS

In 1999, the European Commission started supporting the integration of advanced scientific instruments and data repositories for heritage investigation that has continued uninterrupted since then.[20] E-RIHS results from a long-term tradition of coordination in European heritage research, combined with the ability to develop societal and industrial innovation. It is part of the integration process implemented by major EU-funded research infrastructure projects, such as LabS TECH, EU-ARTECH, CHARISMA and IPERION CH / IPERION HS in conservation science, ARIADNE / ARIADNEplus in archaeology, and SYNTHESYS in natural history.

Since EU-ARTECH, these research infrastructure projects have piloted transnational access to the instruments, resources, expertise and data shared by the participating partners. Major research projects funded by the different framework programmes of the European Commission and by Member States have contributed to structuring the heritage science community, which has been designated as an "advanced community". Consequently, a proposal has been submitted to ESFRI in order to establish a permanent European research infrastructure dedicated to heritage sciences as a key supporting element of the European Research Area (ERA). This initiative was supported by the JPI CH strategic agenda, which describes "Knowledge Sharing and Research Infrastructure" as one of the three priority enabling activities in the field of cultural heritage..[21]

E-RIHS was selected as one of the six new projects on the 2016 ESFRI Roadmap.[22] It is yet the only Research Infrastructure project in the Social and Cultural Innovation section.[23] The preparatory phase of E-RIHS was launched in 2017 and will last until September 2020. The preparation phase addresses the governance, the scientific strategy, the clarification of the financial aspects, and the writing of the draft legal documents of the infrastructure. It is supported by the EU project E-RIHS PP.[24]

DEFINING AN IDEAL OPERATING CHAIN FOR TANGIBLE HERITAGE

The specifics of the field have impact on the entire research process, requiring that **the tangible heritage itself is put at the heart of the whole rationale**.

The European Research Infrastructure for Heritage Science (E-RIHS) will be **the European flagship for the advanced scientific study of tangible cultural and natural heritage** (artefacts, monuments, natural history collections, excavation sites, etc.). This unique infrastructure will contribute to major research

[20] European Commission. *Mapping of Cultural Heritage actions in European Union policies, programmes and activities*. Policy Document. Aug. 2017. URL: https://ec.europa.eu/culture/sites/culture/files/2014-heritage-mapping-version-2017_en.pdf.

[21] JPI CH, *Strategic Research Agenda*, see n. 15.

[22] ESFRI. *Strategy Report on Research Infrastructures. Roadmap 2016*. Strategy Report. 2016. URL: https://www.esfri.eu/roadmap-2016 (visited on 09/04/2019).

[23] ESFRI. *Strategy Report on Research Infrastructures. Roadmap 2018*. Strategy Report. Aug. 2018. URL: http://roadmap2018.esfri.eu (visited on 09/04/2019).

[24] H2020-INFRADEV-2016-2017, Grant Agreement ID 739503, https://cordis.europa.eu/project/id/739503

projects on heritage carried out by European teams in a structured manner, through a coordinated array of fixed and mobile instruments, interdisciplinary expertise and research resources in the form of databanks of sector-specific high-level knowledge held at world-class institutions. E-RIHS will tightly connect all stakeholders and help structure the whole of the tangible heritage research sector, the research communities, heritage institutions like museums and galleries, citizens and industries.

Given the importance of the issues at stake, working collaboratively on these projects is essential. As the European Research Infrastructure for Heritage Science, E-RIHS will intervene when the synergy of collaboration between national facilities makes it possible to address extraordinary cross-disciplinary research questions related to the history, interpretation, diagnosis and preservation of cultural and natural heritage. As the first endeavour on this scale to be 100% devoted to heritage tangible research, **E-RIHS will put the tangible heritage itself at the heart of its day-to-day operation, from sample preparation to data treatment**, by recognising the specificity of the scientific field and their impact on the entire research process.

New solutions to ensure interoperability are needed to enable the fullest possible use of instruments and data to contribute to a demanding heritage research, by elaborating seamless protocols to allow research to develop in all its interdisciplinary dimensions. In particular, this requires simplifying access procedures, while allowing physical interoperability to facilitate the use of complementary instruments throughout the same study. The documentation of data is a priority through the establishment of agreements on vocabularies and the structuring of metadata. Professionals should have equal opportunities of access to E-RIHS means, within research consortia.

E-RIHS will therefore contribute to the creation of a common 'operating sequence' in heritage science. This will further favour integration, understood as the transition from separate research infrastructures to a single distributed infrastructure. E-RIHS will operate a transparent selection process, that will be kept as simple and short as possible, and close attention will be paid to user support. An international peer review panel of external renowned experts will conduct the European evaluation phase. The other steps of the evaluation process, including feasibility / security assessments, will be dealt by each facility. E-RIHS will foster interoperability of instruments to fully exploit the capacities of the research infrastructure and to match the needs of the scientific community.

THE SCIENTIFIC STRATEGY v1.0

The present *Scientific Strategy v1.0* aims to present the context and the main strategic lines of the future E-RIHS infrastructure to its stakeholders and scientific communities, providing an overview of the commonly agreed principles and background information. It applies to the first years of operation of the infrastructure. The list of entering facilities is not known at this early stage of the definition. It is therefore fundamental that a review process is put in place that will allow a strategic review of these activities, at least every ten years, following the common practice established at single-sited large-scale facilities.

The document is divided into five chapters:

➲ **Chapter 1** describes the main scientific drivers for the E-RIHS infrastructure.

➲ **Chapter 2** presents the ten pillars that are at the heart of the ERIC E-RIHS operation. They have been developed to meet the needs of the user community and are based on core values that guide heritage

research in practice.

➲ **Chapter 3** describes the physical infrastructure of E-RIHS through its four platforms gathering physical archives, fixed instruments, mobile instruments and digital archives.

➲ **Chapter 4** details the main procedures developed to allow the most efficient operation of E-RIHS taking into account the core principles of E-RIHS (Chapter 2) and its physical infrastructure (Chapter 3).

Analyses of the main impacts of E-RIHS on science, innovation and society are currently part of additional documents from the preparatory phase of E-RIHS.

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1. SCIENCE DRIVERS

INTRODUCTION

The E-RIHS infrastructure will specifically address research on **tangible heritage**, keeping in mind that the understanding and "preservation of cultural heritage link materials and their physical condition (tangible) to their cultural significance and meaning (intangible)".[1] Thousands of objects from the exceptional collections of European museums, galleries, libraries and archives are continuously studied, interpreted and preserved. Monuments, buildings, archaeological and paleontological sites can now be scientifically probed using innovative techniques that require complementary skills and knowledge from a wide range of disciplines. This results in **thousands of object-centric studies and large-scale major international projects** gathering a large number of laboratories and institutions involved in the diagnostics, conservation and digitisation of heritage resources, and generating massive data sets.

The complexity of the study of heritage is due to the fact that the analytical parameters are not known *a priori* for the study of ancient and historical materials. Ancient systems are intrinsically heterogeneous and their constituents have been subjected to ageing and deterioration under diverse and unknown conditions over time, but it is these same alterations that lead in turn to unique clues about their use and the mechanisms that conducted to their preservation. Heritage materials are fragile and precious: their integrity and safety must be preserved throughout the analysis process, from sampling to appropriate protocols, using a well-defined, consistent, risk management process to minimise the potential for loss or deterioration. Due to their heterogeneity and vulnerability, heritage materials are not easily accessible to standardised analysis. These constraints have an impact on the entire research process, which requires that tangible heritage itself be placed at the heart of the whole rationale. The scientific study of heritage materials is therefore particularly challenging and inspiring.

To meet this challenge, researchers need to develop tools, processes and methodologies, coupling technology and disciplines, matching research questions and technologies. E-RIHS will address these questions in a context of open science, enhancing our general knowledge on heritage, increasing our capacity to address environmental changes and security risks threatening tangible heritage, and making it more accessible to European citizens.

Heritage science projects raise crucial questions related to cultural and natural heritage materials.

Improving knowledge of heritage systems involves understanding their origin and technical context, evolution and history, circulation and use, as well as the political, cultural or symbolic values they embody (➲ **Enhancing Knowledge of Heritage**, p. 12). The study of the deterioration of heritage objects over time, the diagnosis of their current state and the development of means to ensure their conservation and restoration is a necessary undertaking to enable their transmission to future generations (➲ **Preserving Heritage**, p. 14). The creation of E-RIHS in itself contributes to the sustainability of heritage science (➲ **Developing New Capabilities for Heritage Science**, p. 16). The following list of scientific questions is not intended to be exhaustive, but to provide an overview of some of the critical issues that are expected to benefit from E-RIHS in action.

[1] JPI CH, *The Joint Programming Initiative on Cultural Heritage and Global Change: a new challenge for Europe*, see n. 9.

1.1. ENHANCING KNOWLEDGE OF HERITAGE

How were artworks and monuments created? The study of art materials is a field of investigation shared by historians, art historians, natural scientists, data scientists and heritage artefact specialists such as curators and restorers. Multidisciplinary approaches combining the research on historical sources and experimental analysis make it possible to reconsider artistic creation through the understanding of art materials, tools and techniques (Example 1.1). With its wide array of specialised methods and expertise, E-RIHS will facilitate the identification of the materials constituting the works of art by crossing analytical and historical approaches, and participate to the active interdisciplinary communities working on artwork history, technical history, by supporting work that revisit concepts of practice and authenticity.

Example 1.1.: Macro XRF Scanning of Van Eyck's Ghent Altarpiece

A combination of large-scale and micro-scale elemental imaging, yielding elemental distribution maps obtained by, respectively, non-invasive macroscopic X-ray fluorescence (MA-XRF) and by secondary electron microscopy/energy dispersive X-ray analysis (SEM-EDX) and synchrotron radiation-based micro-XRF (SR μXRF) imaging was employed to reorient and optimize the conservation strategy of van Eyck's renowned Ghent Altarpiece. The chemical maps nourished the scholarly debate on the overpaint removal with objective, chemical arguments, leading to the decision to remove all skilfully applied overpaints, hitherto interpreted as work by van Eyck.

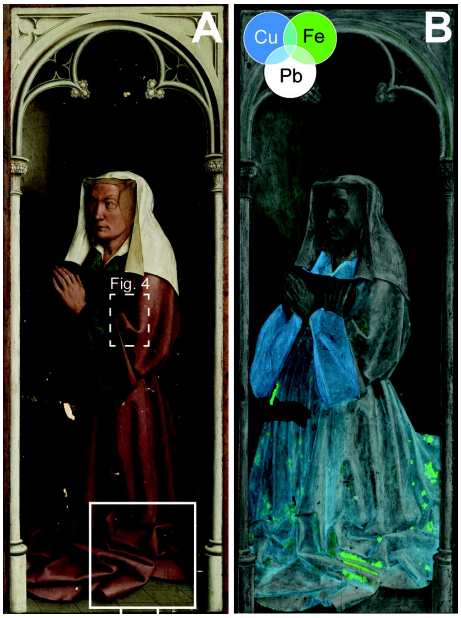

Figure: A) Donor portrait of Elisabeth Borluut. B) Composite elemental image showing the distribution of copper (blue), iron (green), and lead (white).

Geert Van der Snickt et al. "Large-Area Elemental Imaging Reveals Van Eyck's Original Paint Layers on the Ghent Altarpiece (1432), Rescoping Its Conservation Treatment". In: *Angewandte Chemie International Edition* 56.17 (2017), pp. 4797–4801

MA-XRF

How can we identify past social, economic and cultural contexts? The archaeological artefacts and works of art that reach us today constitute authentic archives of the socio-economic, environmental and cultural context in which they were produced. These testimonies of the past must be decoded to decipher the social, economic and cultural life of our predecessors. Heritage and archaeological experimentation inform us about the evolution of objects and contexts over time, and question the adequacy of material models (e.g., "historically accurate reconstructions"). In tight connection with the study of individual objects and sites, such exploration requires the transversal knowledge, intercomparison and interpretation of collections on a wide scale, which E-RIHS will enable by providing multidisciplinary teams of users with coordinated access to archives and collections and by facilitating data intercomparison and interoperabil-

ity.

How did production practices evolve? The cultural history of technical practices is accessible through the characterisation of operating chains (materials, gestures and systems), the analysis of their transmission and dissemination, the study of the production, exchange and consumption networks, which constitute major axes of research in anthropology, archaeology and the economic and social history of techniques. In these fields, the interdisciplinary study of ancient materials is crucial. It reveals the selection of resources made by human beings in their environment, the evolution of the techniques they used, the function and the economic and symbolic value of the objects they created. These studies require the establishment of reference systems (experimental, archaeological or ethno-archaeological), the use of written sources where they exist, the application of physical, geochemical or biological analysis and the processing of statistical data, including modelling. E-RIHS will provide analytical tools that allow studying the traces of these practices in tangible artefacts.

What are the origin and evolution of life and humankind? The last decade has seen significant advances in study techniques and analytical methods or traces of ancient life (DNA, biominerals, proteins and sugars, other traces). They allow characterising the morphology of extinct species (particularly through 3D imaging), as well as their chemical or mineralogical composition. These advances have considerably increased the information that can be extracted from these objects and have brought new concepts based on new morphometric data from high-resolution 2D and 3D imaging (Example 1.2). These works provides new clues on the origin of life and contribute to elucidating evolutionary mechanisms. They help to understand variations in past biodiversity, and the anthropogenic impact on ancient environments (changes in erosion and sedimentation, palaeo-pollution). They contribute to shedding new light on the ways ecosystems have responded to environmental changes.

Example 1.2.: Imaging Rare Earth Distribution Within Paleontological Specimens

In specific contexts fossils are conserved in an exceptional state, that preserve soft tissues such as muscles or other organs. Nevertheless, their interpretation remains particularly difficult because of the limited contrast achieved using microscopy. A new non-destructive and non-invasive approach based on rare earth elements differential localization has been used to study flat fossils which interpretation is often very difficult. Using 2D synchrotron XRF imaging, we imaged well-preserved fishes and shrimps from the Late Cretaceous of Morocco (100 million years). The contrasting elemental distributions greatly improved the discrimination of "hard tissues" (bones or carapaces) from both the sedimentary matrix and the "soft tissues". Rare earth elements imaging reveals previously hidden anatomical features in a peculiar fossil fish, only know from a unique specimen.

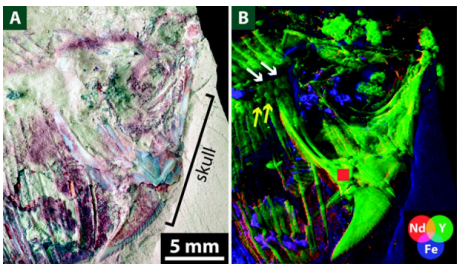

Figure: Visualisation of the anatomical details of a newly discovered fish from the Cretaceous of Morocco using XRF mapping. (A) Optical photograph of the anterior part of the fish (skull is on the right). (B) False colour overlay showing the concentrations of Iron (blue) and the rare earth elements Neodymium (red) and Yttrium (green).

Pierre Gueriau, Sylvain Bernard, and Loïc Bertrand. "Advanced Synchrotron Characterization of Paleontological Specimens". en. In: *Elements* 12.1 (Feb. 2016), pp. 45–50. ISSN: 1811-5209. DOI: 10.2113/gselements.12.1.45. (Visited on 09/03/2019)

IPANEMA and DiffAbs beamline at the SOLEIL synchrotron

1.2. PRESERVING HERITAGE

How do we assess object condition and alteration up to molecular level? Advanced material analysis provides a deeper understanding of the effects of time, deposition conditions and conservation methods on heritage materials and archives. They optimise the benefit of geochemical and molecular analysis towards the most relevant interpretation. In particular, better understanding the effects of treatments for stabilisation, restoration and protection is a critical challenge (Example 1.3), as is the ability to contribute to research that would provide innovative ways to conserve objects, making use for instance of condensed soft matter chemistry. European research teams stay at the forefront in the study of alteration processes affecting artefacts from historical and natural history collections. The specific expertise of European research teams covers the understanding of the behaviour of metals, glass, stones, pigments (such as metal soap formation), fossils, and a wide range of other art, archaeological and paleontological material.

Example 1.3.:
Optical Coherence Tomography to Investigate Rubens Canvases at Whitehall Palace

The set of nine ceiling paintings created by Rubens and studio (1636) is one of the largest and most complex works by the master surviving in-situ. Due to many undocumented past restorations a detailed survey of the state of preservation was needed. Thickness and structure of varnishes were resolved; delaminations as well as retouchings from former restoration campaigns were detected. Different build-up of varnish layers due to past selective cleaning treatments was found in many places and linked do discolourations of the surface. Optical coherence tomography (OCT) is a non-invasive method of structural imaging, providing virtual cross-sections of the build-up of sub-surface layers. It substitutes microscopic analysis of samples thus enabling structural examination of the heritage object in unlimited number of areas.

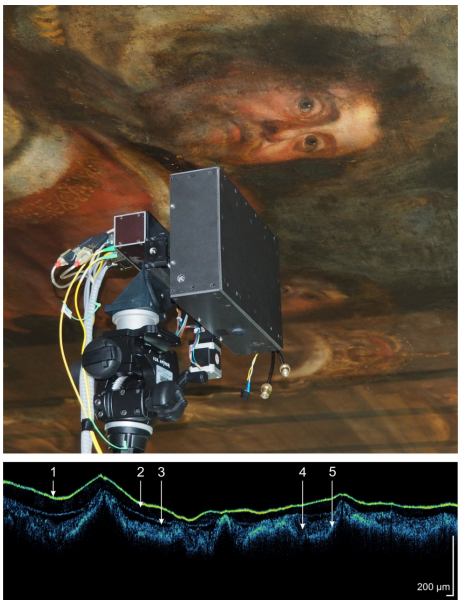

Figure: OCT examination of The Apotheosis of King James I, P. P. Rubens, Whitehall Palace, London with the instrument facing up (top, photo P. Targowski) and the resultant cross-sectional image (bottom).

In the OCT cross-section: 1 - surface of the painting; 2, 3 - two varnish layers; 4 - glazes; 5 - surface of an opaque paint layer.

Constantina Vlachou Mogire et al. "A non-invasive multi-technique investigation of Banqueting House Whitehall Rubens ceiling paintings". In: *Microchemical Journal* (2020), p. 104797
MOLAB access: RUBENS TCR BHW (project leader: Dr Constantina Vlachou-Mogire, Historic Royal Palaces Conservation and Collections Care Department, Hampton Court Palace, Surrey KT8 9AU, UK)

How to prevent risks and inform conservation with hard evidence? The advanced study of alteration and decay processes relies on the combination of advanced material analysis, *in situ* diagnosis of objects and time-based monitoring, coupled to the ability to model the physico-chemical behaviour of complex materials under realistic conditions of exposure, storage or treatment. E-RIHS will thus contribute to the development of factual and measurable evidence for improved preventive conservation measures and the development of new conservation protocols and materials, including the study of the intricacies of artifi-

cial ageing, the prediction of future changes, risk assessment (such as the development of integrated *risk maps*, Example 1.4), support for the development of alternative preventive conservation measures, and better information on valuable modern works of art that have not yet proven their stability. The strength of the E-RIHS partnership will rely here on the importance of imaging methods in E-RIHS, portable instrumentation that can be deployed on site, and increased data interoperability.

Example 1.4.: A Risk Map of Van Gogh's Sunflowers

Van Gogh's Vase with Sunflowers painting held in the Van Gogh Museum in Amsterdam is an icon of Western art. The chrome yellow paints used by the artist are prone to degradation which may result in a risk of colour change over time. Identifying the type of chrome yellow paints and their mechanisms of degradation allows scientists to determine the original state of the painting, while detecting the areas of the surface of the painting that call for careful monitoring over time. Macroscopic X-ray fluorescence scanning (MA-XRF), portable reflection mid-FTIR and Raman spectroscopy showed a degradation process of Cr(III) compounds, including the lightfast $PbCrO_4$ and the sulfur-rich $PbCr_{1-x}S_xO_4$ ($x = 0.5$) variety, known for its high propensity to undergo photoinduced reduction, at the interface between the paint and the varnish. The darkening of chrome yellow, caused by the photo-reduction of original chromates to Cr(III)-compounds, is favoured when the pigment is present in the S-rich form of $PbCr_{1-x}S_xO_4$ ($x > 0.4$, also called light sensitive chrome yellow).

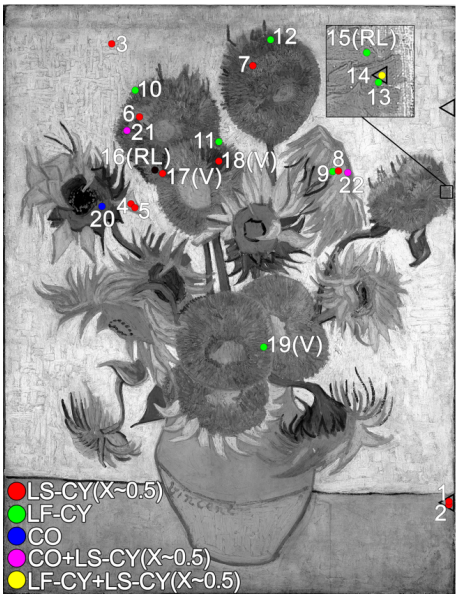

Figure: Raman distribution of different chrome yellow types. Vase with sunflowers, Van Gogh, date, inventory number, Van Gogh Museum, Amsterdam.

LS-CY: light-sensitive chrome yellow; LF-CY: lightfast chrome yellow monoclinic; CO: chrome orange; V and RL: spots also containing vermilion and red lead; white square: only red lead; triangles and roman numerals: regions of FTIR analyses.

Letizia Monico et al. "Evidence for Degradation of the Chrome Yellows in Van Gogh's Sunflowers: A Study Using Noninvasive In Situ Methods and Synchrotron-Radiation-Based X-ray Techniques". In: *Angewandte Chemie International Edition* 54.47 (2015), pp. 13923–13927

How do sites transform in the context of global change? Recent work shows the importance of palaeoenvironmental studies in understanding site formation and artefact / ecofact degradation. The implementation of new quantitative analysis methods to monitor the evolution of materials over time gives a complete vision of the site's origin, homogeneity and value, highlighting the way assemblages are forming. This approach requires to know the mechanisms of material transformation (archaeological remains, biological remains, paleontological objects), their origin (continental or marine environment and heritage collections) and the evolution (amplitude and speed) of the preservation conditions.

How to develop new materials and methods for conservation and in-situ preservation of heritage? The conservation of materials, from museum objects to natural history fossils, requires a material preservation strategy based on a multidisciplinary approach, combining at least the humanities, material sciences, biology and environmental sciences. It is essential to understand entire alteration systems by studying

complex material-environment interactions. To take into account the heterogeneity of materials while preserving the integrity of objects, research is based on multi-scale, micro or non-destructive analyses. They are also based on the study of model samples, which makes it possible to formulate hypotheses of mechanisms. Kinetic parameters are used as input data to feed alteration models, which are validated by analyses on corpora of heritage objects. The preservation of the materials that constitute the objects is directly related to intangible cultural values. Gathering state-of-the art instrumentation and methodologies specifically devoted to non-invasive analysis of valuable objects, E-RIHS will further help develop expertise and training on these very peculiar methods and favour the exchange of valuable data to be applied to the preservation of heritage.

1.3. DEVELOPING NEW CAPABILITIES FOR TANGIBLE HERITAGE

How do we build long-term multidisciplinary capabilities and research environments? E-RIHS will be a model infrastructure providing creative tools and new ways of generating scientific information and knowledge. E-RIHS will support short and medium term research projects, as well as exceptional large-scale projects, which typically require analytical support through multiple access visits to different facilities on the same or different platforms. These long-term partnerships will play a key role in building long-term research capacity in the community beyond the existing fragmentation of the heritage research field. Object-oriented studies will facilitate the joint participation of multidisciplinary scientists. E-RIHS can be considered as a whole as a *training facility*: experimental time at large-scale and mobile facilities, as well as time for consultation and access to physical or digital archives, will provide original means of training. Exchanging within research teams provides an extremely efficient mutual training (Example 1.5). The close interconnection of DIGILAB with MOLAB and FIXLAB will play a key role in strengthening heritage research by promoting the implementation of controlled analytical sequences, ensuring data structuring and sharing around each interdisciplinary project.

How do we accelerate the transfer of top-level instrumentation to research communities? Novel instruments, workstations and techniques emerge continuously as a result of technological innovations and enable scientists to address challenging analytical problems. But often the diffusion of novel tools to other research communities, for instance in the field of heritage sciences, is often slow despite the fact that relevant technical and methodological adaptations demonstrate that such tools enable alternative, often improved, capabilities concerning the compositional characterization of materials and objects (Example 1.6). Getting through such a bottleneck and making top-level instrumentation accessible to user communities requires scientists in access providing facilities to work together with potential users in order to identify those key areas of application where the use of such a new tool will provide distinct advantages. Once these two factors (providers and users) combine efforts in an environment of co-creation further improvements can be achieved concerning instrumentation and/or methodology. This provides further opportunities for exploring additional questions, engaging more users and eventually broadening the domains of application.

The digitisation of collections and scientific results is a challenge going far beyond heritage sciences. In the framework of E-RIHS, the digital world will function as a nucleating place where different means (instruments, expertise, data) foster innovative approaches, methodologies and projects.

Example 1.5.: Sharing dynamic sets of images using IIIF

*The IIIF (*https://iiif.io/*) standard describes a method of disseminating born digital and digitised heritage images for research and engagement. Static descriptions of individual or groups of images can be used to present images using a wide range of freely available IIIF compliant software.* A process was developed to dynamically create IIIF descriptions based on search results, all works "by a given artist" or "in a current location", etc. This work was the basis of the development of a public image re-use system, https://media.ng-london.org.uk, and continues to be exploited. IIIF descriptions, or manifests, are based on a well-documented template, which defines the types, formats and organisation of data required to present images. The work carried out within this project involved building mapping functions, which could format simple search results, returned from existing databases, and use them to construct dynamic IIIF manifest. Further work constructed a web service to return these IIIF manifests based on web searches or via resolvable web links, which incorporated new persistent identifiers. The entire system was then directly exploited to serve a prototype mobile guide application, developed within the H2020 project CrossCult, https://www.crosscult.eu/.

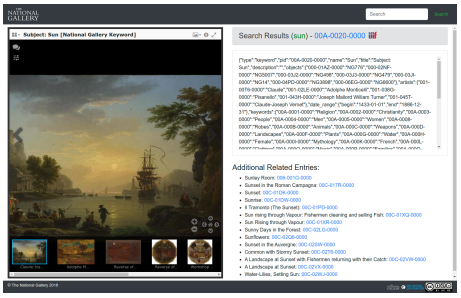

Figure: A screenshot of the National Gallery public IIIF API website, demonstrating the results returned from a search for the keyword "sun". All the images included in the related IIIF manifest are displayed in the IIIF Mirador viewer on the left.

This page can be accessed at https://media.ng-london.org.uk/iiif/examples/&search=sun and the IIIF manifest can be seen at https://media.ng-london.org.uk/iiif/00A-0020-0000/manifest.json

How do we favour curiosity-driven research? By opening up the data generated by state-of-the-art instruments, E-RIHS will encourage fruitful interactions at two critical stages of the research projects: (i) during the life of the project by allowing efficient interaction of interdisciplinary teams, (ii) offering a second life for research data beyond the original projects that generated them. Interoperability and openness of data and science is therefore at the heart of this logic, which will encourage *curiosity-driven* (as a complement to question-driven) research. The interoperability provided by the consistent use of metadata will allow for *transversal* study of large datasets, which is all the more necessary since understanding our past requires in-depth cross-comparison of art, natural history and archaeological collections that are disseminated, and sometimes isolated, across a range of institutions in Europe and beyond. Cross-comparison today requires considerable effort to enable detailed comparison where acquisition protocols and data cannot be easily intercompared. This will also allow better cross-validation of experimental results and their interpretation.

Example 1.6.: Ultrashort Laser Microscopy to Measure Thickness of Acrylic Overpaints

Phthalocyanine acrylic paints are often found in historical paintings as pictorial retouchings. Determination of the thickness of these acrylic layers, without sampling and in a non-invasive way, constitutes an important aid in cleaning interventions. The thickness of copper phthalocyanine paint layers was determined using the technique of Nonlinear Optical Microscopy (NLOM) under the modality of Multi-Photon Excitation Fluorescence (MPEF). Values obtained showed consistency with those retrieved through Optical Coherence Tomography. NLOM is a technique developed to achieve high quality imaging in scattering environments. The instrument, a scanning nonlinear optical microscope, uses a near-infrared laser giving pulses of femtosecond duration that is strongly focused inside the substrate under study with a high numerical aperture objective lens. In the modality of MPEF, the signal generated in the focal volume of the laser is detected in retro reflection. In a set of acrylic paints laid on glass coverslips, the dependence of the MPEF signal with the depth below the surface of the paint allows estimating the layer thickness.

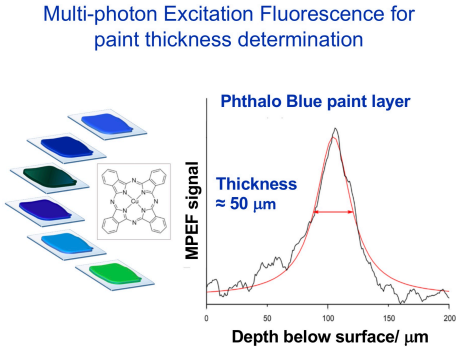

Figure: Nonlinear optical microscopy for paint thickness determination. From left to right: acrylic paint samples, copper phthalocyanine molecule and dependence of MPFE signal with depth below the surface.

Alice Dal Fovo et al. "Multianalytical non-invasive characterization of phthalocyanine acrylic paints through spectroscopic and non-linear optical techniques". In: *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 208 (Feb. 2019), pp. 262–270. ISSN: 1386-1425. DOI: 10.1016/j.saa.2018.09.040. (Visited on 08/28/2019) Collaboration between Instituto de Química Física Rocasolano (IQFR-CSIC) and Istituto Nazionale di Ottica (CNR-INO).

2. THE 10 PILLARS OF E-RIHS

INTRODUCTION

In order to fulfil its ambition, E-RIHS will implement specific best practices that have been identified as successful by the extensive experience of its founding members working in heritage science. E-RIHS will also implement best practices that are inherent to world-class research infrastructures, but whose implementation in the framework of heritage materials needs to be detailed.[1] We here list these best practices and the expected impact following their implementation. These are formulated as ten core values that will be at the heart of E-RIHS. Criteria to include infrastructures in E-RIHS and to support projects at E-RIHS will be defined and implemented in phase with these core values.

2.1. SPECIFIC GOOD PRACTICES

Competencies first – Considering skills as central. Multidisciplinary interactions make E-RIHS special as the breadth of knowledge it interconnects implies that the skills of each scientist involved is extremely precious. E-RIHS will thus recognise the contribution of all staff included in the joint work. In addition, heritage science teams accessing an E-RIHS instrument will usually require significant support or even initiate joint scientific collaboration with the instrument, as the number of methods required to study a heritage property is usually so high that not all groups can handle them internally. In fact, past experience has shown that E-RIHS teams will request "access to expertise" as much as to instruments or to databases. As a consequence, E-RIHS project selection will take into account the adequacy of the competencies of the staff in an "extended feasibility" assessment. Besides, E-RIHS will implement strong team support, meaning support regarding research proposal preparation (support with questions on sample preparation needs, estimation of specific instruments and suitable analyse techniques, time requested for the proposed experiments, etc.). This also means that high-level training and communication are essential. Most researchers enter the field at a postgraduate or post-doctoral level from a diverse range of fields so that training opportunities to develop a variety of skills may be required. E-RIHS will thus organise high-level hands-on specialised training whether on site or at large-scale facilities, which is particularly attractive for students. Training activities will be tightly connected to the infrastructure operation, allowing non-experts to learn how to take the optimal benefit from the infrastructure for their research. Particular attention will also be paid to the training of engineers and technical staff operating E-RIHS facilities, in particular by promoting exchanges between E-RIHS facilities. This will contribute to the continuous improvement of E-RIHS platforms and services.

Interdisciplinarity – Optimising work for teams with complementary culture and practices. Heritage Science research sits in a multidisciplinary landscape. Diverse sources of information on the environmental, geochronological, historical and societal context of heritage are included in this process. E-RIHS will therefore be a model interdisciplinary infrastructure, associating human and experimental sciences that will nurture heritage sciences and will contribute to the development of new knowledge and new methodologies. Experience shows that successful projects are generally carried out by teams associating various knowledge and competencies. E-RIHS will recognise and support team work at all stages of the process

[1] Loïc Bertrand et al. *First version of the E-RIHS Scientific Vision.* E-RIHS PP Deliverable 9.1. Mar. 2018. URL: https://hal.archives-ouvertes.fr/hal-02138538 (visited on 08/28/2019).

Example 2.1.: First IPERION CH Doctoral Summer School

Doctoral Summer Schools are addressed to potential users of E-RIHS allowing the results achieved by Trans National Access and Joint Research Activities to be presented and discussed with postgraduate, PhD and post-doctoral researchers. The skills of both users and potential users of a large number of heritage scientists have been increased through multidisciplinary training and education. Overall, model cross-disciplinary, sustainable education and training initiatives, shaping new professional profiles and skills for the heritage science sector have been created. The results of innovative research activities related to the development of novel instrumentations and analytical methods for the study of heritage materials have presented by international experts belonging to the IPERION-CH consortium. Participants had the possibility to understand the importance of being able to access to large and medium scale facilities, mobile laboratories and data archives within a European dimension. The School allowed new collaborations to be established among participants thanks to their limited number and the organisation of study visits and social events.

Figure: 3rd IPERION-CH Doctoral Summer School, 16–20 July 2018, University of Bologna – Ravenna Campus (IT).

and multidisciplinary teams rather than individuals will access E-RIHS. E-RIHS will associate on equal level researchers from all required disciplines and accessed facilities (experimental sciences, natural sciences, digital sciences, arts, humanities and social sciences). This interdisciplinarity might inspire fields of research beyond heritage science, especially regarding instrumentation research, computing sciences, and the chemistry and physics of novel materials. E-RIHS might also bring new inspiration to environmental and geological sciences, which have in common with the field of heritage science the study of marks and imprints from the past. E-RIHS therefore provides an exceptionally innovative model for interdisciplinary research.

The ARCHLAB access platform provides a good example of some of the concepts developed above. ARCHLAB offers access to a multidisciplinary scientific community that is crossing borders, hence not necessary within the traditional "heritage science sector or community". More and more applications for access come from fundamental science fields, facing pure science questions (chemistry, physics, data sciences...). An illustrative example, showing the marriage of the worlds of fundamental and applied science, is an access proposal from the Department of Chemistry of the University of Hamburg. The proponent team has international renowned knowledge and experience in the crystallisation behaviour of salts from thermodynamical and kinetic points of view that allows explaining the fundamental and theoretical behaviour of salts in conditions of temperature and relative humidity. However, the practical degradation phenomena that are at stake when these salts are present in building materials are less well known, as for example the yellowing of gypsum efflorescence appearing on mural paintings. Having almost no experience in the field of conservation science, the user applied for access to an ARCHLAB provider with a long experience in conservation problems. Such 'innovation' was brought into ARCHLAB, to stretch out the knowledge in both directions (fundamental science vs. applied science and vice versa) thanks to exchange and sharing of information between user and provider.

Co-creation – Building on a paradigm that balances contributions from all participants. Rather than a tool / user relationship, E-RIHS will foster a culture of exchange and cooperation. This approach is similar in many ways to the operation of the ESRF (European Synchrotron Radiation Facility) or the "Contributor" paradigm developed by CERN.[2] The expertise of both the researchers accessing E-RIHS facilities and the scientists who run them is indeed essential in making experiments successful. The scientific communities also have a role in stimulating continuous improvements and innovations at the host facilities. Consequently, E-RIHS will attribute a central role to cross-disciplinary consortia of scientists that associate, on an equal level, researchers from heritage science (in particular conservation, art history, archaeology, and palaeontology and palaeoanthropology) and from the facilities. The new generated knowledge will thus be recognised as co-created by users and platform scientists. As an example, users and platforms scientists will by default co-author the articles published as result of their joint work.

Communication – Exploiting the public-facing nature of heritage institutions. Heritage is by definition in the community and accessed by the community through public-facing institutions like museums, galleries, libraries, archives, sites and monuments. In this framework, heritage science contributes to the care of collections and sites in various ways, extends knowledge and understanding of objects and sites and contributes to the development of technologies that can be used to enhance the way in which the public access and interact with heritage. This provides a direct route for exploitation of E-RIHS research in public-facing institutions that can then have very direct impact on citizens. Museums and heritage sites have synergies and interactions with the creative industries and can therefore be drivers for innovation, providing ample opportunities for enhancing knowledge transfer and impact of the research. An effective way would be to take into account measurable dissemination actions when evaluating research projects.

2.2. BEST PRACTICES GENERIC TO RESEARCH INFRASTRUCTURES

Excellence – Supporting outstanding projects. E-RIHS will foster excellence, meaning ensure amplified support and continuity of research projects. E-RIHS will promote both short and large-scale research projects and major initiatives, and put in place exploratory projects. An E-RIHS label will be created and granted at European level to facilitate outstanding large-scale projects, typically those requiring analytical support through multiple access visits. It will provide a coherent framework to multiple accesses to the same facility, to different facilities from the same platform or to different platforms. Our experience indeed shows that experiments on heritage materials are typically based on the combination of several visits to a facility and/or on-site campaigns while constantly requiring access to archives and data. This balance in medium and large-scale projects will enable the joint progression of knowledge on heritage materials and data, methodological innovations, and a common adoption of the challenges of the field.

Interoperability – Promoting data sharing, intelligent instruments and open access policies. Open Science is one of the main priorities for the European Commission in research and innovation policy. In its Guidelines to the Rules on Open Access to Scientific Publications and Open Access to Research Data in Horizon 2020, the European Commission underlines the importance of "broad access to scientific publications and data to build on previous research results, encourage collaboration and avoid duplication of effort, speed up innovation and involve citizens and society through an improved transparency of the scientific

[2] CERN and Fabienne Landua. *Code of Conduct*. Policy Document. 2017. URL: https://hr-dep.web.cern.ch/content/code-of-conduct.

process".[3] Moreover, in April 2016, the European Commission launched the European Cloud Initiative, to create by 2020 a trusted environment for hosting and processing research data. E-RIHS therefore develops a long-term strategy and offers a comprehensive framework that will work towards open heritage science data. This strategy will be in line with the FAIR principles to make data findable, accessible, interoperable, and reusable, taking into account specific intellectual property issues. E-RIHS will promote the re-use of information, such as experimental schemes, raw data, metadata, algorithms and their applications, to foster replicability. Heritage data are indeed very heterogeneous (various formats), and currently have no clear reuse conditions. This approach is a long-term effort as fragmented practice and work with instruments using closed standards have been a barrier to openness in the heritage science community, addressing every aspect of data storage, transfer capacities, data transparency and data quality. E-RIHS will abide to the Heritage Data Re-Use Charter developed by infrastructures and projects in the heritage field.[4] Scientific processes in E-RIHS will be open to external critical validation and serendipitous discovery of results. This effort will be essential to the overall robustness of the infrastructure. Interoperability is not only a data issue, E-RIHS will also focus on the interoperability of systems and physical instruments (Example 2.2) as a critical simplification for users for which the full strength of the infrastructure will be to interoperate instruments for which similar procedures will be put in place for analysis.

Example 2.2.:
A Common 3D Positioner to Map the Composition at the Surface of Historic Objects

Teams at AGLAE, together with colleagues at BNC, IPANEMA and SOLEIL have developed a 3D positioner for the elemental mapping of non-flat surfaces of heritage objects, and have tested its implementation at the external beam of the AGLAE accelerator. The work results from a joint research activity of the IPERION CH European program. The dedicated procedure is based on three successive steps: (i) the definition of an experimental geometry on a curved surface, (ii) a point-cloud mapping, and (iii) an alignment protocol allowing the positioning of an object with a hexapod. The new 3D positioner for mapping artefacts of complex shapes has been designed, assembled and implemented at the AGLAE scanning external microbeam endstation. It has been successfully tested on a curved porcelaine pot in PIXE mode, allowing the scanning of the object surface despite its curved surface.

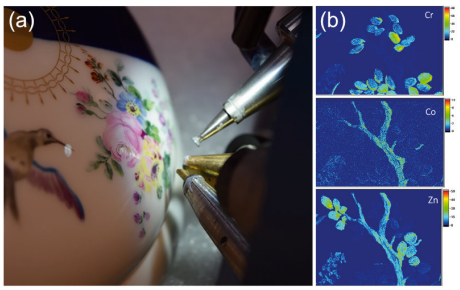

Figure: Test scan of a glazed porcelain pot with a fine polychrome decoration

(a) The pot being scanned at the AGLAE instrument,
(b) from top to bottom, maps of chromium, cobalt and zinc.

Thomas Calligaro et al. "A new 3D positioner for the analytical mapping of non-flat objects under accelerator beams". In: *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 467 (2020), pp. 65–72
AGLAE, BNC, IPANEMA and the SOLEIL synchrotron

Innovation – Stimulating evolution of innovation in heritage science. E-RIHS will contribute to the development and adoption of new research methodologies. New interoperable instruments and digital tools, new protocols and new techniques have a decisive impact on heritage science research, enabling improved understanding of heritage objects and sites. Digital technologies are rapidly expanding and leading to uncharted research territories. E-RIHS will extend the formal frameworks for data interpretation and

[3] *Open innovation, open science, open to the world – a vision for Europe*. Report. OCLC: 958797140. Luxembourg: Publications Office of the European Union, 2016.

[4] DARIAH. *Heritage Data Reuse Charter | Information and developments around the Heritage Reuse Charter*. Tech. rep. Paris, 2019. URL: https://datacharter.hypotheses.org/ (visited on 08/28/2019).

management developed by digital humanities (e.g. DARIAH).[5] To foster innovation, E-RIHS will promote the re-use of information and data fusion. Internal research activities will ensure that E-RIHS pushes the boundaries of innovation to offer the best possible infrastructure to the research community. E-RIHS will stimulate innovation in large-scale instrumentation, non-invasive portable technologies, safer analysis conditions and data science. E-RIHS will foster hybridization and multimodal approaches where coupled techniques enable improved studies and understanding of heritage materials. An exciting example is the rise of new imaging methods that allow the extreme complexity of heterogeneous, chemically complex and multi-scale heritage materials to be studied. E-RIHS will integrate the full power of novel imaging techniques within its instruments, competencies, and training. In-house research in these fields and other key areas will ensure that E-RIHS remains at the cutting edge and always offers the best possible infrastructure to the research community.

International recognition – Collaborating at global level. The challenges of heritage research in practice and the global lead that the EU holds in this field, supported today by an unstable combination of national and EU measures, requires a joint and resolute effort (Example 2.3). E-RIHS will connect with other European infrastructures such as DARIAH ERIC in the field of digital humanities, the neutron source ILL (Institut Laue–Langevin), the ESRF (European Synchrotron Radiation Facility) in terms of large-scale facilities and CERIC (Central European Research Infrastructure Consortium). A specific cooperation will be established with the future ESS (European Spallation Source) towards novel spectroscopy and imaging tools. E-RIHS will also establish cooperation with the International Atomic Energy Agency (IAEA) on accelerator-based and reactor-based research in heritage science. With the aim of developing high-level training activities, E-RIHS will also liaise with national and international professional bodies like the Institute of Conservation (ICON), the International Institute for Conservation of Historic and Artistic Artworks (IIC) or the International Council of Museums (ICOM) to explore education and training needs. The intergovernmental organisation ICCROM (International Centre for the Study of Preservation and Conservation of Cultural Property) is supporting this initiative.

Ethics – Respecting heritage values and encouraging responsible research. The UNESCO defines ethics as "norms of conduct regarding acceptable and unacceptable behaviours within a society or community – not necessarily from a legal perspective, but from a human or cultural perspective".[6] Heritage materials are specific as they are unique, irreplaceable and non-renewable resources (Example 2.4). Moreover, people strongly identify with heritage, which contribute to identity at personal, local, national, European and global levels. Consequently, working on heritage has direct ethical implications. Research on cultural heritage materials indeed gives rise to stimulating ethical issues, including professional standards and responsibilities, notions of stewardship and custodianship, moral implications of working on cultural heritage, ownership of heritage and sharing of knowledge on a heritage to a broad public. E-RIHS will intrinsically consider ethics in all its activities. E-RIHS will ensure full conformity with international, national and local legislation and promote the highest standards of ethical conduct.

Quality – Guaranteeing the best user experience. E-RIHS will be a permanent research ecosystem associating instruments, competencies, governance and societal involvement to provide innovative research

[5] DARIAH, see n. 4.

[6] UNESCO. *Ethical Principles for Safeguarding Intangible Cultural Heritage.* Decision of the Intergovernmental Committee. Windhoek, Nov. 2015. URL: https://ich.unesco.org/en/ethics-and-ich-00866.

Example 2.3.: World Meeting on Heritage Science and Technologies, Paris, Feb. 2019

The World Meeting on Heritage, Sciences and Technologies took place from 13 to 16 February 2019. It was organised by the French Academy of Science and CNRS-IPANEMA, under the aegis of the GID, in partnership with 20 academies from different countries. This multidisciplinary conference provided a synthesis of current works and future perspectives for research on heritage materials, while raising the public awareness on this topic. It ended with a solemn declaration signed up by more than 460 scientists and decision-makers. The two first days, the Scientific Symposium *Frontiers in Heritage Science* gave the floor to high-level speakers interacting with 460 participants from 29 different countries. During the third day, which was opened to all audiences, scientists, institutional actors and heritage professionals engaged in a dialogue with the public at four round tables addressing current challenges and future prospects in the field of heritage, thus opening up research to society. The final declaration called to action to improve the understanding, preservation and enhancement of cultural and natural heritage.

Figure: The solemn declaration "Heritage, Science and Technology: an opportunity for our societies and the global economy" was signed by more than 450 scientists and decision makers, including Minister Costas Fotakis (Greece), the presidents of the CNRS, of the National Museum of Natural History and of the Paris-Saclay University and former Ministers Jose Braga de Macedo (Portugal) and Hany Helal (Egypt).

Scientific Symposium Frontiers in Heritage Science, Paris, France, 13–16 Feb. 2019.

Project funded by the European Commission, the French Ministry of Culture, the French Ministry of Europe and Foreign Affairs, the CNRS, the Ile-de-France Region and the Paris-Saclay University, supported by the Total Foundation, the SwissLife Foundation, and Google Arts and Culture.

of the highest quality in strong correlation with the specificities of heritage science. E-RIHS will implement a quality system applying the principles and options of quality management to all activities of the infrastructure, allowing all parties to have confidence in their results. To reach this purpose, the E-RIHS Quality Manual will be developed. It will guarantee the best user experience and allow all parties to have the greatest confidence in the processes and their results. To assess the impact of E-RIHS, performance indicators will also be proposed, using Horizon 2020 and JPI-CH sets of Key Performance Indicators. The satisfaction on teams accessing E-RIHS will be evaluated. In addition, a robust risk management methodology conforming with International Standards will be implemented.

Example 2.4.: Safe limits for X-ray analysis of paintings

Analysis of paintings using X-rays (synchrotron radiation, proton induced X-ray emission, etc.) gives valuable information on composition and state of conservation but it is necessary to establish safe limits of operation to avoid undesired modifications of materials. In this study, X-ray photoelectron spectroscopy (XPS) serves to follow, as a function of irradiation time, the chemical modifications induced on traditional pigments and their egg-yolk temperas by soft X-rays coming from the same source of the analytical equipment. Samples were irradiated at low power (135 W) and prolonged time intervals with the non-monochromatic source of an XPS system, while spectra were periodically acquired to check for superficial chemical modifications. At high doses, alizarin display the highest radiation stability, while, azurite and malachite experience a progressive Cu^{2+} to Cu^{+} chemical reduction. In the temperas, reduction of Cu is also observed together with degradation of proteins and lipids of the egg-yolk binder. By monitoring modifications of XPS signals, it is possible to establish limits of exposure to radiation, in the form of time intervals (or doses), that should not be surpassed to avoid degradation of the pictorial materials.

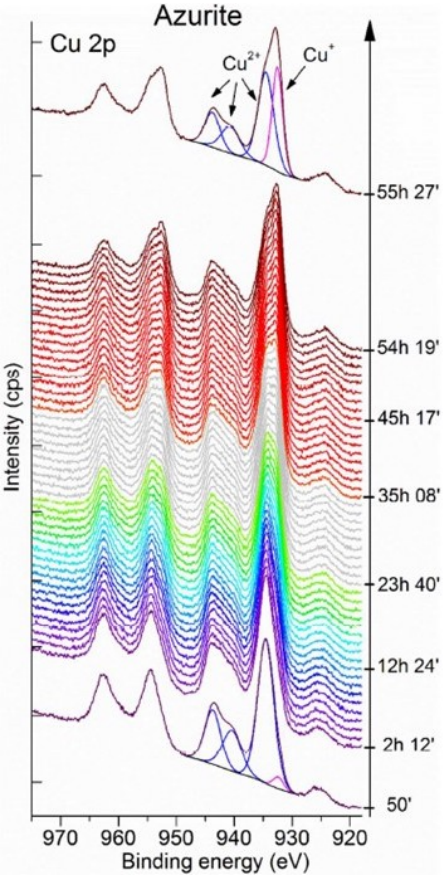

Figure: Evolution of Cu 2p XPS of azurite pigment at different time intervals during soft X-ray exposure. Curve fitting of Cu $2p_{3/2}$ displays the increase of Cu^{+} versus Cu^{2+} after X-ray irradiation.

E Carrasco et al. "X-ray and ion irradiation effects on azurite, malachite and alizarin pictorial models". In: *Microchemical Journal* 137 (Mar. 2018), pp. 381–391

Instituto de Química Física Rocasolano (IQFR-CSIC).

3. INFRASTRUCTURE TO ENABLE NEW SCIENCE

INTRODUCTION

E-RIHS will structure an advanced research community that has been steadily developing over the last two decades in Europe. An early initiative was the creation in 1999 of the LabS TECH consortium, a networking project funded under the fifth framework programme (FP5). The FP6 project Eu-ARTECH then gathered a larger consortium offering, for the first time, a transnational access programme for the field of science applied to cultural heritage. Starting in Eu-ARTECH, research activities aimed at developing the access offer and networking activities consolidated cooperation among researchers across this interdisciplinary area. Subsequent major EU-funded integration research and infrastructure projects, including CHARISMA (FP7), IPERION CH (H2020) and IPERION HS (H2020) added new partners, further extending the access offer, while at the same time conducting research to support advancements in infrastructure. E-RIHS expands this community further by incorporating consortia from the ARIADNE and ARIADNE+ projects, focused on digital archaeology, as well as the two RI cluster projects PARTHENOS and SSHOC (the latter aiming to build the Social Sciences and Humanities Open Cloud). It is also connected to the palaeontology consortium DiSSCo and works in close collaboration with DARIAH.

Building on this accumulated experience, the E-RIHS proposal as been submitted to ESFRI as a permanent European research infrastructure for the heritage science community. Its incorporation into the ESFRI roadmap in 2016 highlighted its relevance to the European Research Area (ERA). Since 2014, the G7 GSO has considered E-RIHS to be among the research infrastructures with a global scope. The preparation of an ERIC was funded by the EU project European Research Infrastructure for heritage science Preparatory Phase[1] and launched in February 2017, with planned completion in 2020.

The Four Access Platforms

At the E-RIHS ERIC creation, each of the four access platforms in E-RIHS – ARCHLAB, DIGILAB, FIXLAB and MOLAB – groups together infrastructures offering a particular type of access, supporting user groups to navigate the large number of complementary instruments, so that they can find the most appropriate for their needs, and they can *build a coherent sequence for their research work*. This concept is crucial in enabling operation as an integrated distributed infrastructure, leading to a coherent strategic structure that shapes the services offered to the users in an infrastructure which will be much more than a mere network of diverse instruments and resources. Access platforms are therefore designed to conform to the general methodology of a heritage science project, including long-term projects.

A specific characteristic of heritage science is that it is a multidisciplinary domain, with projects generally requesting access to multiple techniques, combined with existing multidisciplinary heritage knowledge, expertise and resources to fully address the research questions. Hence, the broad range of high-end facilities combined with domain-specific expertise that will be offered by the four E-RIHS platforms has the potential to greatly enable progress in heritage science research.

ARCHLAB offers unprecedented access to heritage information and data, both physical and digital, in the form of scientific archives – including *grey literature* beyond that available in publications. This sharing of

[1] H2020-INFRADEV-2016-2017

knowledge is valuable at the planning stage of new research projects as well as for the interpretation and comparison of information and data collected by user groups through the instruments of MOLAB, FIXLAB or in their own laboratories.

The non-invasive analysis and imaging available in MOLAB is a frequent starting point to study objects or sites as a whole, providing valuable material information where sampling is not possible, or guiding the selection of samples for further investigation, thereby allowing sampling to be kept to a minimum. A specificity of MOLAB is that it gives researchers access to non-invasive instruments that can travel to the user, as it is necessary for immovable objects or sites.

FIXLAB incorporates a range of specialised analytical techniques not available in most heritage science laboratories, either large-scale facilities such as synchrotron or neutron-based instruments, or, for example, high-end mass spectrometry for biological material analysis, allowing detailed and unique investigation to be undertaken, on samples or on objects if the technique is non-invasive (unlike in MOLAB, the object is then transported to the facility).

The new platform DIGILAB, to be developed within E-RIHS, is a natural extension of the existing ones, now that data are made accessible through digital platforms, in addition to physical access in ARCHLAB. The digital tools used for data processing are more and more sophisticated, and therefore not always easily accessible, creating a need for these to be shared and rationalised through E-RIHS.

E-RIHS will therefore address the scientific needs of multidisciplinary teams of users, gathering SSH scientists, material scientists – such as physicists, chemists and materials scientists working on ancient materials, archaeologists, palaeontologists and data scientists. Teams of users will include curators and restorers bringing their expertise on a given object, or in need of specific measurements before or after interventions. The resulting community will range from researchers to professionals in the field of restoration and cultural heritage management.

3.1. PHYSICAL ARCHIVES

Overview

E-RIHS ARCHLAB will give access to archival collections of objects, samples and data that constitute valuable research resources. More specifically, these collections will include: a) samples taken from cultural objects, archaeological and monumental sites and monuments during previous campaigns of study and conservation, b) reference materials, c) zooarchaeological, archaeobotanical, human skeletal, dendrochronological and archaeotechnology collections, and d) scientific, analytical and technical data and knowledge on cultural objects, crafts, monumental and archaeological sites and related documentation on production technologies, state of conservation, restoration and conservation, etc. They are by themselves extremely valuable heritage and scientific collections.

The archival collections that will be accessed through ARCHLAB are stored in prestigious museums, galleries, natural history institutions, and conservation and research institutions. These distributed facilities, integrated in the E-RIHS ARCHLAB platform, will not only grant access to the valuable research resources of their collections, but also to the related unique expertise available at the facilities that enriches the access experience and promotes a collaborative and interdisciplinary interaction between the provider and

user groups. Furthermore, in some cases, ARCHLAB access will also make possible studies on samples brought by users, in order to confront different results.

ARCHLAB will enable the alignment of research activities between user teams and access providers, hereby offering structured opportunities for research and networking activities.

The ARCHLAB modality of access is crucial for heritage science investigations, due to the fact that objects of the same provenance and comparable properties are very often dispersed in museums, universities or institutions in different countries, as are samples and results. Efficient access to data and corpus belonging to the different institutions is the only way to share and compare results obtained by various research groups, avoiding effort duplication (Example 3.1). Access projects to E-RIHS ARCHLAB will pave the way towards deeper and broader studies of heritage, will promote efficient circulation of knowledge among European researchers, to achieve high quality results and to stimulate wider cooperation among European institutions for the study of cultural objects, and monumental and archaeological sites.

Example 3.1.: Investigating Rare Curious Corrosion Phenomena

Understanding deterioration of artefacts is a prerequisite for rational conservation measures. To study phenomena occurring rarely, information from stray sources need to be combined. These can be discovered in the archives of conservation science labs with long tradition. Analytical reports at the British Museum London and the Cultural Heritage Agency of the Netherlands – Amsterdam revealed interesting details, of, e.g., calcium acetate efflorescence on calcareous materials, 'black spots', curly malachite, and copper hydroxide on bronzes, or glass-induced metal corrosion. An ion chromatographic method developed in Amsterdam detected acetate, formate, and nitrate in a calcareous efflorescence caused by exposure to wooden products (acetate, formate) and NO_x (nitrate). This helped to determine its crystal structure and formula from powder diffraction data. Another calcium acetate formate efflorescence caused by wood and reported on molluscs (UK) was found on a vulture eggshell (Stuttgart) and a marble relief in the British Museum. Reference data (powder diffraction, vibrational spectroscopy) from a synthesised sample will allow its easy future detection.

Figure: Unknown efflorescence needles on the eyebrow and the ear of a glazed terracotta lion head, 17th c., E3768, Landesmuseum Württemberg, Stuttgart (Marian Schüch 2015)

Sebastian Bette et al. "Characterization of a new efflorescence salt on calcareous historic objects stored in wood cabinets: $Ca_2(CH_3COO)(HCOO)(NO_3)_2{\cdot}4H_2O$". in: *Corrosion Science* 132 (2018), pp. 68–78; Sebastian Bette et al. "Efflorescence on calcareous objects in museums: crystallisation, phase characterisation and crystal structures of calcium acetate formate phases". In: *Dalton Transactions* 48.42 (2019), pp. 16062–16073

ARCHLAB access: RaCoPrIO (Rare Corrosion Products of Inorganic Objects) project, Prof. Eggert Gerhard, State Academy of Art and Design Stuttgart (DE)

Genesis

While MOLAB and FIXLAB were created within the Eu-Artech project (2004–2009), the creation of an additional, complementary platform was considered necessary within the seventh framework programme of the European Commission. ARCHLAB was born within the CHARISMA project (2009–2014), consisting of six access providers. Within the following integrating activity, IPERION CH, the ARCHLAB platform

grew up to an integrated system of 10 distributed facilities located in outstanding European museums and research centres (Example 3.2). Gradually, a need to further enlarge the scope of services within the field of heritage science was considered, extending to the fields of palaeontology and palaeoanthropology, archaeology and craft science. Since spring 2020, in the IPERION HS project, ARCHLAB widened its access offer to 13 facilities. This updated distributed platform of facilities aimed at delivering services to a wider community, which now also includes: a) archaeological teams who study human–environment interactions over time, including how people procured their livelihoods and their social relationships with animals, plants and their socio-economic context, b) researchers active in the field of heritage crafts with the goal to improve practices through the developments of craft skills and techniques.

Example 3.2.: The Michel Sittow and the Luna Chapel in Toledo Cathedral

Michel Sittow (ca. 1469–1525/26) one of the most important Flemish painters, worked at the court of queen Isabel of Castilla with a salary higher than any other artist under her service. Not much is known about how Sittow entered in the Spanish court. A young Sittow might have been involved in the execution of the Luna altarpiece in Toledo. The Luna altarpiece in the Saint James chapel of the cathedral of Toledo was commissioned on 1488 to Sancho de Zamora and Juan de Segovia. There is evidence that beside these two masters, at least one further and more «Northern» artist must have been involved: Michel Sittow. Images study with Infrared reflectography, X-ray radiography, high-resolution photography, and materials analysis with SEM-EDX, FTIR-ATR and liquid chromatography (LC-DAD-QTOF) demonstrate that the painting technique in four of the fourteen picture panels of the altarpiece closely conforms to what we know from the other Sittow works. This hypothesis, fruit of a research project by Complutense University of Madrid (UCM) and the Spanish Cultural Heritage Institute (IPCE) among others, was confirmed by Matthias Weniger, an expert in Michel Sittow's work.

Figure: Details of the radiography and infrared reflectography of the panel of Saint John the Evangelist. Oil on wood. Altarpiece of Santiago of the chapel of Don Álvaro de Luna. Toledo Cathedral. Instituto del Patrimonio cultural de España (IPCE).

Olga Pérez Monzón, Matilde Miquel Juan, María Martín Gil, eds. Sílex Ediciones, Madrid, España, 2018.; SBN: 9788477379614; Washington D.C. National Gallery of Art; New Haven:Yale University Press. 128 pp, 90 illus. ISBN 978-0-300-23286-8.

ARCHLAB access: The possible intervention of Michel Sittow in the execution of the altarpiece of the Luna Chapel in Toledo Cathedral. Spanish Cultural Heritage Institute, IPCE, Feb 2017.

Annex F.1 provides details of the ARCHLAB facilities included in the four integrating activities under CHARISMA, IPERION CH and IPERION HS.

ARCHLAB in E-RIHS

Based on the precedent set in previous EU-funded integration and research and infrastructure projects, and capitalising on the accumulated access experience, the E-RIHS ARCHLAB platform will incorporate new providers, according to identified gaps and needs and respecting uniform quality criteria setup for all four E-RIHS platforms, hereby opening new facilities to European and international users.

E-RIHS aims at widening up and increasing the research community. Through the provision of access to archives and technical data on cultural heritage objects and related samples, the ARCHLAB platform will allow researchers to study collections of reference samples, zooarchaeological, archaeobotanical, human

skeletal, dendrochronological and archaeotechnology collections to support them in fields of archaeology, palaeontology and craftsmanship.

As in all E-RIHS platforms, user groups in the heritage field will benefit from the precious and unique association of archives, knowledge and expertise of host researchers. ARCHLAB will hence enable the alignment of research activities between user teams and access providers, hereby offering structured opportunities for collaborative research and networking activities.

3.2. DIGITAL DATA

Overview

E-RIHS DIGILAB is a distributed platform designed to offer improved access to digital research data, services, tools, resources, expertise and training, in the field of heritage sciences. Its main scientific goal is the development of a digital ecosystem for research in the heritage science area allowing the data handling and processing of experiments that require the availability of scalable computing, storage and connectivity capabilities. The platform will gather a dynamic wide range of available digital solutions, created across and beyond the consortium. From the architectural point of view, DIGILAB will be a distributed cloud-based infrastructure, compliant with EU policies and strategies, in particular EOSC, concerning scientific data management, designed using standard models and frameworks and supporting distribution, interworking, portability, platform and technology independence. Combining the technology with clear guidance, practical examples and training on how they can be used to improve the efficiency of our research activities and access to the research data we produce. The main goal of DIGILAB is to support the E-RIHS scientific network in the research process, by designing and implementing a practical Digital Ecosystem (i.e., an online platform) where researchers and experts can find digital resources (tools, services, data, etc.) and use them to perform tasks connected to their research activities in a highly integrated and interoperable environment, adding value beyond the traditional fragmentation affecting the data landscape and overcoming the risk of platform isolation, and in tight interaction with the other E-RIHS Labs.

Genesis

Within the preparation phase of E-RIHS, it was clear that a new fourth LAB platform was required to interconnect the developing digital opportunities, to maximise the potential of digital research data and services that are being produced by MOLAB, FIXLAB, ARCHLAB and the heritage science community as a whole.

In general, the DIGILAB platform is envisaged to answer, for the heritage science domain, the global challenge of both maintaining and making available, on a large scale, digital information representing the cultural treasures of Europe in terms of shared knowledge, diversity, cultural growth, and economic potential.

DIGILAB will begin with recommendations, of best practice, for the production of Data Management Plans, including descriptions of how activities, methodologies and research data, created within MOLAB, FIXLAB, ARCHLAB and DIGILAB, can be described, preserved and accessed via a range of online digital Reposito-

ries. As the use of these Repositories develops aggregated search systems / functions will also be provided, drawing on the information already stored in the multiple repositories to provide a single DIGILAB portal to direct researchers to where they can access the information and data they require. In addition to this initial portal, DIGILAB will also present a joint resource registry; cataloguing E-RIHS validated services, tools, applications and software through which it is possible to process data and information used within the E-RIHS digital ecosystem, including existing applications (e.g., MoViDa, Entropy) and other candidates from relevant projects, such as PARTHENOS, ARIADNE, IPERION CH, SSHOC, etc. Going beyond online services this DIGILAB registry will also include details of the facilities, people and expertise required to carry out or more specialised digital services recommended by E-RIHS.

DIGILAB will serve the E-RIHS user groups providing both generic (i.e., cross-domain) and specialised (i.e., domain-specific) services, according to the FAIR approach

DIGILAB in E-RIHS

Beyond the initial set-up of DIGILAB, work will move on to focus on the digital integration of all four E-RIHS Labs and the E-RIHS central hub, initially with the continued development of integrated access proposals and a DIGILAB knowledge base. Developing, supporting and maintaining an up-to-date collections of guides, howtos, best practice and training resources. These activities will represent a significant ongoing investment of resources and where possible will need to maximise the potential of external collaboration with DARIAH and connected EU projects, SSHOC, EOSC, etc., to continue to build on existing and developing knowledge.

DIGILAB will continue to examine the digitisation and documentation of existing research, principally to aid the capture of previous accesses and to explore how DIGILAB can enhance the accessibility of some of the appropriate resources made available via ARCHLAB.

Beyond technical needs, a critical aspect will be to incorporate in DARIAH an efficient mechanism regarding the rights to share and reuse the data generated for the benefit of the research communities, heritage institutions and innovation activities, based on the DARIAH Heritage Data Reuse Charter, co-developed within EU projects IPERION CH and PARTHENOS (Example 3.3).

As the scope and range of available digital heritage science data continues to grow, further work will be required to ensure that it can be semi-automatically categorised and linked to new research questions and requirements for new digital solutions and services can be identified.

Hence, fully semantically documenting research activities, procedures and methodologies will be required to improve automated interoperability and trust. Allowing DIGILAB to produce and maintain a complex semantic graph, representing the relationships between entities involved in heritage science research and will provide access to a growing amount of digital resources made available by the E-RIHS scientific network partners.

Into the future, DIGILAB will continue to develop, ensuring that the services and solutions offered continue to be relevant and represent best-practice, guided by the more fundamental digital research carried out within a variety of related initiatives and projects, such as DARIAH, RDA, OpenAIRE, GoFAIR.

Example 3.3.: Fostering data reuse in the cultural heritage sector

Disseminating the results of heritage science experiments is a major challenge that can only be solved by making all stakeholders, researcher, cultural heritage institution and research facility, agree on the reuse conditions of the corresponding data sets. The heritage data reuse charter aims at setting up an agreement framework between the stakeholders involved in heritage science experiments to agree on basic principles related to the creation, enrichment, curation and dissemination of all data sets where complex technological or copyright conditions apply. The heritage data reuse charter was initiated by several European organisations (APEF, CLARIN, DARIAH, Europeana, E-RIHS) and European projects (Iperion-CH, PARTHENOS) involved in the cultural heritage domain. A mission statement elicits 6 principles on which CHIs, researchers and facilities should agree in the context of heritage science experiments: reciprocity, interoperability, citability, openness, stewardship, and trustworthiness. These principles go much further than the FAIR principles while being compatible to them by construction.

Figure: The E-RIHS Data Reuse Charter. Source: http://datacharter.hypotheses.org

Anne Baillot et al. "Access to cultural heritage data. A challenge for digital humanities". In: *Digital Humanities 2017*. 2017. URL: https://hal.archives-ouvertes.fr/hal-01582176

DIGILAB

3.3. FIXED INSTRUMENTAL CAPACITIES

Overview

E-RIHS FIXLAB will offer to the heritage science community outstanding access opportunities to a distributed network of key fixed research facilities. As the name suggests, FIXLAB gathers the non-mobile instrumentation within E-RIHS. Samples and transportable objects will be studied and measured at E-RIHS FIXLAB facilities, taking advantage of the availability of large scientific instruments (particle accelerators, synchrotrons, ion and neutron sources, proteomics facilities, C14 dating installations and others) that provide specific competences and / or are specialised (laser platforms, tomography facilities, etc.) in archaeology, palaeontology, palaeoanthropology, restoration or preventive conservation.

As in all E-RIHS platforms, user groups in the heritage field will benefit from the precious and unique association of instruments and expertise of host researchers and technicians in the application of these techniques to cultural heritage. Based on the availability of advanced unmovable instruments and of the specialised expertise of the host, E-RIHS FIXLAB access projects will make possible key scientific developments in studies of heritage objects, both samples and entire items, such as to describe materials microstructure, ageing and physicochemical properties, and thereby to give insights into historical technologies, material alteration or to document authenticity.

Example 3.4.: Laser Cleaning the Athens Acropolis Sculptures

The Athenian Acropolis is a unique complex of fine-curved marble monuments exposed to weathering and pollution for more than 2500 years. Removal of dark encrustations was considered imperative but all proposed cleaning techniques were found inadequate. A pioneering laser cleaning methodology, which employs two laser beams in temporal and spatial overlapping, was developed for this purpose. The contribution of each beam has a decisive role for the adjustment of the prevailing ablation process and thus the cleaning result. Two-wavelength laser ablation proved to be the appropriate cleaning methodology as safeguarding of the original surface without damage or discoloration can be guaranteed. FORTH developed this innovative methodology to overcome unwanted 'yellowing' colorations. Indeed thermal effects linked with infrared laser cleaning can be significantly reduced with the parallel use of an ultraviolet beam, favouring this way the contribution of other ablation mechanisms. Fine-tuning of the fluence values of each beam on the basis of the involved materials allows for an optimum cleaning result.

Figure: Laser cleaning of Caryatid #A, using the prototype station developed at FORTH. The intervention takes place inside the in-situ laser laboratory which operates the past 9 years at the Acropolis Museum, Athens (Acropolis Museum: 2010).

Paraskevi Pouli et al. "The two-wavelength laser cleaning methodology; theoretical background and examples from its application on CH objects and monuments with emphasis to the Athens Acropolis sculptures". In: *Heritage Science* 4.1 (2016), pp. 1–11
https://www.e-rihs.gr/fixlab/,
https://www.iesl.forth.gr/en/research/photonics-heritage-science,
https://al5801.wixsite.com/lasersforartsake

Genesis

The construction of the FIXLAB platform started in 2004 within the EU-ARTECH project where access was provided to the AGLAE ion beam facility (C2RMF). In 2009, within the project CHARISMA, three more facilities joined: in France, IPANEMA / Synchrotron SOLEIL (Paris-Saclay) and in Hungary the micro-PIXE facility MTA Atomki and the neutron facility Budapest Neutron Centre (BNC) with its ten irradiation experimental stations located at the Budapest Research Reactor. This upgraded FIXLAB platform opened exceptional instruments at European level, extending at the same time the number of available techniques beyond ion beams to intense photon and neutron beams. In 2015, the existing FIXLAB offer was upgraded and further expanded under IPERION CH. Innovation in the FIXLAB access provision was achieved through new diagnostic capabilities for high-level scientific investigations on samples or whole objects. For instance, the IPANEMA platform, located at the SOLEIL synchrotron, started operating at full capacity. IPANEMA and SOLEIL collaborated to bring new diagnostic possibilities to FIXLAB users including a world-premier synchrotron beamline devoted to heritage studies, PUMA. Under this project, unique FIXLAB services were offered to the cultural heritage community to provide advanced state-of-the-art instrumentation and dedicated facilities with teams of experts in the field of micro-analysis of heritage artefacts. Development of both new sample-positioning devices at the micro-scale, safer protocols of objects studies, and software tools for the integration of imaging data illustrate ways to further optimise and enhance the FIXLAB offer through concerted European means.

From 2020, with EC project IPERION HS, FIXLAB is significantly increasing its offer capacity to serve a much wider heritage science community, further addressing the needs of archaeology (see Example 3.6) and natural history (paleontology, paleoanthropology). Under IPERION HS, FIXLAB consists on 23 fixed

Example 3.5.: Building a Metal Threads Scientific Database

Metal thread characterisation could help textiles chronological and geographical assignment. The METHIT project focuses on the investigation of metal thread materials and manufacturing technique from a set of 80 Spanish and Italian medieval textiles. The review of the analytical data achieved by previous studies dealing with metal threads allowed to build a reference database of analytical data that at the end of METHIT investigation will enable to draw up conclusions of scientific validity and evidence. By the access to the scientific archives of five institutions, analytical reports and studies, often unpublished, on metal threads from medieval textiles, especially Spanish and Italian ones, were consulted. The data collected have been incorporated in the reference database built on the scientific literature. Crossing analytical results with those incorporated in the scientific database allowed to reach a consistent set of cases to evaluate if the same production technology could be assigned to the same period and textile workshop.

Figure: Metal thread wefts. Metal-coated leather threads. Tapestry fragment, first half of the 12th century, Sicily (Palermo?), I 1bis, Gandini Collection, Museo Civico d'Arte, Modena (Cristina Scibè: 2016).

ARCHLAB access: M. Martín Gíl and P. Borrego Díaz (IPCE), M. Galeotti and I. Tosini (OPD), I. Joosten (RCE), H. De Clercq and I. Vanden Berghe (KIK-IRPA), I. Reiche and C. Waidenschlager (SPK).

research facilities providing transnational access to instruments and to the associated scientific expertise of their staff. Within IPERION HS, users therefore have access to: a) large scientific instruments (synchrotron, ion beam analysis, neutrons, proteomics, C14 dating, etc.); b) specialised scientific platforms for cultural heritage (laser, 3D imaging, etc.); c) specialised scientific platforms for archaeology, palaeontology and palaeoanthropology; d) specialised scientific platforms for restoration and preventive conservation.

Annex F.2 provides the extensive list of FIXLAB facilities included in the three mentioned projects EU-Artech, CHARISMA, IPERION CH and IPERION HS.

FIXLAB in E-RIHS

Supported by this solid background of access experience, the growing scope of E-RIHS FIXLAB is guided by the objective of providing a broader and simplified coverage of services for the heritage science community. In E-RIHS FIXLAB, access will be offered to researchers in heritage science to help address major questions regarding the materiality of heritage objects in terms of their genesis, manufacturing processes, alterations, conservation, preservation and restoration. Breakthrough results are expected from access projects encompassing all the different material aspects of cultural and natural objects.

Their projects will aim at answering multi-disciplinary research questions related to the history, interpretation, diagnosis and preservation of cultural heritage. Typically, a multi-disciplinary team of users will be engaged and only part of the team will need to access physically a given facility. The FIXLAB offer in E-RIHS will cover a wide range of key facilities and laboratories, thus ensuring wider engagement of users and user groups.

Example 3.6.: Iron from the heavens: The Gerzeh iron beads

Humanity's earliest use of iron metal was based on meteorites, long before the invention of iron smelting. However, demonstrating the meteoritic origin of iron is a major challenge, particularly for heavily corroded objects. The three analysed iron beads from Gerzeh in Egypt, excavated in 1911 and dating to c. 3,100 to 3,400 BCE, contain several weight percent nickel, a fraction of a percent cobalt, and small but significant traces of germanium, identifying them as meteoritic. Prompt Gamma Activation Analysis (PGAA) and Particle-Induced X-ray Emission (PIXE) spectrometry at the Centre for Energy Research and PIXE spectrometry at the Wigner Research Centre for Physics, both in Budapest, enabled non-invasive bulk analysis of the beads, confirming previously disputed meteoritic origin as the earliest known iron objects shaped by humans. Neutron Radiography showed that the beads were shaped by hammering, a typical metallurgical skill, and not by drilling, as was done for the stone beads found at the same tomb. Clearly, humans understood the metallic nature of iron long before they were able to smelt iron metal in furnaces.

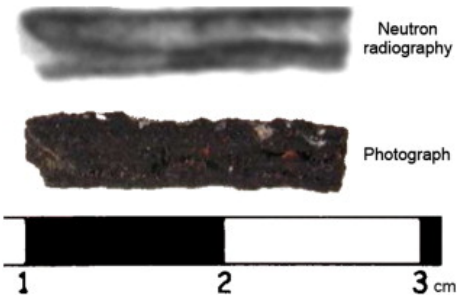

Figure: Neutron Radiograph of Gerzeh bead. First image of the NORMA setup at the Budapest Neutron Centre. Length of bead c. 18 mm. Side (left) and longitudinal view (right), showing its rolled and hammered structure.).

Different grey shades represent different neutron attenuation; the light grey structure beneath the beam on the left is its support during imaging.

The Gerzeh beads are held at the UCL Petrie Museum of Egyptian Archaeology, London. The bead shown has the accession number UC10740.

Thilo Rehren et al. "5,000 years old Egyptian iron beads made from hammered meteoritic iron". In: *Journal of Archaeological Science* 40.12 (Dec. 2013), pp. 4785–4792. DOI: 10.1016/j.jas.2013.06.002. (Visited on 09/03/2019)

FIXLAB access: Wigner Research Centre for Physics.

Further developments in the E-RIHS catalogue of services are expected, led by user needs and based on the scientific criteria defined in section 4.3. New FIXLAB services emerging from the capabilities of the advanced partners and facilities that will be part of the E-RIHS consortium may include geochronology, marine archaeology, mass spectrometry, biomolecular and DNA analysis, to name a few areas which were not sufficiently covered or were inexistent in the previous projects.

3.4. MOBILE INSTRUMENTAL CAPACITIES

Overview

E-RIHS MOLAB will give access to a selection of mobile analytical instrumentation for non-invasive measurements on objects, artworks, collections, buildings, monuments and sites allowing *in situ* investigations for complex multi-technique diagnostic projects. The E-RIHS MOLAB platform consists of a unique collection of integrated instruments under a unified management structure, based on a set of state-of-the-art, mobile equipment and includes related unique expertise and competences in the application of the related techniques to heritage assets. E-RIHS MOLAB delivers to users within the heritage science community not only advanced, integrated and interoperable experimental resources and technologies, but also methodological approaches that are compliant with good practices to allow them to undertake their projects in conditions otherwise impossible.

MOLAB users are enabled to carry out non-invasive measurements at the same site where the actual object

or site under examination is located or exhibited, i.e. museums, restoration workshops, open air locations, research institutions. This mode of operation permits scientists, conservators, art historians, archaeologists and other users to tackle investigations otherwise impossible, e.g. when sampling is prohibited on particularly precious objects and collections or when the state of conservation or the dimensions of the object to be examined render transportation impossible.

MOLAB access platform within E-RIHS possess unique, distinctive qualities. The user group does not travel to the infrastructure, but it is the pool of requested instrumentation that moves to the site where the group works. The instruments also travel to the object even in the case of movable heritage (such as paintings, ceramics, gems, manuscripts, etc.), when it is not recommended, or even impossible, to move such objects to a laboratory due to the risks and costs connected with their transportation and to their often fragile state.

- A toolbox of different, high-performance and well-integrated portable experimental techniques (ranging from point analysis, 2D/3D imaging, multispectral / hyperspectral imaging, remote sensing, etc.) is at user' disposal complemented with highly qualified expertise of the fully trained equipment operators.
- The role of the operators is to assemble the various instruments *in situ*, to carry out the measurements in direct collaboration with the user, to aid interpretation and to discuss the results with the users.
- *In situ* measurements yield an extra value to MOLAB type of access related to the generation of real time results. This permits the immediate discussion of the recorded data and can drive further measurements or changes in the strategy of the investigation. As a consequence, not only the quality of the undertaken studies is highly improved, but it successfully contributes to the creation of a "common language" between users, whether scientists, conservators, scholars, archaeologists, paleontologists and other experts, overcoming barriers imposed by their different disciplinary background.[2]

Genesis

The E-RIHS MOLAB platform is rooted in the first (and unique) mobile transnational access program supported by the European Commission, through the Eu-ARTECH and CHARISMA projects. Starting by two country providers, i.e. Italy (UNIPG-CNR) and France (CNRS-C2RMF), MOLAB made available to transnational users a set of 15 different portable instrumentations. The MOLAB platform within IPERION CH project was upgraded to five MOLAB partners with new instruments. The unified platform set in place within IPERION CH project was constituted by several national platforms distributed in Italy, France, Poland and Greece. To meet the demands of advanced research in heritage science, capabilities within IPERION CH included advanced mapping / imaging multi-/ hyperspectral tools for 2D and 3D examinations, not only to reveal the chemical composition of materials but also to map their spatial distribution. Some of the added instruments to the MOLAB repertoire in IPERION CH were prototypes specifically developed and optimised within the preceding CHARISMA joint research activities, as is the case of integrated absorption–emission and fluorescence decay measurements, terahertz spectroscopy and imaging, Optical Coherence Tomography, Digital Holographic and Speckle Pattern Interferometry and Single-Sided

[2] Loïc Bertrand, Mathieu Thoury, and Etienne Anheim. "Ancient materials specificities for their synchrotron examination and insights into their epistemological implications". In: *Journal of Cultural Heritage* 14.4 (2013), pp. 277–289. DOI: 10.1016/j.culher.2012.09.003.

NMR Depth Profiling (NMR-MOUSE).

Under the fourth integrating activity, IPERION HS, MOLAB platform is designed to further integrate the one operative within IPERION CH. Upgrading the offer meant including mobile laboratories with unique competencies in ground and aerial remote sensing as a key to enable multidisciplinary research in new fields and application scenarios such as: i) exploration, survey and documentation of archaeological interests, ii) preventive and landscape archaeology, iii) interpretation, documentation and diagnosis of the state of conservation of built and monumental heritage. While the offer of hyperspectral imaging devices was strongly enhanced, driven by the wide interest on such technologies experienced in all the ten transnational access calls of IPERION CH, the platform capability was widened with the integration of two key facilities bringing unique equipment and expertise to enable innovative research in the field of conservation science (e.g. bio-deterioration and metal corrosion).

Annex F.4 provides details of the MOLAB facilities included in the four integrating activities under EuARTECH, CHARISMA, IPERION CH and IPERION HS.

Previous transnational access to the MOLAB platform have allowed users to undertake high-quality multidisciplinary studies on materials and execution techniques of ancient and modern paintings (by Giotto, Leonardo, Rubens, Van Gogh, Munch, Picasso, etc.), the conservation state of buildings and archaeological sites (e.g. Merida, Alcázar of Seville, both UNESCO World Heritage Sites), writing, decoration and illuminations of ancient manuscripts (e.g. Islamic codices and opisthographic and multilayered papyri from Herculaneum, as in Example 3.7) and of other types of heritage objects (wall paintings, sculptures, violins, as in Example 3.8, or stained glass windows).

MOLAB in E-RIHS

The capacities of the MOLAB platform within E-RIHS will be extended to provide for the needs of new potential users. The future E-RIHS MOLAB platform will include new instruments of the participating partners. Along this line, E-RIHS MOLAB will incorporate new mobile instruments and unique competencies to enable multidisciplinary research in new fields and application scenarios. The future E-RIHS MOLAB platform will offer cutting-edge imaging systems and ground and aerial remote sensing capabilities. These will serve the exploration, survey and documentation of archaeological assets, and will support preventive and landscape archaeology and the interpretation, documentation and diagnosis of the state of conservation of built and monumental heritage. Also the offer of hyperspectral imaging devices will be strongly enhanced, driven by the wide interest on such technologies experienced in all transnational calls of access launched under the IPERION CH project. To that purpose, the platform capability will be widened with the integration of new key facilities bringing unique equipment and expertise to enable innovative research in the field of conservation science (e.g., bio-deterioration and metal corrosion).

Example 3.7.: Unravelling the Concealed Text of an Herculaneum Papyrus

Text on the verso *of unrolled Herculaneum papyri permanently glued to paperboard are concealed. Removing the extremely fragile papyrus fragments would result in their irreparable destruction so the application of advanced non-invasive techniques is the best way to recover their legibility.* The application of shortwave-infrared (SWIR; 1000–2500 nm) hyperspectral imaging (HSI) to an unrolled papyrus held at the National Library of Naples, Italy has revealed portions of Greek text hidden on the back. These promising results paves the way to aimed investigations of ancient carbonized papyri. Hidden textual portions were indirectly known through their mechanical unrolling in 1795. SWIR HSI, is a recently demonstrated tool for content extraction and contrast enhancement through layered structures, with a high penetration capacity. Its use on 9 papyri fragments, has produced better contrast and legibility with a substantial impact on the text reconstruction even on the extensive text preserved on the front compared to former imaging of Herculaneum papyri at 950 nm. The higher contrast obtained through SWIR HSI was through applying chemometric methods allowing previously illegible or indecipherable words and letters to be read.

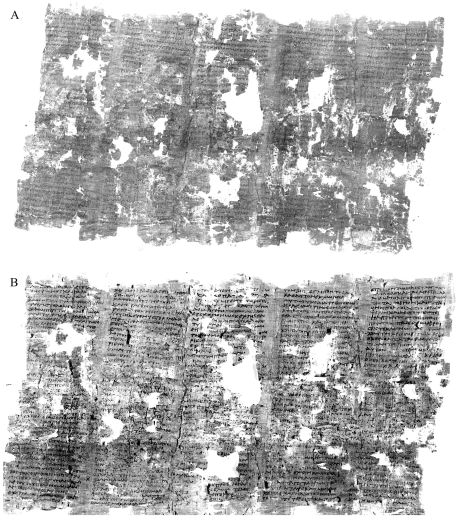

Figure: PHerc. 1021 general view, by permission of Ministero per i Beni e le Attività Culturali.

A) Image at 950 nm. B) PC1 SWIR hyperspectral image. (photo credits: Steven W. Booras and Consiglio Nazionale delle Ricerche, Biblioteca Nazionale "Vittorio Emanuele III," Napoli respectively)

A Tournié et al. "Ancient Greek text concealed on the back of unrolled papyrus revealed through shortwave-infrared hyperspectral imaging". In: *Science advances* 5.10 (2019), eaav8936

MOLAB access: IPERION CH. User Leader: Graziano Ranocchia. Venue: Officina dei Papiri Ercolanesi, 'Vittorio Emanuele III' National Library of Naples (IT), CNR Institute of Heritage Science, Naples (IT)

Example 3.8.: Insight into Old Master Violins by Mobile NMR

The art of violin making began in Italy in 1550 and was mastered by few including Stradivari, the Amaty and Guarneri families. The renowned acoustics, quality and preservation of such instruments are of continued art-historical and scientific interest. Nuclear magnetic resonance (NMR) as a non-invasive non contact tool was used to assess the correlation between the wood density and the age of master violins and violas at the Ashmolean Museum (Oxford) collection of string instruments. Ten violins and violas from the golden age of luthiers were investigated by portable NMR to collect depth profiles with the purpose of differentiating between the wood and the varnish layers. Results revealed a homogeneous wood density throughout the maple back plate. NMR relaxometry was then used to record the longitudinal and transverse relaxation times both in the wood layer and in the varnish layer. This permitted the dependence of the relaxation time with different violin age and different wood materials that were used in the violin manufacture to be observed, where specifically shorter relaxation times at the wood surfaces may be traces of previous treatments. The relaxation times can be correlated to the wood density information and plays an important role in the quality of the instrument, with the age of the violin. This information can potentially have great impact in the art of producing a high quality string instrument and as evidence in the authentication of master violins.

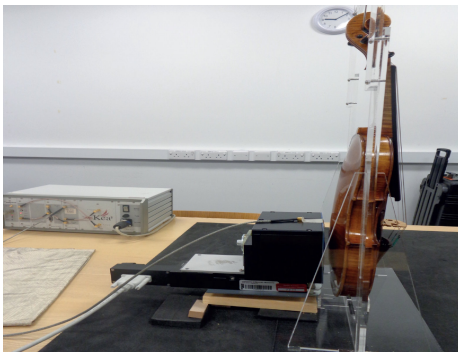

Figure: Portable NMR at the Ashmolean Museum, Oxford

M. Baias and Bernhard Blümich. In: *Modern Magnetic Resonance.* Ed. by Graham A. Webb. Springer, Cham, 2018

MOLAB access: IPERION CH. User Group Leader: Colin Harrison. Venue: Ashmolean Museum, Oxford, UK, www.ashmolean.org/

4. IMPLEMENTATION

INTRODUCTION

E-RIHS will give access to a wide range of instruments needed for heritage studies, offering new opportunities to heritage experts and scientists. The *Access Policy* describes the way multidisciplinary teams of users and individuals will be granted access from the selection of the most promising projects, to the joint publication of results by user teams and access providers. The *Data Policy* sets up a framework for the production and the exchanges of data in the context of E-RIHS, and in full compliance with the DARIAH Heritage Data Reuse Charter,[1] aiming at facilitating exchanges between experts, researchers and professionals in the field of heritage sciences. The selection of access providers is also subject to a well-defined procedure designed to gather first-rate instruments through a transparent process. They were drafted in accordance with the ten Pillars of the E-RIHS Scientific Vision which they implement in practice.

4.1. ACCESS POLICY

Through E-RIHS, multidisciplinary teams of users conducting heritage research will be granted access to a wide range of complementary instruments. The conditions of access will be defined by an *Access Policy*, with scientific excellence as a core principle. This *Access Policy* determines the scope of the access as well as the process by which access requests are submitted and selected, the selection criteria and the composition of peer panels responsible for selecting the most relevant projects. It also pays particular attention to results and data management. Designed to implement E-RIHS Scientific Vision, this set of policies reflects its ten Pillars.

Scope of the access

Access to E-RIHS platforms will be open to both European and international research teams. The E-RIHS governance structure and its core principles will ensure an optimal quality level to the users, including a compliance with European and national rules on access to research infrastructures. E-RIHS will not provide market-driven accesses. Scientific excellence is the core principle of this access policy, but it is not meant to preclude some level of differentiation between European and international users, especially when it comes to the attribution of travel and accommodation grants. In order to maintain a certain ratio of European users, the access policy might include quotas of non-European users. E-RIHS pledges to provide access with no access or submission fee. As a general rule, E-RIHS access should remain as free as possible, but it does not mean that no costs will be borne by the users. In particular, users' costs may include travel and accommodation fees, as well as insurance costs for the artefacts.

Submission and selection of access requests

E-RIHS will provide enhanced access to its platforms by supporting users from the elaboration of their proposal to the final dissemination of their results. While most accesses, including some parts of E-RIHS DIGILAB, will require to go through an evaluation process, a significant part of digital resources will be

[1] DARIAH, see n. 4.

directly available. The evaluation of proposals will be carried out by Peer-Review Panels (PRP, see composition below). E-RIHS will enable multi-platforms and large-scale projects. Large-scale projects will allow users to access multiple facilities in a time span of several years. In order to carry out large-scale projects, multidisciplinary teams of users will have to apply for an E-RIHS certificate through the normal access selection procedure. The E-RIHS PRP will then perform an extensive evaluation of the project during the first call, and regular assessments will be carried out along the duration of the large-scale projects. E-RIHS access providers will announce yearly their ratio of large-scale projects to the E-RIHS Head Office. Combined with short exploratory projects, large-scale projects will encourage the co-creation of knowledge by different categories of users and providers, therefore fostering crosscutting innovation.

1. **Pre-submission enquiry.** Potential users may contact the E-RIHS Helpdesk gathering scientists in all involved facilities. This Helpdesk will assist the users in the preparation of their proposal. The key feature of this preliminary support will be to offer a contact with the potential access providers to facilitate the preparation of proposals for access.

2. **Proposal submission.** Access proposals will be submitted online through a single access point, and they will include:

   (i) A **description of the scientific content** of the proposal, including:

      (a) The scientific impact in the heritage field and the proposed ways to disseminate the results.

      (b) The adequacy of the research proposal with the requested access service, with a presentation of preliminary studies that show how the proposal is integrated into an existing research project.

   (ii) **Key terms and a publishable summary.**

   (iii) **A commitment to acknowledge E-RIHS** in all communications, to use open IPR (Intellectual Property Rights) solutions as outlined in the E-RIHS data management plan. The users' future data sets must be re-usable according to the principles of the heritage data reuse charter and the proposal should integrate an assessment of the sensitiveness of the resulting data.

   (iv) **Administrative information**

Peer Review Panel

The E-RIHS Peer Review Panel (PRP) is composed of internationally renowned experts external to the ERIC E-RIHS, who cover the full range of Heritage Science. It is multidisciplinary, and it includes both expertise in knowledge of relevant collections, objects or artefacts, and techniques applied to heritage. It directly involves stakeholders (curators, conservators, art historians, archaeologists and palaeontologists, etc.) as well as specialists of the techniques involved.

Scientific criteria to select projects

The access policy for E-RIHS will have implications for its research management, but also on the global mobility of the researchers that will compete for access to the RI resources. The access to E-RIHS will be established on the basis of a peer review process with a focus on scientific excellence.[2] The peer review process will recommend access based on the most promising emergent ideas, regardless of the country of origin or the ability of the proposer to contribute financially. E-RIHS will foster the sharing and management of scientific data and information, especially by continuing engagement with community-based activities such as the Research Data Alliance (RDA).

A series of criteria was previously set up in the context of IPERION CH Project.

- Technical Feasibility
- Scientific Excellence
- Suitability of the method
- Other criteria

Access to results

E-RIHS will support an Open Access policy to data. However, access limitations may be necessary for copyright reasons, personal and privacy-sensitive data protection, and to protect legitimate Intellectual Property Rights (IPR). E-RIHS will abide by the DARIAH Heritage Data Re-Use Charter.[3]

Data resulting from an E-RIHS access will eventually need to be made accessible to the public according to the data management conditions listed in the access proposal.

Scientific data will be stored and curated at "local" repositories under the responsibility of a partner or a cooperating institution, with possible exceptions for a small number of reference datasets, such as vocabularies, reference tables, manuals, etc., which may be shared through the E-RIHS DIGILAB Catalogue to facilitate searches or to support the E-RIHS DIGILAB use.

Finally, all publications resulting from research carried out in relation to an E-RIHS platform should be made available in Open Access, with at least the author's accepted manuscript deposited in an OpenAire compliant repository. Publications should also make a clear reference to the facilities that have been used, as well as to the heritage or cultural institutions from which samples have originated.

Coherence with the Ten Pillars of E-RIHS

The coherence between the Access Policy and ten Pillars of E-RIHS is presented in Table 4.1.

[2] G7 Science Ministers. *G7 Science Ministers' Communiqué.* Communiqué. Turin, IT, Sept. 2017. URL: http://www.g7.utoronto.ca/science/2017-science-communique.html; European Commission. *European Charter for Access to Research Infrastructures. Principles and Guidelines for Access and Related Services.* Publication. Brussels, BE, 2016. DOI: 10.2777/524573.

[3] DARIAH, see n. 4.

Table 4.1.: Coherence between the Access Policy and the ten Pillars of E-RIHS.

Pillar	Matching implementation
1 - Competencies first	The completeness of user joint competencies, experience and level of expertise will be considered for the selection of proposals. The access catalogue will link information on instruments to the associated competencies.
2 - Interdisciplinarity	Access will be granted to most promising projects working on a common scientific question. The Peer-Review Panel will itself be multidisciplinary and involve Heritage stakeholders as well as technical experts.
3 - Co-creation	Access providers will cooperate in designing research projects. Selected projects will then be conducted in cooperation between users and access providers, who will usually co-publish their results.
4 - Communication	Data resulting from E-RIHS will be made accessible to the public and E-RIHS will implement open access policies.
5 - Excellence	One of the core evaluation criteria will be scientific excellence, from the viewpoint of the heritage disciplines.
6 - Interoperability	Users will benefit from instrumental interoperability in the framework of long projects. Data sets produced in the frame of the projects will be re-usable as stated in the DARIAH Heritage Data Reuse Charter
7 - Innovation	The peer-review process will recommend access based on the most promising emerging ideas. Projects leading to industrial innovation will be considered with particular attention.
8 - International recognition	E-RIHS access are often international by nature with extra-European users embedded in European teams. The interoperability and open access to data and publications will ensure the widest international recognition of E-RIHS projects.
9 - Ethics	Administrative admissibility criteria will ensure that pre-selected project respect ethical standards. The PRP will evaluate projects on ethical grounds, including by checking that measurements are done using the safest possible conditions to the objects.
10 - Quality	E-RIHS will ensure the best user experience by regularly assessing the quality of the access.

4.2. DATA POLICY

4.3. POLICY AND PROCEDURE FOR THE SELECTION OF ACCESS PROVIDERS

The policy and procedures for the selection of Access Providers of E-RIHS will be aligned with its *Scientific Strategy* and will be compliant with the quality criteria of the Research Infrastructure, expressed in its *Scientific and Technical Description*, and described in the form of ten pillars or core values in Section 2 of this document (page 19). Thus, provider proposals will need to focus on quality in terms of excellence of the facility and associated scientific expertise embodied by its staff, skills, interdisciplinarity, ability to support outstanding projects, innovation to stimulate the development of heritage science, global cooperation and ethics, with the ultimate goal of delivering an optimal user experience.

Selection criteria

Criteria for including Access Providers in E-RIHS will be defined and developed considering the following factors:

1. Uniqueness of the access offer at European level. This encompasses both scientific instruments, methods, reference collections or digital tools (please see the definition of Access in the E-RIHS Glossary, page 59), and the specific expertise of the staff. These are interrelated and operate in synergy, as, in some cases, the specific scientific or heritage expertise of access providers, even when associated with relatively conventional equipment, can make the facility entirely unique at European level.

2. Proven track record of heritage science research, evidence of ability to work across disciplines and information on how the access provider's offer builds on previous access experience (based on preceding European Commission programs in the field of heritage sciences). Where there is no heritage science track record (see 'technology watch' approach mentioned below), then the facility must demonstrate exceptional potential for future research and provide evidence of successful pilot applications in the heritage science field.

3. The access capacity and degree of excellence in relation to the services offered to users. This should be assessed by analysing factors such as the commitment to a minimum level of access (quantified according to a possible set of variables: number of days, of users or of projects but also by evaluating what level of access offer is appropriate for the type of facility). Assessment should also be guided by the qualifications and experience of staff personnel interacting with users on a day-to-day basis, and the engagement of the host institution in the supervision, management and quality checks of the work carried out through access and associated training activities.

4. The innovation potential of the access offer. This refers to the degree to which a facility will enhance the capacity of the research community to generate new cutting-edge research, whether through making rare facilities and associated expertise more widely available, or through new instruments with improved analytical or research capabilities. There should also be close alignment with user needs. The bulk of the access offer will be based on providers already in the heritage science field, but E-RIHS will also adopt a 'technology watch' approach, to identify new types of facilities or methodologies with no previous track record of applications to heritage but with great promise for this field of research, to stimulate continuous innovation in the infrastructure itself. This is particularly important to contribute to integrating new research trends and emerging research communities underrepresented in previous accesses at European level.

5. Evidence of robust data management plans and policies, so that data generated through access is preserved and can be re-used, as well as commitment to working towards alignment with harmonised data management policies and plans across E-RIHS and EOSC.

Membership procedure

In order to develop a coherent, innovative and integrated access offer for E-RIHS, and to ensure rigorous and consistent selection of access providers, a formal procedure will be established. This procedure will

be based on a regular call for access provision, where the applicant organisations will be asked to complete a questionnaire. The questionnaire will be designed to collect the necessary information to assess the candidate organisation on the criteria outlined above, including the specific contribution to E-RIHS in the form of specific services to ARCHLAB, DIGILAB, FIXLAB or MOLAB platforms, as well as details on data management, training and dissemination and so on.

Annex E provides two examples of forms or questionnaires for selection of Access Providers, one used for the IPERION HS project and a second used for the French node of E-RIHS. E-RIHS at European level can take advantage of the experience developed through these initiatives, using feedback on their effectiveness to improve the forms further so that they are fit for purpose.

Proposals received will be evaluated by the E-RIHS Scientific Advisory Committee that will apply the selection criteria listed above. To ensure a fair evaluation procedure, potential applicants will receive clear and specific guidelines to clarify key aspects, including what constitutes a facility that is unique at European level, what is the minimum access commitment needed to be eligible as an E-RIHS access provider and which criteria will the peer review committee use for selection.

The criteria and membership procedures that E-RIHS will implement will lead to the design of a coherent, strategically chosen Access Offer easy for users to navigate and understand. Nevertheless, E-RIHS will also adopt a proactive search for facilities or technologies that have the potential to become useful or interesting for heritage science research, or will promote the construction of new infrastructures as a result of gap analysis or landscaping foresight studies.

Participation of Access Providers in E-RIHS will be monitored periodically. Facilities will have to demonstrate enough demand from users, or otherwise to put forward a strong scientific argument to guarantee a future strong demand (i.e. for a new technology not yet much used in the heritage field but with great potential). This approach might prove useful to introduce new technologies and foster a route to innovation within the infrastructure.

History of the document

The E-RIHS consortium has developed valuable experience for selection of Access Providers through the implementation of specific procedures put in place in the elaboration of proposals for the preceding European Commission programs, such as EU-ARTECH, CHARISMA, IPERION CH, ARIADNE and IPERION HS.

In particular, for the IPERION HS program, the selection of Access Providers was made according to the principles outlined in section 4.3 that will constitute the guidelines of selection for E-RIHS. The process was initiated by a letter issued by the interim Governance of E-RIHS to National Coordinators in December 2018 asking them for support for enlargement of the community of Access Service Providers, beyond that available through the preceding IPERION CH program. They were informed of the related guidelines and criteria and were asked to prepare the offer of their respective Nodes. To this end, a form was prepared (see below) and prospective providers were asked to complete it for each access offer proposed for integration in the IPERION HS ARCHLAB, MOLAB or FIXLAB platforms (DIGILAB was not opened for access in this call). As a result of this request numerous offers of services were received from 14 National Nodes: 9 for ARCHLAB, 27 for FIXLAB and 24 for MOLAB. Evaluation of access offer proposals was carried out

by a committee formed of the Coordinators of the ARCHLAB, FIXLAB and MOLAB platforms, the interim Integration Director of E-RIHS and the IPERION HS Coordinator. The outcome of this exercise was the present Access Offer of IPERION HS.

Scientific, strategic and practical issues derived from the implementation of the provider selection process as described above constitute valuable background for putting in place the corresponding E-RIHS procedures.

See the forms attached in Annex E.

Appendices

Appendix A.

PROCESS OF PREPARING THIS DOCUMENT

The present *Scientific Strategy v1.0* results from an international collaborative writing in the European project E-RIHS PP. It has been prepared in the framework of Task 9.1 of the project, under the coordination of CNRS-IPANEMA (Loïc Bertrand), in collaboration with Marta Castillejo (IQFR-CSIC), Hilde De Clercq (KIK-IRPA), Marika Spring (NGL), Fanny Dubray, Bénédicte Charbonnel and Sophie David (CNRS-IPANEMA). They together formed the T9.1 subtasks leaders' Extended Group.

THE SCIENTIFIC VISION OF E-RIHS

The first document to be produced in this task was the E-RIHS *Scientific Vision*, which main elements were included in the E-RIHS *Scientific and Technical Description*, one of the core documents requested to apply for the ERIC status. The *Scientific Vision* was discussed, elaborated and articulated in a comprehensive document, "D9.1 – First version of the E-RIHS Scientific Vision",[1] delivered to the European Commission in March 2018 (M13). It represents an essential background to the present Scientific Strategy.

PREPARATION OF THE E-RIHS SCIENTIFIC STRATEGY v1.0

On this basis, work intensified on the drafting of the E-RIHS *Scientific Strategy v1.0*, with the following steps:

1. Literature was reviewed and exchanges were intensified with the groups working on the interconnected deliverables of the E-RIHS PP and IPERION CH projects. The work focused in particular on identifying the specificities of practices in the field, strengthening interdisciplinary interfaces between HS and other scientific fields, monitoring gaps in the E-RIHS service catalogue and ways to stimulate the provision of new services;

2. The structure of the document was worked on, discussed and approved. Templates were produced, particularly for the preparation of the highlights. A shared LaTeX document was created to allow the joint writing process, and implemented on the collaborative platform *Overleaf*;

3. Contents were produced by a large number of contributors and integrated under the supervision of the Subtasks' leaders. A large number of presentations were made in various formats by the Task leader (see below);

4. A review of the document was carried out at several key stages, including by the E-RIHS PP National Coordinators Committee, and comments were incorporated towards finalisation of the deliverable.

Throughout the process, the extended T9.1 Subtasks' Leaders group interacted on a regular basis and met regularly physically and virtually. Before each main meeting, the latest version of the documents was circulated between Subtasks' leaders to provide feedback. A number of additional colleagues were invited during coordination work meetings, taking advantage of the various location of the meetings and their proximity with meetings of the E-RIHS partnership.

[1] Bertrand et al., see n. 1.

WORK AND CONSORTIUM MEETINGS

The main meetings of the T9.1 Subtask leaders' Extended Group took place:

- in 4th May 2017 in Brussels,
- in 30 August 2017 in Paris,
- in 17 November 2017 in Brussels,
- in 22 February 2018 in Amsterdam,
- in 5 September 2018 in Warsaw,
- in 19 October 2018 in Florence,
- from 13 to 16 February 2019 in Paris, in the context of World Meeting on Heritage, Sciences and Technologies,
- on 11 April 2019 in Aachen,
- on 9 June 2019 in Brussels,
- on 29 August 2019 in Madrid.
- on 13 July 2020 (virtual meeting).

Progress on the work was regularly presented at E-RIHS PP Interim Meetings, Annual meetings and Days. Discussions with the participants on the content of T9.1 documents followed the presentations. Those main presentations and discussions were held:

- in March 2017, E-RIHS PP Kick-off meeting, Florence,
- in May 2017, E-RIHS Day, Heraklion,
- in September 2017, E-RIHS PP First Interim Meeting, Prague,
- in November 2017, E-RIHS Day, Brussels,
- in February 2018, E-RIHS PP First Annual Meeting, Amsterdam,
- in April 2018, E-RIHS Day, Copenhagen,
- in September 2018, E-RIHS PP Mid-term meeting, Warsaw,
- in October 2018, E-RIHS PP Interim meeting, Florence,
- in February 2019 E-RIHS PP Second Annual Meeting, Madrid,
- in January 2020, E-RIHS PP Interim meeting, Evora.

Additional working documents were produced to encourage discussion among E-RIHS PP partners and national communities:

- a poster entitled the *Scientific Vision of E-RIHS* was generated, regularly updated and used in various meetings to generate convergent thinking and strategy, used several times with direct annotations to incorporate comments (see Annex D; Fig. A.1);
- a six-page flyer used by the Coordinator to present the strategy,
- and exchanges in the production of the *Scientific and Technical Description* of E-RIHS.

BROADER CONSULTATION

A large number of experts from the heritage science community were consulted throughout the process, and in particular at several formal meetings:

- on 23 February 2018, the Scientific Vision was approved after presentation at the E-RIHS Stakeholder Advisory Board.
- on 18 October 2018, the Scientific Vision was presented at the International Workshop *From cross-disciplinary research to heritage science* in Florence.

Figure A.1.:
On the background, the E-RIHS Scientific Strategy poster is presented to the attendance of the 1st Annual Meeting E-RIHS PP in Amsterdam in February 2018.

- On 20 March 2019, the E-RIHS Scientific Strategy was discussed at the REACH Symposium in Brussels.
- On 20 May 2019, the E-RIHS Scientific Strategy was discussed was discussed at the ECHOES meeting in Brussels.
- On 4 September 2019, the E-RIHS Scientific Strategy was presented to students during a round table at the Universidad Internacional Menéndez Pelayo Summer Course on *Nuevos retos en la caracterización y conservación de los bienes del Patrimonio Cultural*, in Santander, Spain.
- from 22 September to 4 October 2019, a panel of experts and members of the E-RIHS PP consortium, including members of the E-RIHS PP National Coordinators Committee, was consulted on the document.
- on 3 October 2019, the E-RIHS Scientific Strategy was presented and gathered feedback from the IPERION HS Scientific Advisory Board.
- on 3 October 2019, the E-RIHS Scientific Strategy was presented and gathered feedback from the NETCHER Consortium.
- in December 2019, the E-RIHS Scientific Strategy was presented at the workshop *EU Horizon 2020 Framework Program: Opportunities for the Use of Research Infrastructures for Ukrainian Scientists and Entrepreneur* in Odessa, Ukraine.

The scientific vision and scientific strategy documents have also been presented at meetings of national E-RIHS consortia, in particular:

- in November 2017, Heritage Science Days in Vienna.
- in December 2017, E-RIHS.uk meeting in London.
- in January 2018, E-RIHS.fr meeting in Paris.
- in February 2018, E-RIHS.nl meeting in Amsterdam.
- in October 2018, E-RIHS.fr Day in Paris.
- in February 2020, E-RIHS.es meeting in Madrid.

Appendix B.

ACRONYMS

ARIADNE EC project Advanced Research Infrastructure for Archaeological Dataset Networking in Europe (2013–2017, Grant agreement ID: 313193), https://cordis.europa.eu/project/id/313193

ARIADNEplus EC project Advanced Research Infrastructure for Archaeological Data Networking in Europe – plus (2019–2022, Grant agreement ID: 823914), https://cordis.europa.eu/project/id/823914

ATR Attenuated total reflectance

CERIC Central European Research Infrastructure Consortium, https://www.ceric-eric.eu/

CERN European Organization for Nuclear Research [French: *Conseil européen de la recherche nucléaire*], http://home.cern

CHARISMA EC Project Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to Conservation/Restoration (2009–2014, Grant agreement ID: 228330), https://cordis.europa.eu/project/id/228330

DAD Diode Array Detector

DARIAH Digital Research Infrastructure for the Arts and Humanities, https://www.dariah.eu

DHSPI Digital Holographic Speckle Pattern Interferometry

DiSSCo Distributed Systems of Scientific Collections [of Natural History], https://www.dissco.eu

EC European Commission, https://ec.europa.eu

EDI European Data Infrastructure, https://eudat.eu/european-data-initiative

EDX Energy-dispersive X-ray spectrometry

EOSC European Open Science Cloud, https://www.eosc-portal.eu

ERA European Research Area

e-RI e-Research Infrastructure

ERIC European Research Infrastructure Consortium, https://ec.europa.eu/info/research-and-innovation/strategy/european-research-infrastructures/eric_en

E-RIHS European Research Infrastructure for Heritage Science, www.e-rihs.eu

E-RIHS PP EC project European Research Infrastructure for Heritage Science Preparatory Phase (2017–2020, Grant agreement ID: 739503), https://cordis.europa.eu/project/id/739503

ESFRI European Strategy Forum on Research Infrastructures, https://www.esfri.eu

ESRF European Synchrotron Radiation Facility, Grenoble, http://www.esrf.eu

ESS European Spallation Source, Lünd, https://europeanspallationsource.se

EU European Union https://europa.eu/

FAIR Findable, Accessible, Interoperable and Re-usable

FTIR Fourier Transform Infrared Spectroscopy

GRI Global Research Infrastructure

GSO Group of Senior Officials on Global Research Infrastructures, https://www.gsogri.org/

HPC High-Performance Computing

HSI hyperspectral imaging

IAEA International Atomic Energy Agency, https://www.iaea.org

IBA Ion Beam Analysis

IBIL Ion beam-induced luminescence

ICCROM International Centre for the Study of the Preservation and Restoration of Cultural Property, https://www.iccrom.org

ICOM International Council of Museums, https://icom.museum

ICON Institute of Conservation, https://icon.org.uk

IIC International Institute for Conservation of Historic and Artistic Works, https://www.iiconservation.org

IIIF International Image Interoperability Framework, https://iiif.io

ILL Institut Laue–Langevin, Grenoble, https://www.ill.eu

IPERION CH EC project Integrated Platform for the European Research Infrastructure On Cultural Heritage (2015–2019, Grant agreement ID: 654028), https://cordis.europa.eu/project/id/654028

IPERION HS EC project Integrated Platform for the European Research Infrastructure On Heritage Science

IPR Intellectual Property Rights

JPI-CH Joint Programming Initiative on Cultural Heritage and Global Change, https://jpi-ch.eu

KPI Key Performance Indicator

LabS TECH EC project Laboratories on Science and Technology for the conservation of European Cultural Heritage (2001–2004, Grant agreement ID: HPRI-CT-2000-40018), https://cordis.europa.eu/project/id/HPRI-CT-2000-40018

LEAPS League of European Accelerator-based Photon Sources, https://leaps-initiative.eu/

LC Liquid chomatography

LIBS Laser Induced Breakdown Spectroscopy

MPEF Multi-Photon Excitation Fluorescence

NETCHER EC project NETwork and digital platform for Cultural Heritage Enhancing and Rebuilding (2019–2020, Grant agreement ID: 822585), https://cordis.europa.eu/project/id/822585

NMR Nuclear Magnetic Resonance

NLOM Nonlinear Optical Microscopy

OCT Optical Coherence Tomography

OECD Organisation for Economic Co-operation and Development, https://www.oecd.org/

OpenAIRE European Open Science Infrastructure, for open scholarly and scientific communication, https://www.openaire.eu/

PARTHENOS EC project Pooling Activities, Resources and Tools for Heritage E-research Networking, Optimization and Synergies (2015–2019, Grant agreement ID: 654119), https://cordis.europa.eu/project/id/654119

PIGE Particle Induced Gamma-ray Emission

PIXE Particle-Induced X-ray Emission

QTOF Quadrupole Time of Flight

RBS Rutherford Backscattering Spectrometry

RDA Research Data Alliance, https://www.rd-alliance.org

REACH EC project Re-designing access to CH for a wider participation in preservation, (re)use and management of European culture (2017–2020, Grant agreement ID: 769827), https://cordis.europa.eu/project/id/769827

RI Research Infrastructure

SEM Scanning Electron Microscopy

SERS Surface-enhanced Raman Scattering

SOLEIL Source Optimisée de Lumière d'Énergie Intermédiaire du Laboratoire d'utilisation du rayonnement électromagnétique, https://www.synchrotron-soleil.fr

SSH Social Sciences and Humanities

SSHOC EC project Social Sciences and Humanities Open Cloud (2019–2022, Grant agreement ID: 823782), https://cordis.europa.eu/project/id/823782

SWIR Shortwave Infrared

TDS Time-Domain Spectroscopy

TNA Transnational Access

UNESCO United Nations Educational, Scientific and Cultural Organization, https://en.unesco.org

VRE Virtual Research Environment

XRD X-ray Diffraction

XRF X-ray Fluorescence

Appendix C.

GLOSSARY

Access **Access** refers to the authorized physical, remote or virtual admission to use of E-RIHS platforms and to offered services. It encompasses, but is not limited to, instrument time, computing resources, software, data, data-communication services, sample preparation, archives and collections consultation, the set-up and execution of experiments, analytical services and expert support.

Access Provider Research organisation providing access to one or more facilities. **E-RIHS Access Providers** are organisations that commit to provide access through E-RIHS.

Advanced Community Community that has already received financial support in the frame of an Integrating Activity project under a previous European Research Infrastructure programme.

ARCHLAB Research facility or facilities consisting of physical and digital archives and collections useful for heritage research, such as images, analytical data and reports ('grey literature'), conservation documentation, samples and reference materials, as stored in museums, galleries, monuments, conservation and research institutions, made available for access through E-RIHS together with the related specialized expertise.

DIGILAB Online research facility or facilities consisting of digital tools, digital services and digital research resources concerning heritage and data, including the related specialized expertise, made available for access through E-RIHS with the aim to make heritage science data FAIR (Findable, Accessible, Interoperable and Re-usable). This includes and enables access to searchable registries of datasets, reference collections, thesauri, ontologies, etc., and supports data interoperability through the creation of shared knowledge organization systems.

ERIC European Research Infrastructure Consortium, specific legal form that facilitates the establishment and operation of Research Infrastructures with European interest, as defined in the Council Regulation (EU) No 1261/2013 of 2 December 2013 amending Regulation (EC) No 723/2009.

ESFRI Landmark The **ESFRI Landmarks** are Research Infrastructures that were implemented, or reached an advanced Implementation Phase, under the Roadmap and that represent major elements of competitiveness of the ERA. The Landmarks can be already delivering science services and granting user access, or can be in advanced stage of construction with a clear schedule for the start of the Operation Phase. The Landmarks need continuous support and advice for successful completion, operation and – if necessary – upgrade to achieve optimal management and maximum return on investment.

ESFRI Project The **ESFRI Projects** are Research Infrastructures in their Preparation Phase which have been selected for the excellence of their scientific case and for their maturity, according to a sound expectation that the Project will enter the Implementation Phase within the ten-year term. They are included in the Roadmap to point out the strategic importance they represent for the European Research Area, and to support their timely implementation as new Research Infrastructures or major updates of existing RIs. The Projects can be at different stages of their development towards implementation according to their respective date of inclusion in the Roadmap.

External researcher Person or team accessing or having accessed E-RIHS ERIC platforms. **External researchers** can come from academic institutions, research centers, industry or other private and public institutions involved in Heritage Science activities. They are involved in the conception or creation of new knowledge, products, processes, methods and systems or in project management. Teams of users can include researchers, technical staff and students undertaking research in the framework of their studies. The expertise of both the researchers accessing E-RIHS facilities and the experts who run them is essential for successful research. User communities have a role in stimulating continuous improvements and innovations at the level of facilities.

Facility A unit within an organisation whose staff and/or equipment can be accessed for the purpose of research, e.g. a scientific laboratory, a conservation workshop, a history department.

FIXLAB Research facility involving equipment which is not moved on the site of the studied object, including the related specialized expertise, made available for access through E-RIHS.

Heritage Data Reuse Charter Charter aiming at fluidifying the exchanges of information between heritage institutions and researchers. The basis of the charter is a moral contract, the mission statement all stakeholders must adhere to. It comprises of six core principles: Reciprocity, Interoperability, Citability, Openness, Stewardship, Trustworthiness. As defined by DARIAH: https://www.dariah.eu/activities/open-science/data-re-use/

Heritage Science **Heritage Science** is the interdisciplinary domain of scientific study of heritage. Heritage science draws on diverse humanities, sciences and engineering disciplines. It focuses on enhancing the understanding, care and sustainable use of heritage so it can enrich people's lives, both today and in the future. Heritage science is an umbrella term encompassing all forms of scientific enquiry into works of man and combined works of nature and man of value to people. As defined on Wikipedia: https://en.wikipedia.org/wiki/Heritage_science

IIIF The International Image Interoperability Framework (https://iiif.io/) defines several application programming interfaces that provide a standardised method of describing and delivering images over the web, as well as "presentation based metadata" (that is, structural metadata) about structured sequences of images. As defined on Wikipedia: https://en.wikipedia.org/wiki/International_Image_Interoperability_Framework

Internal researcher A researcher working within an E-RIHS facility offering access to external researchers.

Label The **E-RIHS Label** refers to the name of the infrastructure, its acronym, its logo, its visual identity or any other feature that identifies its scientific activities or its services as distinct from those of other institutions. The authorized use of the E-RIHS label by the ERIC or its National Nodes for the pursuit of our common objectives will generate recognition and establish a reputation of cross disciplinary excellence in Heritage Science, to the benefit of the ERIC and its Members. It will overall strengthen the field of study and the European Research Area.

MOLAB Mobile research facility consisting of portable or transportable instruments and other associated equipment for measurements on site, including the related specialized expertise, made available for access through E-RIHS.

National Node **E-RIHS National Nodes** are entities set up to conduct E-RIHS activities in a given Mem-

ber of the E-RIHS ERIC. National Nodes coordinate their national facilities and monitor the national in-kind contribution to the ERIC. This implies both qualitative and quantitative oversight of the facilities and the access services they provide to E-RIHS. National Nodes may conduct other activities that are not mandated by the ERIC. These activities may include national training programmes, conferences and events, national users representation, public engagement, etc. National activities respect the E-RIHS values and objectives, as well as the policy elaborated at the European level for the use of the E-RIHS Label.

Peer Review Panel The **E-RIHS Peer Review Panel** evaluates access proposals for all types of physical access to E-RIHS platforms. It is constituted of world-class experts, both researchers and professionals, and covers a wide range of knowledge and expertise within the field of Heritage Science.

Platform An integrated set of facilities, resources and services accessible to the E-RIHS researchers. There are four E-RIHS platforms, designated as LABs: ARCHLAB, DIGILAB, FIXLAB and MOLAB.

Preparatory Phase The **Preparatory Phase** of the ERIC aims at bringing the project for the new or upgraded research infrastructure identified in the ESFRI roadmap or in the European strategy for particle physics (CERN Council) to the level of legal, financial, and, where applicable, technical maturity required for implementing it. The preparation of the legal agreements (including site, governance, financing of the new research infrastructures) is one of the main activities and deliverables and must be finalised before the end of the project (e.g. through the signature of a Memorandum of Understanding).

RDA The Research Data Alliance, https://www.rd-alliance.org/.

Research infrastructure "Facilities, resources and services that are used by the research communities to conduct research and foster innovation in their fields. They include: major scientific equipment (or sets of instruments), knowledge-based resources such as collections, archives and scientific data, e-infrastructures, such as data and computing systems and communication networks and any other tools that are essential to achieve excellence in research and innovation".[1]

Scientific instrument A **Scientific Instrument** is a device or a tool used for scientific purposes, including the study of both natural phenomena and theoretical research. As part of a Facility, instruments can be accessed through E-RIHS.

[1] European Parliament and Council of the EU. *Regulation (EU) No 1291/2013 of the of 11 December 2013 establishing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020) and repealing Decision No 1982/2006/EC Text with EEA relevance.* en. Statute 32013R1291. Dec. 2013. URL: http://data.europa.eu/eli/reg/2013/1291/oj/eng (visited on 09/01/2019).

Appendix D.

POSTER – THE SCIENTIFIC VISION OF E-RIHS

The following document is the poster *The Scientific Vision of E-RIHS*, used during the working sessions and optimized iteratively, sometimes by direct annotation by the participants, noting the changes with a marker pen.

The **Scientific Vision** of E-RIHS

Research Area

Major Heritage questions
Values: identification and perception, well-being, societal environment

Preservation for future generations: natural risks, conflicts…

1000s of object-specific studies
Conservation

Documentation

Interpretation

Major Heritage projects
Major collection studies

Major excavations

EU flagship projects…

Scientific studies on tangible heritage
Origins – Where do they come from?

Current state – What are they?

Future – Where are they going?

Material systems
Unknown production, history and ageing conditions

Heterogeneous & multiscale…

Socio-economic impact
Tourism and creative industries

Training

Society, civilisation

Scientific diplomacy

Societal challenge

Knowledge

European-level needs (subsidiarity)
E-RIHS will act when the synergy of collaboration between national facilities makes it possible to address extraordinary cross-disciplinary research questions

Cooperation at national and global levels

Research Infrastructure

Impact in Heritage Science
New generated knowledge for understanding, preservation and use of Heritage

Enabling and better operating innovative Heritage research

Enlarging research communities

A coordinated body contributing to research strategies

New methodologies within the field

Efficient use of resources

Public engagement

Training

Connection with international partners

E-RIHS

Four Platforms

FIXLAB — Material studies

MOLAB — **Knowledge and multi-disciplinary expertise**

DIGILAB — Data resources

ARCHLAB

… and beyond
Application of methodologies beyond the field

Emergence of new materials

Inspiration for next-generation students

Versatile researchers that can confidently cross disciplines

New intellectual frameworks

Ten pillars promoting excellence through best practice

E-RIHS specific
- Interdisciplinarity
- Competencies first
- Co-creation
- Communication
- International recognition

Generic
- Excellence
- Innovation
- Interoperability
- Ethics
- Quality

E-RIHS PP T9.1 20-02-2018

E-RIHS
EUROPEAN RESEARCH INFRASTRUCTURE FOR HERITAGE SCIENCE

The Preparatory Phase of E-RIHS is supported by the European Union's Horizon 2020 research and innovation programme E-RIHS PP under grant agreement No 739503.

Appendix E.

EXAMPLE APPLICATION FORMS FOR NEW ACCESS PROVIDERS

Two forms are provided:

1. The form used to select access providers in the European Commission's IPERION HS. Please also refer to explanations at section 4.3, page 44.
2. A sample *Application form to join the E-RIHS infrastructure*, generated and used at the national level by several national infrastructures to select new providers. Several countries (in particular Spain, France, Italy and the United Kingdom) have developed and used such forms, and have therefore exchanged these documents, while enriching them with the comments received from their authorities. The form contains country-specific questions, the particular example taken here is the French questionnaire.

This overall iterative process has allowed improving this document, while bringing it closer to the core values of the E-RIHS infrastructure.

DESCRIPTION OF ACCESS OFFER FOR IPERION HS PROPOSAL ***□ FIXLAB/ □ MOLAB/ □ ARCHLAB*** *Select the platform and fill one questionnaire per each type of access offer*
Name of the large/medium scale laboratory, mobile laboratory or archive *Country of the National Node*
Contact details
Name of the large/medium scale laboratory, mobile laboratory or archive: *Contact person:* *e-mail:* *phone number:*
Description of the Access Offer
General description and uniqueness of the access offer
Applications to different types of materials or heritage objects, and information that can be obtained (for FIXLAB/MOLAB), or *Content and related type of objects/collection materials (for ARCHLAB)*
Description of the characteristics of the equipment/s, applicable for FIXLAB/MOLAB
Selected bibliography about the technique(s) or method (FIXLAB and MOLAB) or related to the resources available (ARCHLAB) published by the provider (up to 5 references)
Previous experience of the provider in the Heritage Science
General description of the team and its experience
Previous national and international projects on Heritage Science involving the proposed access offer
Selected publications by the provider (up to 5 references)
Number of requests of transnational access foreseen per year (based on past experience of the provider if applicable)
Describe data management actions you will implement in favour of an integration into the future digital platform
Other comments
□ *I hereby authorize the use of my personal data in accordance to the GDPR 679/16 - "European regulation on the protection of personal data".*

E-RIHS
EUROPEAN RESEARCH INFRASTRUCTURE FOR HERITAGE SCIENCE

Application to join the E-RIHS infrastructure

Application Form

1. **Candidate organisation** (laboratory, large-scale facility, etc.)	
1.1 General information	
Name	Click here to enter text.
Acronym	Click here to enter text.
European (MERIL, etc.) or national identifier (if applicable)	Click here to enter text.
Address	Click here to enter text.
Shareholders (if applicable)	Click here to enter text.
1.2 Contacts	
Representative at the General Assembly of Access Providers	Click here to enter text.
Representative on the working group on Access	Click here to enter text.
Representative on the working group on Full Costs	Click here to enter text.
Representative to the working group on Data	Click here to enter text.
Representative on the working group on Training	Click here to enter text.
1.3 Information for E-RIHS France communication	
Logo of the organisation	*Please send it as an attachment.*
Description of the organisation in French (max. 200 words)	Click here to enter text.
Description of the organisation in English (max. 200 words)	Click here to enter text.

2. Contribution to E-RIHS	
The information below describes the contribution (instruments, archives, services, methodological research) that you are willing to provide as part of E-RIHS. In the event that your organisation makes several contributions of a different nature, please duplicate this table.	
2.1 General information	
Name of the contribution (instruments, archives, services, methodological research)	Click here to enter text.
Acronym	Click here to enter text.
Location (if different from the organisation)	Click here to enter text.
Date of entry into service	Click here to enter text.
Description (max. 200 words)	Click here to enter text.
Logo (if different from the structure)	*Please send it as an attachment.*

2.2 Skills and expertise		
Staff and skills of the team devoted to this contribution to E-RIHS access (max. 200 words)	Click here to enter text.	
Indicate a maximum of five bibliographic references related to the contribution	Click here to enter text.	
Position in the national landscape	Click here to enter text.	
Position in the European landscape	Click here to enter text.	
Have you ever provided access within the frame of national projects? Specify, if applicable.	☐ Yes ☐ No Click here to enter text.	
Have you already provided access within the frame of European projects? Specify, if applicable.	☐ Yes ☐ No Click here to enter text.	
2.3 Current access modalities		
How many user teams do you host on average per year?	National: Click here to enter text.	International: Click here to enter text.
Are projects selected according to a call for projects procedure? If so, describe it.	☐ Yes ☐ No Click here to enter text.	
Do you have a project selection committee? If so, who is it composed of?	☐ Yes ☐ No Click here to enter text.	
2.4 Access to E-RIHS France		
How many user teams will you host on average per year?	National: Click here to enter text.	International: Click here to enter text.
Access unit (time, day, shift of *x* hours...)	Click here to enter text.	
Access volume per year (in the access unit)	Click here to enter text.	
Average duration of a project (in the access unit)	Click here to enter text.	
Can you provide access to long term projects (typically three years)?	☐ Yes ☐ No	
Can you provide access to exploratory projects?	☐ Yes ☐ No	
2.5 Coverage of costs		
Are public institutions charged to access your contribution?	☐ Yes ☐ No	
If so, what is the principle of your pricing?	Click here to enter text.	
What is the cost of an access unit?	Click here to enter text.	
Has this cost been audited?	☐ Yes ☐ No	
2.6 Reception conditions for user teams		
What support will you provide in setting up and submitting proposals?	Click here to enter text.	
What support will you provide during the use of the contribution?	Click here to enter text.	
What support will you provide in the analysis of the results?	Click here to enter text.	
Will you provide accomodation to users?	☐ Yes ☐ No	

3. Data	
The questions below apply to the data generated by your contribution to E-RIHS projects.	
Estimated volume of data generated per project	Click here to enter text.
How will the generated data be transmitted to the user teams?	Click here to enter text.
If your data policy is described in a specific document, please attach it or add link.	Click here to enter text.
Will the data be generated in a standardised format? If so, please specify.	☐ Yes ☐ No Click here to enter text.
Will it be an open format?	☐ Yes ☐ No
Will your staff be co-owners of the generated data?	☐ Yes ☐ No
Would you recommend a data reuse license (CC-BY, etc.)? If so, which one?	☐ Yes ☐ No Click here to enter text.
Will you offer a data hosting service? In case of a public repository, please specify.	☐ Yes ☐ No Click here to enter text.
How long will the hosting service be granted?	Click here to enter text.
Who will have access to the hosted data?	Click here to enter text.

4. Training and Dissemination	
How will you train the E-RIHS user community (tutorials, seminars, etc.)?	Click here to enter text.
How will you disseminate the results to the general public?	Click here to enter text.
Does the team operating the contribution provide academic courses in the heritage field? Please specify the five main institutions.	☐ Yes ☐ No Click here to enter text.
Does the the team operating the contribution supervise doctoral and post-doctoral students in the heritage field? Specify how many students are concerned.	☐ Yes ☐ No Click here to enter text.

Appendix F.

LIST OF FACILITIES

The following list contains the participating organisations to the four LABs in the infrastructure projects CHARISMA, IPERION CH and IPERION HS.

F.1. ARCHLAB

CHARISMA project ARCHLAB was composed of:

- Centre de Recherche et des Restauration des Musées de France, Paris, France (CNRS-C2RMF), http://www.c2rmf.fr/
- The National Gallery, London, United Kingdom (NG), http://www.nationalgallery.org.uk
- The British Museum, London, United Kingdom (BM), http://www.britishmuseum.org
- Opificio delle Pietre Dure, Florence, Italy (OPD), http://www.opificiodellepietredure.it
- Rijksdienst voor het Cultureel Erfgoed, Amsterdam, The Netherlands (RCE), http://www.cultureelerfgoed.nl
- Museo Nacional del Prado, Madrid, Spain (PRADO), http://www.museodelprado.es

IPERION CH project ARCHLAB was composed of:

- The British Museum, London, United Kingdom (BM), http://www.britishmuseum.org
- Centre de Recherche et des Restauration des Musées de France, Paris, France (CNRS-C2RMF), http://www.c2rmf.fr/
- Instituto del Patrimonio Cultural de España (IPCE), Madrid, Spain, http://ipce.mcu.es
- Koninklijk Instituut voor het Kunstpatrimonium/Institut Royal du Patrimoine artistique, Brussels, Belgium (KIK-IRPA), http://www.kikirpa.be
- The National Gallery, London, United Kingdom (NG), http://www.nationalgallery.org.uk
- Opificio delle Pietre Dure, Florence, Italy (OPD), http://www.opificiodellepietredure.it
- Museo Nacional del Prado, Madrid, Spain (PRADO), http://www.museodelprado.es
- Rijksdienst voor het Cultureel Erfgoed, Amsterdam, The Netherlands (RCE), http://www.cultureelerfgoed.nl
- Centre for Art Technological Studies and Conservation, Copenhagen, Denmark (SMK-CATS), http://www.cats cons.dk
- Rathgen Forschungslabor Staatliche Museen zu Berlin – Stiftung Preußischer Kulturbesitz, Berlin, Germany (SPK), http://www.smb.museum

IPERION HS project Within IPERION HS, 6 new providers joined integrating facilities active in the field of palaeontology, archaeology, and craft science, while 2 providers withdrew, Museo Nacional del Prado, Madrid, and CATS, Copenhagen:

- Koninklijk Museum voor Kunst en Geschiedenis / Musée Royal d'Arts et Histoire, Brussels, Belgium (KMKG/MRAH), http://www.kmkg-mrah.be/
- Groningen Institute of Archaeology, University of Groningen, The Netherlands (RUG), https://www.rug.nl
- Laboratoire de recherche des monuments historiques (LRMH), Champs-sur-Marne, France, https://www.lrmh.fr/
- National Institute of Heritage (NIH), Bucharest, Romania, https://patrimoniu.ro/
- The Craft Laboratory, Department of Conservation, Faculty of Science, University of Gothenburg, Swe-

den (CL), https://craftlab.gu.se
- Historic England Laboratory, Fort Cumberland, Portsmouth, United Kingdom, https://historicengland.org.uk

F.2. DIGILAB

DIGILAB will be entirely created with E-RIHS ERIC.

F.3. FIXLAB

EU-Artech project FIXLAB was composed of:
- AGLAE at C2RMF, Paris, France, http://www.c2rmf.fr/

CHARISMA project FIXLAB was composed of:
- AGLAE at C2RMF, Paris, France, http://www.c2rmf.fr/
- IPANEMA/Synchrotron SOLEIL, Saint-Aubin, France, http://ipanema.cnrs.fr/
- ATOMKI-HAS,Debrecen, Hungary, https://www.atomki.hu/en/
- Budapest Neutron Centre-WIGNER, Budapest, Hungary (BNC-WIGNER), https://www.bnc.hu

IPERION CH project FIXLAB was composed of:
- AGLAE at C2RMF, Paris, France, http://www.c2rmf.fr/
- IPANEMA/Synchrotron SOLEIL, Saint-Aubin, France, http://ipanema.cnrs.fr/
- ATOMKI-HAS,Debrecen, Hungary, https://www.atomki.hu/en/
- Budapest Neutron Centre-WIGNER, Budapest, Hungary (BNC-WIGNER), https://www.bnc.hu

organised in two platforms (France and Hungary).

IPERION HS project FIXLAB is composed of:
- FIXLAB CZ ITAM
- FIXLAB DE consists of two facilities:
  - FIXLAB DE-1 Curt Engelhorn Zentrum Archäometrie
  - FIXLAB DE-2 Heinz Maier-Leibnitz Zentrum
- FIXLAB ES consists of three facilities:
  - FIXLAB ES-1 CENIEH-Geochrono and MatCharact
  - FIXLAB ES-2 IQFR-CSIC
- FIXLAB FR consists of five facilities:
  - FIXLAB FR-1 C2RMF/AGLAE
  - FIXLAB FR-2 HS omics
  - FIXLAB FR-3 IPANEMA
  - FIXLAB FR-4 MNHN/CRC
  - FIXLAB FR-5 Synchrotron SOLEIL
- FIXLAB GR FORTH
- FIXLAB HU consists of two facilities:
  - FIXLAB HU-1 BNC-EK/WIGNER
  - FIXLAB HU-2 MTA Atomki
- FIXLAB IT consists of two facilities:

  - FIXLAB IT-1 INFN-CHNet Firenze
  - FIXLAB IT-2 INFN-CHNet, LNGS unit
- FIXLAB NL Geological and geochemical Lab Amsterdam
- FIXLAB PT LNEC
- FIXLAB SI Heritage Macromolecular Lab
- FIXLAB SE consists of two facilities:
  - FIXLAB SE-1 Heritage Lab
  - FIXLAB SE-2 SciLife Lab
- FIXLAB UK consists of three facilities
  - FIXLAB UK-1 BioArCh
  - FIXLAB UK-2 Historic England
  - FIXLAB UK-3 UCL

organised in 12 national platforms: Czech Republic, France, Germany, Greece, Hungary, Italy, Portugal, Slovenia, Spain, Sweden, The Netherlands, United Kingdom.

F.4. MOLAB

EU-Artech project MOLAB was composed of:

- Università degli Studi di Perugia, Italy (UNI-PG), https://www.unipg.it
- Istituto per la Conservazione e la Valorizzazione dei Beni Culturali, Consiglio Nazionale delle Ricerche, Florence, Italy (CNR-ICVBC), http://www.icvbc.cnr.it/
- Opificio delle Pietre Dure, Florence, Italy (OPD), http://www.opificiodellepietredure.it/
- Istituto Nazionale di Ottica Applicata, Consiglio Nazionale delle Ricerche, Florence, Italy (CNR-INOA), https://fed.ino.it/

CHARISMA project

- Università degli Studi di Perugia, Italy (UNIPG), https://www.unipg.it
- Laboratoire d'Archéologie Moléculaire et Structurale, Centre National de la Recherche Scientifique, Paris, France (CNRS-LAMS), http://www.impc.upmc.fr/fr/unites_de_recherche/lams_umr_8220.html
- Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, Florence, Italy (CNR-INO), https://fed.ino.it/

IPERION CH project

- Istituto di Scienze e Tecnologie Molecolari, Consiglio Nazionale delle Ricerche, Università degli Studi di Perugia, Italy (CNR-ISTM), http://www.istm.cnr.it/
- Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, Florence, Italy (CNR-INO), https://fed.ino.it/
- Laboratorio di Diagnostica per i beni culturali di Spoleto, Italy (LabDia), http://www.diagnosticabeniculturali.it/
- Centro di Eccellenza SMAArt, Università degli Studi di Perugia, Italy (UNIPG), as a third party, https://www.unipg.it
- Centre de Recherche sur la Conservation, Centre National de la Recherche Scientifique (CNRS-CRC), Paris and Champs-sur-Marne, France. http://crc.mnhn.fr
- Centre de Recherche et de Restauration des Musées de France, Centre National de la Recherche Scientifique, Paris, France (CNRS-C2RMF), http://www.c2rmf.fr/

- Foundation for Research and Technology–Hellas, Heraklion, Greece (FORTH), https://www.forth.gr/
- Uniwersytet Mikołaja Kopernika w Toruniu, Nicolaus Copernicus University, Torun, Poland (NCU), https://www.umk.pl
- Rheinisch-Westfaelische Technische Hochschule, Aachen University, Germany (RWTH), https://www.rwth-aachen.de

IPERION HS project MOLAB is composed of:

- MOLAB.it, Istituto di Scienze e Tecnologie Molecolari, Consiglio Nazionale delle Ricerche, Università degli Studi di Perugia, Italy (CNR-ISTM), http://www.istm.cnr.it/, molecular spectroscopies by point analysis and hyperspectral imaging
- MOLAB.it, Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, Florence, Italy (CNR-INO), https://fed.ino.it/, 3D / 2D optical methods
- MOLAB.it, Istituto per i Beni Archeologici e Monumentali, Catania, Italy (CNR-IBAMa), https://www.ibam.cnr.it, X-ray scanning / imaging methods
- MOLAB.it, Istituto per i Beni Archeologici e Monumentali, Potenza, Italy (CNR-IBAMb), https://www.ibam.cnr.it, aerial remote sensing
- MOLAB.gr, Foundation for Research and Technology–Hellas, FORTHa (OADC), Heraklion, Ormylia, Greece (FORTHa), 3D / 2D optical / acoustic methods
- MOLAB.gr, Foundation for Research and Technology–Hellas, Heraklion, Greece (FORTHb), geophysical prospection
- MOLAB.fr, Centre National de la Recherche Scientifique, Centre de recherche et de restauration des musées de France, Paris, France http://www.c2rmf.fr/, imaging / optical methods / X-ray diffraction
- MOLAB.pl, Uniwersytet Mikołaja Kopernika w Toruniu, Nicolaus Copernicus University, Torun, Poland (NCU), https://www.umk.pl, Optical Coherence Tomography
- MOLAB.de, Rheinisch-Westfaelische Technische Hochschule Aachen University, Germany (RWTH), https://www.rwth-aachen.de, Nuclear magnetic resonance
- MOLAB.uk, Nottingham Trent University, Nottingham, United Kingdom (NTU), https://www.ntu.ac.uk, ground remote sensing
- MOLAB.ro, Institutul Național de Cercetare-Dezvoltare pentru Optoelectronică, Magurele, Romania (INOE), https://www.inoe.ro, aerial remote sensing
- MOLAB.es, Consejo Superior de Investigaciones Científicas, Madrid, Spain (CSIC), https://www.csic.es, electrochemistry
- MOLAB.cy, The Cyprus Institute, Nicosia, Cyprus (CYI), https://www.cyi.ac.cy, dendrochronology / 3D documentation
- MOLAB.pt, HERCULES, Evora, Portugal, https://www.hercules.uevora.pt, biochemistry

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