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Abstract

This Scientific Vision aims to monitor the landscape of the setting up of the E-RIHS infrastructure, to describe the main scientific ambitions of E-RIHS in the coming years and to outline what pathways will be used to achieve them.
The E-RIHS Scientific Vision will be the introduction of the E-RIHS Scientific and Technical description, one of the documents that will be produced to apply for the ERIC status.

The first version of the E-RIHS Scientific Vision was elaborated in the framework of the task 9.1 “Excellence: priorities and strategy” of the WP9 of E-RIHS PP. European and national communities, as well as international partners, were widely consulted throughout the preparation process.

A six pages flyer and a poster illustrating the Scientific Vision were also produced.

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Abstract (for dissemination)	This documents aims to monitor the landscape of the setting up of E-RIHS, to describe the main scientific ambitions of E-RIHS in the coming years and to outline what pathways will be used to achieve them.
Keywords	Scientific Vision, Ambition, Core Values

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Abbreviations

CERN	European Organization for Nuclear Research
CHARISMA	Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to Conservation/Restoration
DARIAH	Digital Research Infrastructure for the Arts and Humanities
ERA	European Research Area
ERIC	European Research Infrastructure Consortium
E-RIHS	European Research Infrastructure for Heritage Science
ESFRI	European Strategy Forum on Research Infrastructures
ESRF	European Synchrotron Radiation Facility
ESS	European Spallation Source
EU	European Union
FAIR	Findable, Accessible, Interoperable and Re-usable
GRI	Global Research Infrastructure
GSO	Group of Senior Officials on Global Research Infrastructures
IAEA	International Atomic Energy Agency
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOM	International Council of Museums
ICON	Institute of Conservation
IIC	International Institute for Conservation of Historic and Artistic Works
ILL	Institut Laue-Langevin
IPERION CH	Integrated Platform for the European Research Infrastructure On Cultural Heritage
JPI-CH	Joint Programing Initiative on Cultural Heritage and Global Change
LabS-TECH	Laboratories on Science and Technology for the conservation of European Cultural Heritage
UNESCO	United Nations Educational, Scientific and Cultural Organization

Executive Summary: The E-RIHS Scientific Vision in a Nutshell

E-RIHS will be the flagship **European Research Infrastructure for Heritage Science**.

Heritage science research has direct **socio-economic impact** through increasing knowledge and interpretation of heritage, enhancing **public engagement and access**, particularly in **public-facing institutions** such as museums and galleries. It strongly benefits Europe's economy through **cultural tourism**. It supports European cohesion through intercultural dialogue and science diplomacy. The exceptional collections in European museums, galleries, libraries and archives means that there are literally uncounted objects that need to be 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 range of disciplines. This calls for thousands of **object-specific studies** and **major international projects** requiring the collaboration of a large number of research laboratories and institutions from all over Europe.

These projects raise crucial research questions related to cultural and natural heritage materials. A first set of questions regards the **origin** of heritage materials and the necessity of understanding their history, their technical background, their circulation and use, their political, cultural, symbolic or other values they embody, and their alteration over time. A second set of questions addresses the **diagnosis** of the current state of those materials. A third set concerns their **future**: their conservation and restoration for the benefit of coming generations. Answering these crucial questions requires to taking the specificities of the material constituents into account: heritage objects and sites are intrinsically heterogeneous and complex. Indeed, heritage materials are not model materials for which the analytical parameters are known a priori. In addition, they have been subject to decay through use and ageing under diverse and often unknown conditions over many decades, centuries 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. As a consequence, experiments on heritage materials cannot be easily reproduced.

E-RIHS will support **the most advanced scientific investigation of heritage** 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. Through a concerted procedure, E-RIHS will deliver **integrated access to cutting-edge analytical technologies and scientific archives**, namely to four platforms:

- **FIXLAB** for large-scale analytical facilities and **MOLAB**, a fleet of advanced mobile instruments that travel to a site, and,
- **DIGILAB** for online scientific data and tools, and **ARCHLAB** for physical archives.

E-RIHS will support both object-specific studies and large-scale projects, especially those requiring analytical support through multiple visits to the same facilities, to different facilities from the same platforms or to different platforms. Such projects will be granted long-term access to E-RIHS and its capabilities.

E-RIHS will promote excellence through best practice by implementing a quality management system, independent project selection and data policies guided by principles that are inherent to all world-class research infrastructures. In addition, E-RIHS will develop practices designed to respond to the specific

character of heritage science, based on the extensive experience of its founding members. The scientific strategy of E-RIHS builds upon ten core values:

1. **Competencies first** – Considering skills as central
2. **Interdisciplinarity** – Optimising work for teams with complementary culture and practices
3. **Co-creation** – Building on a paradigm that balances contributions from all participants
4. **Communication** – Exploiting the public-facing nature of heritage institutions
5. **Excellence** – Supporting outstanding projects
6. **Interoperability** – Promoting data sharing, intelligent instruments and open access policies
7. **Innovation** – Stimulating evolution of E-RIHS and in heritage science
8. **International recognition** – Collaborating at global level
9. **Ethics** – Respecting heritage values and encouraging responsible research
10. **Quality** – Guaranteeing the best user experience

These ten values will be at the heart of E-RIHS.

Collaboration is essential to avoid duplication of investments and fragmentation of research efforts. E-RIHS will foster a **culture of interdisciplinarity, exchange and cooperation** associating researchers from the required disciplines **on equal level** (experimental sciences, arts, humanities and social sciences or digital sciences). Newly generated knowledge will be co-created by users and platform scientists. Multidisciplinary interactions within E-RIHS will be an intrinsic element of its identity, as it is of defining importance to heritage science. E-RIHS will provide access to expertise and competences as well as to instruments or databases.

E-RIHS will contribute to the **development and adoption of new research methodologies**. New instruments, 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 management developed by digital humanities (e.g. DARIAH[1]). E-RIHS will promote the re-use of information, such as experimental schemes, raw data, metadata, algorithms and their applications, to foster replicability and innovation. Methodological research activities jointly performed by the members of the E-RIHS consortium 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 and data science. E-RIHS will foster 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 studies. E-RIHS will integrate the full power of novel imaging techniques within its instruments, competencies, and training.

Building on the leading international standing of European heritage science, E-RIHS will establish an infrastructure of global interest that will integrate partners and facilities outside the EU and reach its worldwide community of users.

1 DARIAH, Digital Research Infrastructure for the Arts and Humanities

E-RIHS will **directly impact Heritage Science** through **generating new knowledge for understanding, preservation and use of Heritage**. E-RIHS will enable and improve execution of innovative Heritage research. It will constitute a **coordinated body** that enlarges research communities, contributes to implementation of research strategies and promotes efficient use of resources. European expertise and interest in Heritage science is such that it will connect and integrate partners outside the EU, as a research infrastructure with a global reach, sharing a diverse, generous and multicultural view of some of the world's most admired treasures. E-RIHS will foster public engagement. It will promote the **use of new research techniques** and contribute to the **development and adoption of novel methodologies** with the objective of maintaining facilities that are at the highest level, while continuing to train its staff and users in state-of-the-art methodologies.

The impact of E-RIHS will extend **far beyond Heritage Science**. Part of the methodology developed will be applicable beyond the heritage science field. The research and processes put in place at the infrastructure will be a source of inspiration for the next generation of students and contribute to the training of versatile researchers that can confidently cross disciplines. E-RIHS will also contribute to establishing new intellectual frameworks built on intensively multidisciplinary research.

The E-RIHS Scientific Vision

The progress made within past European initiatives and the on-going consultation of the research community has led to the development of this vision statement. It aims to describe the main scientific ambitions of E-RIHS in the coming years and to outline what pathways will be used to achieve them.

1. Context

Tangible cultural and natural heritage is central to European society and economy as a whole and the undeniable value and the importance of preserving our heritage for future generations is widely recognized. In its *Framework Convention on the Value of Cultural Heritage for Society*, the Council of Europe defines heritage as a "group of resources inherited from the past which people identify, independently of ownership, as a reflection and expression of their constantly evolving values, beliefs, knowledge and traditions".[2] Moreover, the European Commission underlines the intrinsic economic and social value of heritage, stating that heritage is an "irreplaceable repository of knowledge and a valuable resource for economic growth, employment and social cohesion, […] 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".[3] As people identify with heritage, strengthening heritage knowledge and interpretation and improving its dissemination and accessibility has a significant impact on societal cohesion and on the well-being of citizens. As stated by the Joint Programming Initiative in Cultural Heritage and Global Change (JPI-CH), the richness of Europe's heritage and its diversity can contribute to the development of intercultural dialogue and promote shared understanding, thus consolidating a sense of European identity.[4]

At the international and geopolitical level, heritage is often a common ground for dialogue and a tool to build peace through cultural and scientific diplomacy. In this respect, since June 2016, the EU has been constructing a strategy that places cultural relations at the centre of its diplomatic relationships. Among others, this strategy promotes science as a tool to improve international relations by recognizing that "international research cooperation uses the universal language of science to maintain open channels of communication and enable researchers to exchange ideas regardless of their cultural, national or religious background".[5]

If cultural and natural heritage is a key component of Europe's society, identity, well-being, and economy, its fragility cannot be underestimated. Heritage objects and sites are indeed exposed to many different risks against which they need to be protected and preserved for future generations. Natural decay mechanisms need to be better understood. Climate and environmental change is also a major cause of heritage degradation. Cultural and natural heritage is also threatened by natural disasters. In this respect, the Academies of Science of G7 countries jointly stated in May 2017 that "building the resilience of cultural heritage to natural disasters" is a key scientific priority.[6] The Academies emphasized the need to enhance public awareness of the specificities of the vulnerability of cultural heritage and presented several

2 Council of Europe, 2005
3 European Commission, 2014
4 Joint Programming Initiative on Cultural Heritage and Global Change, 2014
5 European Commission, 2016
6 G7 Academies of Science, 2017

recommendations and prospective actions such as establishing protocols on measures to be implemented after a disaster, properly funding conservation and restoration schools and making them interact with research centres. Heritage is also put at risk by human activities: examples of pressures on sites due to rising urbanisation, of looting in areas of conflict and of destruction of cultural heritage by terrorist groups have multiplied over the past years. The UNESCO List of World Heritage in Danger illustrates the diversity of threats faced by cultural and natural heritage. The List is established to inform and call the international community for action regarding threats to properties listed in the World Heritage List. 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).

The nature of these challenges requires a broad array of answers, from diplomacy to educational policies, from environmental policies to policies for maintenance, restoration, accessibility and exploitation of heritage both at local, national and European levels. Scientific research on cultural and natural heritage materials is a corner stone in answering these challenges and tackling their consequences. As stated by the European Commission's Communication *Towards an integrated approach to cultural heritage for Europe*, "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".[7] To address the multiple challenges that cultural and natural heritage is facing, the JPI-CH is thus identifying four priorities that research on heritage materials can tackle: developing a reflective society, connecting people with heritage, creating knowledge and safeguarding our cultural heritage resource.[8]

2. Heritage science

If both tangible and intangible heritage are the common wealth of our societies, the present document will address research on tangible heritage materials (artefacts, monuments, natural history collections, excavation sites, etc.), keeping in mind that, as stated by the JPI-CH, the understanding and "preservation of cultural heritage link materials and their physical condition (tangible) to their cultural significance and meaning (intangible)".[9]

Thousands of objects from the exceptional collections of European museums, galleries, libraries and archives are studied, interpreted and preserved. In addition, monuments, building, archaeological and palaeontological sites can now be scientifically probed using innovative techniques that require complementary skills and knowledge from a range of disciplines. This 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.

These projects raise crucial questions related to cultural and natural heritage materials themselves (*tangible heritage)* in a wider context. A first set of questions regards the origin of heritage materials, and the necessity of understanding their history, their technical background, their circulation and use, their

7 European Commission, 2014

8 Joint Programming Initiative on Cultural Heritage and Global Change, 2014

9 Joint Programming Initiative on Cultural Heritage and Global Change, 2010

political, cultural or symbolic or other values they embody, and their alteration over time. A second set of questions addresses the diagnosis of the current state of those heritage materials. A third set concerns their future: their conservation and restoration, for the benefit of coming generations. All these scientific questions 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.[10] In addition, they have been subject to ageing, use and deterioration under diverse and unknown conditions over many 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 specificities 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 application of science to the needs of 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, palaeontological 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.

3. Ambition

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 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. As such it will be a critical asset of the "enabling framework" described by the JPI CH in view of addressing the four missions of 'Developing a reflective society', 'Connecting people to heritage', 'Creating knowledge' and 'Safeguarding the cultural heritage resource'.[11]

10 Bertrand, L., Thoury, M., Anheim, E., 2013
11 Joint Programming Initiative on Cultural Heritage and Global Change, 2014

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 science, E-RIHS will put the tangible heritage itself at the heart of its day-to-day operation, from sample preparation to data treatment. Heritage will indeed be placed at the centre of the whole rationale by recognizing the specificities of the scientific field and their impact on the entire research process. E-RIHS aims to be the central core of this European research, associating research infrastructure, competencies of people operating them, governance and societal involvement to provide innovative research of the highest quality in strong correlation with the core intrinsic requirements of heritage science. E-RIHS will establish a unified platform which gives access to the most advanced European instruments for the analysis, interpretation, preservation, documentation, and collection management of heritage. Through E-RIHS, new imaging and data processing from mobile instruments to large-scale facilities will allow the material complexity to be addressed as it is, from the sample to the object, the collection or the site. Heritage science explores information in its environmental context, closely associating cultural and natural paradigms. E-RIHS will thus implement service activities with a case-by-case approach, using excellent and consistent methodologies.

Data processing, storage and sharing will be taken into account from the start of E-RIHS, as it aims to be an infrastructure where scientific results are shared assets that may be found, accessed and re-used. The ambition of E-RIHS is to become the reference platform around which heritage science research will congregate. The new infrastructure seeks a paradigm shift towards a truly holistic approach connecting multiple research communities through excellent research projects, while dynamically involving heritage institutions, administrations, and citizens.

4. Infrastructure to enable new science

E-RIHS has a unified vision in terms of access, integration and interoperability. E-RIHS is a distributed infrastructure that associates major centres of research in heritage science, including outstanding research institutes, as well as prestigious research laboratories and conservation centres in museums and universities. Four platforms providing access to **Analysis** and **Data** were set up in the framework of previous research projects funded by the European Commission (CHARISMA, IPERION CH). Building on this experience, E-RIHS will develop and fully integrate these platforms that have day-to-day practice and the most advanced instruments for research in heritage science.

Experimental data will be generated at two of the platforms:

FIXLAB: access to large-scale and medium-scale fixed facilities – particle accelerators and synchrotrons, neutron sources, non-transportable analytical instruments (e.g. micro-CT), weather simulating facilities (e.g. climatic wind tunnel) – offering unique expertise to users in the heritage field for sophisticated scientific investigations on cultural and natural heritage objects, both samples and whole items, revealing various features like their microstructure, chemical composition, provenance and age, and giving essential

and invaluable insights into historical technologies, materials, distribution of materials and objects (e.g. trade routes…), alteration and degradation phenomena or authenticity.

MOLAB: access to a comprehensive array of advanced mobile analytical instrumentation for non-invasive measurements on precious, fragile or immovable objects, archaeological sites and historical monuments. The MObile LABoratory allows its users to implement complex multi-technique diagnostic projects, permitting the most effective in situ investigations. MOLAB can also intervene in emergency situations, traveling on site after natural or man-made disasters.

Heritage science data (both that generated through FIXLAB and MOLAB as well as that in existing archives) will be stored, consulted, mixed and reworked at:

ARCHLAB: physical access to specialised knowledge and organized scientific information – including technical images, samples and reference materials, analytical data and conservation documentation – in datasets largely unpublished from archives of prestigious European museums, galleries, heritage and research institutions.

DIGILAB: online access to scientific data concerning tangible heritage, making it findable, accessible, interoperable and re-usable (FAIR principles). It includes and enables to access searchable registries of specialized digital resources (datasets, reference collections, thesauri, ontologies, etc.); supports data interoperability through the creation of shared knowledge organization systems and provides tools to process them according to researchers' needs and research questions. Such data will primarily consist of measurement results and scientific information (texts, images, 3D models and more). Tools and software will be made available or further developed to support evaluation (e.g. quantitative evaluation of XRF data) and multimodal data visualisation (enabling annotations and creations of links among the different resources).

This vision will be facilitated by coordination through a central hub dealing with general administration, financial management, risk management and quality system monitoring. Criteria for inclusion of an access provider within E-RIHS will be defined. An external Scientific Board will evaluate their application

5. Implementation: promoting excellence through best practice

In order to fulfil this 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 all world-class research infrastructures, but whose implementation in the framework of heritage materials needs to be detailed. We here list these best practices and the expected impact of their implementation. These ten values 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.

a. Specific best 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 involved. Moreover, a heritage team accessing an E-RIHS instrument will usually be provided far more support than other users, often indeed launching a joint scientific collaboration. Indeed, past experience has shown that E-RIHS users 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 user 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...). 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 organize high-level hands-on specialized 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 most benefit from the infrastructure for their research. Specific care will also be taken to train engineers and technical staff running E-RIHS facilities, including through promotion of exchange between the E-RIHS facilities. This will contribute to the 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, geo-chronological, 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 recognize and support team work at all stages of the process and multidisciplinary teams rather than individuals will access E-RIHS. E-RIHS will foster a culture of interdisciplinarity, exchange and cooperation, associating 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.

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.[12] 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

12 CERN, 2010

thus be 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.

b. 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 both support short and medium research projects and major initiatives. An E-RIHS label will be created and granted at European level to support outstanding large-scale projects, typically those requiring analytical support through multiple access visits. It will provide a coherent framework to support multiple accesses to the same facility, to different facilities from the same platform or to different platforms. Our experience shows indeed 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 longer-term projects will enable the joint progression of knowledge on heritage materials and data, methodological innovations, and a common adoption of the challenges by the field. E-RIHS will therefore contribute to the creation of a common "operating sequence" in heritage science. This will further favour integration, meaning 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 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.

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 process".[13] 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

13 European Commission, 2017

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. The infrastructure will focus on the interoperability of systems and physical instruments, 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.[14] 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.

Innovation – Stimulating evolution of E-RIHS and 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 management developed by digital humanities (e.g. DARIAH[15]). 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 projects 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. 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. 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

14 In the framework of the Heritage Date Re-Use Charter, datasets are identified with a simple of reference metadata, standard formats facilitate reuse and dissemination, and access procedures, re-use conditions and citation model are clearly stated.

15 DARIAH, Digital Research Infrastructure for the Arts and the Humanities.

intergovernmental organization ICCROM (International Centre for the Study of Preservation and Conservation of Cultural Property) is supporting this initiative and is committed to help setting up the future legal entity of the global infrastructure.

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". Heritage materials are specific as they are unique, irreplaceable and non-renewable resources. 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 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.

6. Impact on the European and global research area

E-RIHS will have impact on the European and global research area, both in heritage science and beyond. The most direct impact of E-RIHS in heritage science will be the generation of new knowledge to understand and preserve heritage. E-RIHS also aims to enable and better operate innovative heritage research, especially through the enlargement of research communities. E-RIHS will contribute to the development of new methodologies within the field, particularly through in-house research and will promote an efficient use of resources. Heritage science can also be used as a nice way to engage people, including school children and students, with science. E-RIHS will promote the involvement of citizens and communities within science through innovative training and community-based science, further developing efforts already made in the natural history field.

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 Group of Senior Officials on global Research Infrastructures (GSO) in

2014.[16] In its 2015 Progress Report, the GSO identified E-RIHS as an infrastructure of global interest.[17] This international initiative is carried out in parallel with the preparatory phase of E-RIHS with the aim to connect and include partners and facilities outside the EU, gradually reaching the status of a global distributed research infrastructure of which E-RIHS could be the leading partner. As stated in the GSO progress report, "international partners will be asked to play seminal roles by introducing in their regional ecosystems the innovations and cutting-edge tools provided by the global infrastructure. Furthermore, they will make it possible for the distributed infrastructure to widen its scope providing access to highly advanced facilities to an extended community of users".[18] The JPI-CH will in particular help E-RIHS consortium to build strong cooperation policies at global and transnational levels, with the aim of widening the scope of E-RIHS beyond the pan-European area while at the same time providing active support to the alignment of research policies in the heritage science domain. Synergies with other EU initiatives and international organisations like UNESCO will be identified to foster cooperation on strategic planning of cultural heritage research.

E-RIHS will also have impact beyond heritage science. Methodologies developed in the framework of E-RIHS can indeed be applied beyond the field. Moreover, new materials can emerge from the in-depth study of the exceptional properties of ancient materials. Many recent works indeed illustrate the diversity of these properties and their potential to inspire the development of more durable and resilient new materials and to limit their environmental impact.[19] E-RIHS should also inspire the next generation of students, nurturing versatile researchers that can confidently cross disciplines and ultimately contribute to the creation of new intellectual frameworks.

E-RIHS addresses a research field with an extremely strong socio-economic impact. The cultural heritage sector fosters a wide array of employment in a range of sectors (cultural industries, indirect impact of cultural tourism, such as production of professional equipment), amounting to 7.8 M person.year.[20] Cultural tourism, accounting for 40% of all European tourism,[21] is a key driver of the European economy. E-RIHS will contribute to the development of this sector, especially through the exploitation of its results in museums, sites and other public facing institutions. About 300,000 persons work directly in the cultural heritage sector in the European Union.[22] Developments of new instruments, digital methodologies, standards, as well as conservation treatments will also have an impact in the related industries. This number could seem limited, but E-RIHS will furthermore impact society as a whole, contributing to reinforcing the identification of citizens with heritage and intercultural understanding, therefore fostering their societal cohesion and the well-being of citizens.

16 The GSO aims to informally explore cooperation opportunities in Global Research Infrastructures and is composed of representatives from Australia, Brazil, Canada, China, the European Commission, France, Germany, India, Italy, Japan, Mexico, Russia, South Africa, UK and USA.
17 Group of Senior Officials on Global Research Infrastructures, 2015
18 Group of Senior Officials on Global Research Infrastructures, 2015
19 Bertrand, L., Gervais, C., Masic, A., Robbiola, L., 2017
20 Sanetra-Szeliga, J. on behalf of CHCfE Consortium, 2015
21 European Commission, DG Growth website, 2018
22 European Commission, 2017

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Appendix

History and status of E-RIHS

In 1999, the European Commission started supporting integration of advanced scientific instruments and data repositories for heritage investigation that has continued uninterrupted since then. The long-term tradition of coordination of European research in this field, the ability to combine it with societal and industrial innovation, and the integration promoted by major EU-funded research infrastructure projects, such as LabS-TECH, EU-ARTECH, CHARISMA and IPERION CH in conservation science, ARIADNE in archaeology, and SYNTHESYS in natural history, represent the background of E-RIHS.

Since EU-ARTECH, these research infrastructure projects have piloted transnational access to the resources offered 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. These efforts have led to the designation of the Heritage science community as an "Advanced community", leading to a proposal to ESFRI (European Strategy Forum on Research Infrastructures) to establish a permanent European research infrastructure to serve the Heritage science domain. ESFRI highlights the relevance of research infrastructures as key supporting elements of the European Research Area (ERA). The JPI-CH also defined four priority research areas in its Strategic research agenda and a number of "Enabling Activities", setting up research infrastructures being among them.

E-RIHS is one of the six new projects incorporated into the ESFRI Roadmap in 2016, and currently the only Research Infrastructure project in the Social and Cultural Innovation section. At the heart of E-RIHS is a coordinated group of highly qualified researchers, instruments and services provided to the European user community.

The setting up of E-RIHS is funded by the EU project E-RIHS Preparatory Phase (H2020-INFRADEV-2016-2017). This phase was launched in 2017 and will last until 2020. The main goal of the preparatory phase is to address governance, scientific strategy, financial aspects, and the legal documents of the infrastructure. The infrastructure should be legally established in 2022.

History of the document

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1	26.07.17	B. Charbonnel	Sent to T9.1 ST leaders
2	05.09.17	L. Bertrand	Sent to all E-RIHS PP Partners before the Prague meeting
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January 2018, E-RIHS.fr meeting, Paris
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