In 2021, the Arts and Humanities Research Council (AHRC) awarded funding for five infrastructure policy and engagement Fellowships, as part of its ongoing process of portfolio scoping and prioritisation. Two Fellowships were awarded to undertake research and engagement in the creative industries, and three Fellows were funded by AHRC to undertake research and engagement in heritage science and conservation research.

A report by the three Fellows in heritage science and conservation research is now available.

The Fellows' report refers throughout to a bid by AHRC to the UKRI Infrastructure Fund. The AHRC bid is to establish a networked, distributed infrastructure for UK heritage science, RICHeS. Securing public investment on the scale envisaged for RICHeS must go through a rigorous process to comply with rules for managing public money. At the time the Fellows' report was written (2021) and in mid-2022, the AHRC bid was still undergoing development and assessment. The Fellows' report should therefore be viewed as supporting wider conversations around heritage science and should not be read as defining the operational or funding decisions for RICHeS, which remain a matter for AHRC.

Scoping a UK Heritage Science Infrastructure

Priorities, Risks and Values. A report to the Arts and Humanities Research Council

Executive summary

This document is an interim report on work catalysed by the Arts and Humanities Research Council (AHRC) to scope significant infrastructure investment for heritage science in the UK. The term heritage science came to UK prominence in 2006, through a House of Lords Science and Technology Committee inquiry.[1] Although progress has been made since 2006, such as the establishment of the National Heritage Science Forum (NHSF),[2] many issues for the field of heritage science identified in the 2006 inquiry remain and new issues have emerged. AHRC is therefore leading a programme of work (outlined to date at Annex D) to address specific long-term structural issues for heritage science.

Science performs important roles for heritage. Heritage science (HS) is now understood as an umbrella term which encompasses a wide range and variety of applications of science to heritage. Heritage science creates public value through enabling the investigation and management of heritage, informing our understanding of past people, objects, and environments. Heritage science also plays an important role in enabling access to, and broader understanding of, the UK's iconic heritage. Addressing specific issues facing heritage science would enable the field to create even greater public value.

Creating greater public value from heritage science would entail leveraging the field within the UK capability as a science and innovation superpower. A long-term programme would be required which incorporates investment in people and knowledge environments alongside technological developments. An infrastructural approach is thus the most appropriate route to realise the potential of UK heritage science. In 2020-2021, AHRC consequently submitted a bid to the UKRI Infrastructure Fund for a programme termed throughout this document as RICHeS. At the time of writing, the AHRC bid was under active consideration within UKRI. It was therefore considered timely to report back to those in the research and wider communities who have given generously of their time and expertise to inform and strengthen the bid through multiple cycles of consultation.

[1] House of Lords Science and Technology Committee (2006) 9th Report of Session 2005–06. Science and Heritage. Report with Evidence. Published by the Authority of the House of Lords. London: The Stationery Office Limited. HL Paper 256. https://publications.parliament.uk/pa/ld200506/ldselect/ldsctech/256/25602.htm

[2] NHSF https://www.heritagescienceforum.org.uk Accessed 13/8/21

Several key messages have emerged strongly from the consultation. The first is the importance of **people** in heritage science infrastructure. It is people who conduct scientific investigations, using tools and technologies of varying sophistication. A high degree of specialisation is characteristic of heritage science. An individual heritage scientist may necessarily develop a highly specialised blend of professional skills, disciplinary and technical knowledge. Such specialisation has consequences for the survival and transmission of skills and knowledge. Moreover, it is vital that specialist technical skills are applied appropriately for heritage and that outcomes are interpreted with attention to the complexities of heritage contexts. A long-term approach to people and skills is therefore vital to connect and support individual expertise with multi and inter-disciplinary research and innovation (MIDRI).

This highlights a second theme: **connectivity**. Resources, including people, are distributed across the UK. Poor interconnections prevent this distribution from being a positive characteristic - many resources are effectively 'hidden' except by accident of personal networks. An infrastructure approach as proposed in the AHRC bid would enable a whole 'landscape' approach, allowing enhanced discovery and potentiation of resources.

A third key message is of **values, principles, and risks**. Heritage is a shared inheritance, and as such accessibility and sustainability are crucial concerns for heritage scientists. Consultations to date have highlighted multiple potential hazards both to heritage and to heritage science. Addressing these issues will require the type of sustained intervention best delivered through long-term programmes.

A remaining key message is of **potential**. Heritage materials and problems present unique challenges, both technical and ethical, which have driven innovation and indeed the whole development of the field. The innovation roadmap between some heritage science and fields beyond the heritage sector, for example forensic science, is well established. Long-term infrastructure investment would provide the cross-sectoral connectivity essential to transformative 'downstream' value from heritage science.

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Authored by Freya Horsfield, Ben Edwards, and Rebecca Stacey, 2021

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Comments and feedback are welcomed to: infrastructure@ahrc.ac.uk

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Workshop and survey consultees who gave such valuable insights

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1. Introduction

1.1 Purpose and intended readership of this document

The aim of this report is to present the results of AHRC-led research on infrastructure for heritage science in the UK which was undertaken March-July 2021 by three Policy and Engagement (PE) fellows. The research used landscape mapping, online survey, consultation workshops and individual conversations with stakeholders in the sector to gather evidence to support development of a AHRC bid for funding to establish a UK infrastructure for heritage science.

The intended readership is the heritage science community in the UK and potential international partners. The report summarises key messages which emerged during consultations with the heritage science community. It also offers suggestions on how the proposed infrastructure might meet the needs identified.

1.2 Objectives and success criteria

The critical success criteria for infrastructure investment in heritage science were identified by AHRC as follows:

1. strategic fit: the programme meets the criteria of the Infrastructure Fund scheme, the needs identified in the consultation, and complements but does not duplicate adjacent strategies and programmes

2. value: the programme optimises value for heritage science, the wider Research and Innovation sector, and society as a whole

3. sector capacity and capability: the programme can gain buy-in from prospective providers and suppliers, and would be attractive to users

4. affordability: the programme is affordable within the budget of the Infrastructure Fund, and AHRC has the operational capacity to deliver it

5. achievability: it has been demonstrated that the sector, AHRC and the individual organisations are able and willing to deliver the programme, and the proposed outputs, outcomes and impacts are realistic

6. sustainability beyond the life of the investment. If successful, the investment will have enabled the field of HS in the UK to become self-organising, so that at the end of the programme the benefits can be sustained.

1.3 Definition of terms and scope

Heritage science is a broad and dynamic field within which definitions are necessarily fluid. This report therefore differentiates between:

a) definitions necessary to establish the high-level functions of the main elements of the infrastructure, and hence perform as preconditions for funding the infrastructure as a whole

b) definitions which may best be addressed closer in time to operational need, such as specific funding arrangements and programmes. Such definitions can be considered a 'charcoal sketch' which can be revised and supplemented as appropriate.

The range of scientific techniques which are currently or potentially applied to heritage is vast. A list of some of the techniques currently applied to heritage is included in Rebecca Stacey's report at Annex A. Early stages of the scoping, before March 2021, overtly foregrounded one specific scientific area prominent in heritage science, namely conservation research. The acronym from this early stage of project development (RICHeS) has been retained here, as being a relatively well-understood shorthand for the proposed infrastructure. Where the term heritage science is used in this report, it is understood as encompassing conservation research.

Research infrastructure in the arts, humanities and social sciences includes collections of research objects and data, and the tools, techniques, and expertise on which research relies. It is characterised by a large and diverse user base, disciplinary agnosticism, and dispersal across multiple locations.[3]

The RICHeS bid relates primarily to UK heritage science infrastructure, but given the collaborative, trans-national nature of scientific enterprise RICHeS' operational design will need to pay attention to wider international arrangements. The UK has played a development role in heritage science infrastructure at EU level, under the European Research Infrastructure for Heritage Science (E-RIHS[4]). RICHeS operational design will therefore enable mesh with the organisation of the E-RIHS programme around four 'access platforms.' The 'access platforms' bring together cutting-edge tools and expertise and provide advanced services to the heritage science community and heritage industry:

[3] UKRI 2020 The UK's research and innovation infrastructure: Landscape analysishttps://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-LandscapeAnalysis-FINAL.pdf Accessed 16/8/21

[4] http://www.e-rihs.eu/; E-RIHS is a European Research Infrastructure Consortium (ERIC) scheduled to become fully operational in 2022.

E-RIHS FIXLAB: access to large-scale and medium-scale fixed facilities – e.g. particle accelerators and synchrotrons, neutron and laser sources and other essentially immovable research facilities including the associated unique expertise

1. **E-RIHS MOLAB**: access to a comprehensive selection of mobile analytical instrumentation for measurements on objects, buildings, and sites, allowing the implementation of complex multi-technique diagnostic projects for in situ investigations

2. **E-RIHS ARCHLAB**: access to physical heritage science collections, such as technical images, samples and reference materials, analytical data and conservation documentation, as stored in museums, galleries and research institutions

3. **E-RIHS DIGILAB**: online access to data concerning heritage, with the aim to make it findable, accessible, interoperable and re-usable, based on the **FAIR** principles. 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 organisation systems'

4. The realisation of an integrated infrastructure will be important in securing the future sustainability of projects and programmes. While the LAB definitions offer useful high-level indications of a broad scope of activities and resources, treating such definitions as being either fixed or discrete is potentially problematic. For example, technological advances lead to blurring of distinctions between fixed and mobile facilities. The distinction between data and collections is similarly artificial.

   An important secondary aim of this proposed infrastructure is to grow the capability of the UK's researchers to participate in international consortia such as E-RIHS, and to ensure that structures are in place that can interface seamlessly with these collaboration platforms which the UK has played a leading role in developing. At the same time, this scoping exercise seeks to ensure that the UK infrastructure meets the specific needs of UK-based researchers and end users and generates socio-economic benefit within our own nation.

1.4 What we have not covered, and what remains unknown

This report does not seek to replicate or supersede the comprehensive review of heritage science research undertaken by the House of Lords select committee,[5] or the strategic framework and supporting policy papers developed for the sector by the National Heritage Science Forum. Pertaining specifically to the research infrastructure, it does not give preference to any disciplinary area, institution, or facility, though the delivery mechanism will primarily rely on organisations and activities eligible for UKRI funding.

[5] Note 1 above

Existing and planned strategic initiatives by the AHRC and other national institutions and funding bodies have potential implications for heritage science infrastructure. Such aspects were beyond the formal scope of this study except in so far as consultees offered comments on these matters. It will however be crucially important for AHRC to articulate the strategic implications of the proposed infrastructure such as the 'place' aspects.

2. Heritage science (HS) in the UK

2.1 UK research funding context

The role of the research funder in the UK is diversifying. In addition to excellence-based project funding, the value of end-to-end funding of the research and innovation ecosystem is increasingly recognised.[6] Today the UK is globally recognised as a leader in research and innovation, having the most productive science base in the G7 based on field-weighted citations impact and research papers produced per unit of R&D expenditure.[7] These successes are in large part founded on a network of internationally competitive, high-quality and accessible research and innovation infrastructures. The UK research and innovation infrastructure landscape is diverse, from large-scale physical research facilities such as synchrotrons, research ships and scientific satellites, to networks of imaging technologies and knowledge-based resources such as scientific, cultural, or artistic collections, archives, clinical and population cohorts, data, and computing systems.[8]

2.2 Heritage science – concept and international context

The processes by which AHRC identified heritage science as a strategic priority for investment, and the relationship between RICHeS and other AHRC and UKRI initiatives, are set out in Annex D. The use of science in support of heritage research in the UK has a long history. The British Museum for example has hosted an in-house science laboratory for over 100 years.[9] The first dedicated heritage science journal was launched from Oxford University in 1958 as the *Bulletin of the Research Laboratory for Archaeology and the History of Art* (now *Archaeometry*). The subsequent proliferation of journals dedicated to subjects in the field (and its associated disciplines) attests to its growth and development.

Technological advances have diversified and intensified the application of science to heritage questions in recent decades. These advances have broadened the

[6] https://www.ukri.org/our-work/creating-world-class-research-and-innovation-infrastructure/
[7] Department for Business, Energy and Industrial Strategy: The UK's Industrial Strategy (accessed 5 May 2019); Department for Business, Energy & Industrial Strategy, International Comparative Performance of the UK Research Base, 2019 (accessed 10 July 2019
[8] Note 3 above
[9] https://www.britishmuseum.org/our-work/departments/scientific-research

opportunities both for new kinds of knowledge generation and improved our understanding of threats to our heritage assets and new means to protect and preserve them.

All branches of physical science (chemistry, physics, biology, medical, engineering) are used in HS and are applied across the full range of heritage types: landscapes, buildings, buried and submerged remains, and the UK's rich collections of cultural objects. The quality of the scientific research developed by HS is demonstrated by its publication in the highest profile international science journals.

UK HS is outward looking with researchers collaborating internationally across the full remit of the sector. UK HS institutions participated in past EU research infrastructure projects for heritage science.[10] These projects paved the way for the current development of the European Research Infrastructure for Heritage Science (E-RIHS). The contributions of the participating UK institutions have been pivotal in shaping the development of the E-RHIS project over the last 20 years.

The UK does not currently have an integrated or centralised HS infrastructure. Centres of expertise have grown organically in different institutions resulting in a fragmented and diverse set of physical facilities (Annex A). The RICHeS infrastructure is an opportunity to bring these facilities together to tackle the challenges arising from the existing *ad hoc* structure and, with strategic investment, to secure and grow the vital tools on which the future understanding and management of our heritage depends.

The RICHeS model is distinct from the investment route provided by AHRC CapCo (World Class Labs). Unlike CapCo, RICHeS addresses not only equipment needs but also the staffing and expertise that is vital to support equipment, the connectivity needed for transformative activity, and a widening of access to ensure that the resource is used to maximum potential. RICHeS therefore would enable sustainability to safeguard the scientific needs of our heritage for the long-term.

Similar moves to bring together heritage science infrastructure on a national basis are underway in other countries. In Italy, the 2019 formation of the Instituto di Scienze del Patrimonio Culturale (ISPC)[11] brought together cross disciplinary groups working in sciences and humanities, with distributed research centres (in Catania, Firenze, Lecce, Milano, Potenza and Roma) coordinated from headquarters in Naples. The ISPC sits within the Consiglio Nationale delle Richerche (CNR)[12] which leads E-RIHS at EU level and the development of the Italian node of E-RIHS. The developing French node of E-RIHS has been underpinned by two consortium projects under the Fondation des Sciences du Patrimoine comprising mobile and fixed infrastructure access programmes

[10] EU-ARTECH, CHARISMA and IPERION-CH under FP6 and FP7 programmes 'Integrating Infrastructure Initiatives' and Horizon2020 programmes 'Integrating and opening existing national and regional research infrastructures of European interest'.
[11] www.ispc.cnr.it
[12] http://www.e-rihs.eu/partners/cnr-it/

and collaborative research activities.[13] RICHeS will provide an important means for the UK to work with other national infrastructure initiatives as they develop as well as acting as a national link to the E-RIHS ERIC.

2.3 Value of Heritage science

The importance and value of heritage science to our society is woefully underestimated. This is because the value sits behind the overarching public value of heritage itself (see Heritage Counts reports).[14] Work is underway elsewhere to establish a formal approach to value culture and heritage capital.[15] Scientific technologies, methods and expertise underpin almost every aspect of heritage-related research and are widely deployed in routine investigative and preservation practice. Thus, heritage science underpins, extends, and safeguards the value of our heritage. A snapshot of the public value of HS within the specific area of archaeology can be gained from the 'News' section of the July/August issue of *British Archaeology*; 5 out of the 12 stories featured explicitly mention scientific technology (lidar, C14, aDNA, residue & isotope analysis, x-rays/CT), a further 3 have unreported science behind them (routine geophysics, Treasure/PAS analysis) and 1 is archaeozoology.[16] Thus together at least 75% of those stories are underpinned by science. All were widely covered by the press, adding beneficial impact for local communities to the wider public interest and heritage protection outcomes.

Heritage materials and problems present unique challenges, both technical and ethical. The challenges presented by heritage materials and models have driven innovation and indeed the whole development of the field. The quality, ingenuity and novelty resulting from HS provides a rich resource for knowledge and innovation beyond the heritage sector, as evidenced by case studies compiled in 2013 and in the original RICHeS bid.[17]

The crucial role of HS in heritage investigation creates demand for commercial activity where a marketplace can be supported, e.g., driven by the needs of planning policy[18]or

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[13] http://www.sciences-patrimoine.org/; projects PATRIMEX and PATRIMA http://www.sciences-patrimoine.org/equipex-patrimex/

[14] Published by Historic England on behalf of the Historic Environment Forum, Heritage Counts provides research-based evidence for the value of heritage to our economy, society and environment. For reports and regional case studies see https://historicengland.org.uk/research/heritage-counts/

[15] https://www.gov.uk/government/publications/valuing-culture-and-heritage-capital-a-framework-towards-decision-making/valuing-culture-and-heritage-capital-a-framework-towards-informing-decision-making Accessed 15/8/21

[16] British Archaeology July/August 2021

[17] Cassar, M., Williams, D. (eds.), (2013). *Sustaining the Impact of UK Science and Heritage Research Contributions to the AHRC / EPSRC conference Science and heritage programme conference 29-30 October 2013.* https://issuu.com/heritagescience/docs/sustaining_the_impact_of_uk_science Accessed 15/8/21

[18] Evidenced, for example, by the growth in commercial geophysics in commercial archaeology initially through PPG16 and now the NPPF. https://www.gov.uk/government/publications/national-planning-policy-framework--2

the art market.[19] It is further recognized by the requirements of statutory heritage protection in The Treasure Act.[20]

There is also a *moral duty* on researchers and research funders to preserve the results of heritage science, particularly if analyses are destructive or compromise the material under study. This is particularly true when heritage and scientific reference collections are considered. It is common however for collections to be held by organisations that are not eligible for programmes such as Towards a National Collection (TANC). There is consequently a risk that the potential of collections is not fully realised, leading to duplication of destructive analyses on the finite resource of heritage assets.

The most valuable contribution of the RICHeS infrastructure may however lie beyond benefits experienced by the largest institutions or higher education providers. In times of financial hardship, it is often smaller collections, archives or university research departments that face existential threats; whilst economic restrictions can limit the activities of larger organisations, they can threaten the existence of already marginal ones. Unfortunately, the *size* of a heritage organisation, collection, archive or research department is not a predictor of the *importance* of their contents to the future of heritage science. No size of organisation has a monopoly over nationally or internationally important collections or research. Heritage is highly heterogenous and distributed. Both the heritage and heritage science sectors are traditionally fragmented.[21]

Fundamentally, connections between people, knowledge, technologies, and objects of study ensure the maximum value is realised from publicly funded research projects. Ensuring that such connections exist digitally and sustainably are important pillars in terms of public value. The principles termed FAIR[22] (**F**indability, **A**ccessibility, **I**nteroperability, and **R**eusability) are emphasised throughout this report. Sustainable long-term accessibility, interoperability and reusability of scientific results that are findable, not only justifies the expense of research, but provides for future, as yet un-realised opportunities for down-stream value-added outcomes. Future-proofing the digital existence of heritage science data will enable research using techniques and technologies which have yet to be developed.

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[19] https://news.artnet.com/market/the-importance-of-provenance-in-determining-authenticity-29953

[20] As in the Treasure Act Code of Practice (section G56), https://finds.org.uk/documents/treasure_act.pdf

[21] The House of Lords Science and Technology inquiry in 2006 (Note 1 above, section 1.2. 6.4.1) described the heritage science sector – then understood as primarily the field of conservation science and research - as ‘extraordinarily fragmented.’ Subsequent consultations have confirmed that this is a fair descriptor of the wider heritage science sector as a whole.

[22] https://www.go-fair.org/fair-principles/

3. Methods

3.1 Consultation and evidence collection pre-2021

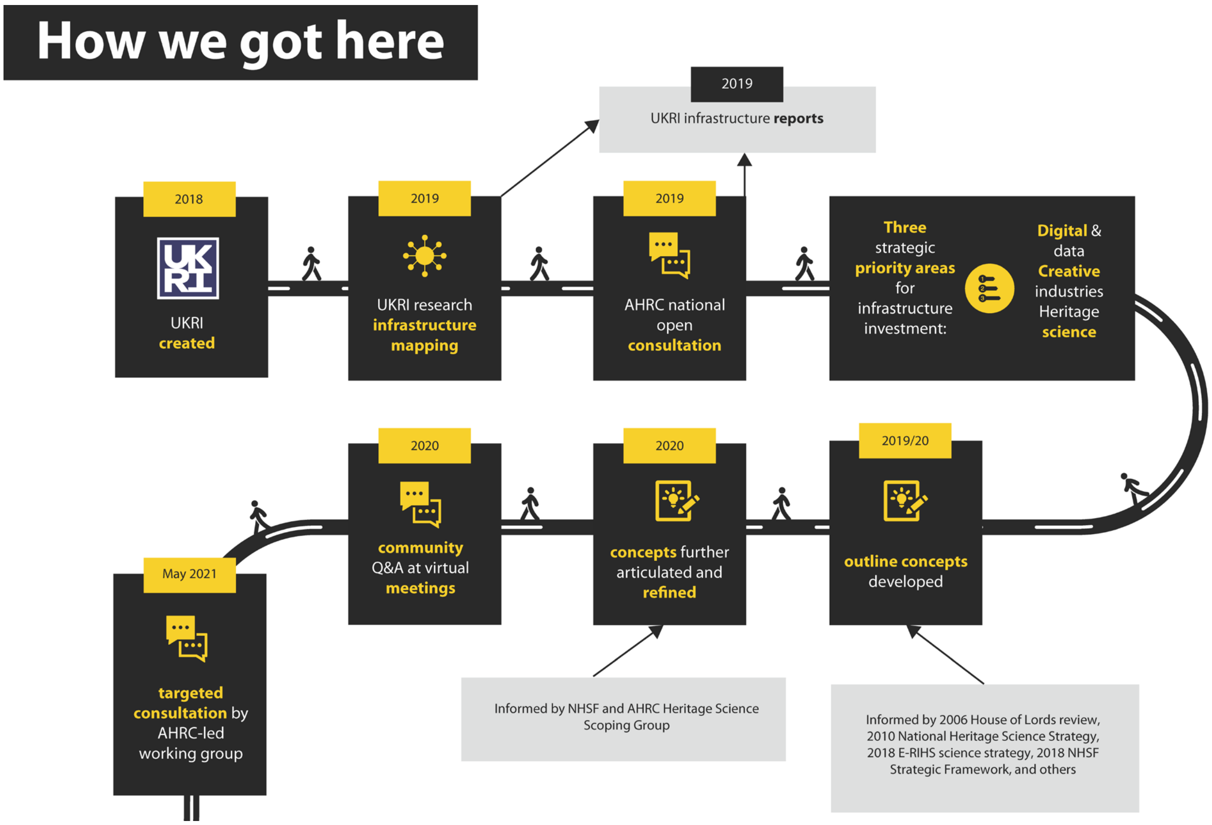

Figure 1: RICHeS Consultation pre-2021. Credit: Monika Flakowska

Successive exercises from 2018 onwards identified the need for investment in research infrastructure in heritage science and conservation research (RICHeS) (Annex D). The proposed programme summary descriptor was subsequently simplified to 'heritage science', although the scope continues to encompass conservation research in addition to multiple other allied research areas. AHRC submitted a bid for RICHeS to the UKRI Infrastructure Fund in 2020. The proposal was well-received with some specific areas identified as requiring further detail before the bid could progress. During 2020 the wider research context changed rapidly. The COVID-19 pandemic further highlighted the crucial role in human wellbeing played by connectivity, including digital connectivity, to resources including heritage and culture.

3.2 The Policy and Engagement Fellowships

In 2021, AHRC created three Policy and Engagement fellowships to refine and develop the RICHeS bid.[23] Each fellowship was focussed on a different component of the infrastructure, the first four of which were based on E-RIHS definitions: physical facilities (FIXLAB/MOLAB); archives and digital platforms (ARCHLAB/DIGILAB); while the last focussed on governance. An integrated overall approach however was crucial as there is considerable overlap between the strands: physical infrastructure generates both data and archives, while investment in and access to these facilities and resources demands governance and administrative activity.

3.3 The consultation process

The three Fellows (Ben Edwards, Rebecca Stacey, and Freya Horsfield) and the AHRC Senior Investment Manager (Joanna Dunster), collectively termed henceforward 'the team', worked collaboratively between March and July 2021 to address the issues identified by UKRI's Infrastructure Advisory Group. Strategy and foresight practitioner Dr Matt Finch[24] facilitated two workshops for the team. The first considered stakeholders, relationships, and values in the heritage science ecosystem, identifying where the RICHeS programme could potentially intervene to produce transformational change. The second workshop mapped known uncertainties facing this ecosystem and used a range of future scenarios to challenge the existing design of the RICHeS programme. These future-facing exercises provided both immediate and strategic utility. The workshops brought the new team together rapidly, helped develop a collective understanding of the objectives and parameters of the project, and identified key approaches to develop evidence necessary to strengthen the bid.

Capturing stakeholder perspectives was considered important, both in terms of those who might potentially access or otherwise benefit from the proposed infrastructure directly, and those with less direct but still pertinent insights. Some of the concepts and scope of the RICHeS proposals are however complicated to convey succinctly. A UX (User eXperience) graphic designer, Monika Flakowska,[25] was therefore commissioned to articulate aspects of the RICHeS bid. These graphics were used throughout the consultations, and some are reproduced in the current report.

Between April and May 2021, Rebecca Stacey and Ben Edwards carried out rapid mapping exercises to understand the FIXLAB/MOLAB and ARCHLAB/DIGILAB picture in broad terms. Their respective reports are included below, as Annex A and B respectively. Material from those reports is also incorporated within this summary report.

[23] https://www.ukri.org/opportunity/ahrc-infrastructure-policy-and-engagement-fellowships/
[24] https://mechanicaldolphin.com/
[25] https://monikaf.carbonmade.com

A range of consultees have been generous with their time and insights throughout the genesis of the RICHeS proposals. This project reviewed consultation material gathered by AHRC from 2019 onwards. There were certain common characteristics of the consultations prior to 2021. Consultees were not necessarily representative of the entire sector, with small local institutions under-represented. Higher Education Institutions were notably under-represented, an interesting pattern as the majority of AHRC projects are run by investigators in universities. The pre-2021 consultation pattern is legacy of the evolution of the national infrastructure concept which has been heavily influenced by UK organisations involved in E-RIHS and its precursor projects and the membership of the NHSF, both of which are dominated by IROs active in heritage science. The association with national heritage collections means that science infrastructure embedded in IROs can be more stable than that in HEIs, and the research activity is more likely to be emphatically heritage-led to align with the remit of the hosting organisation. IROs are also more strongly orientated towards the public interface with heritage and heritage science, and this can translate into a deeper understanding of the needs of potential infrastructure beneficiaries. All of these factors mean an increased tendency for IRO type organisations to identify with the national infrastructure concept compared with HEI researchers, despite the substantial proportion of the infrastructure being hosted in HEIs (see later sections). Participants to pre-2021 consultations tended to be from large national institutions that would be active in delivering the infrastructure, rather than from smaller local bodies that might want to access it. The evidence therefore is biased towards the needs of delivery rather than those of demand.

The need to consult a wider pool was one reason why the project team consulted a wider set of stakeholders in May and June 2021, although this consultation also suffered from some structural limitations. For example, despite attempts to do so, it did not prove possible to secure engagement with stakeholders in Wales and Northern Ireland, so there is the potential for geographic bias. The next stages of RICHeS design will therefore need to recognise and address current structural silos and mitigate the 'capture' of the field by specific professionalisms.

The team therefore sought both to retain connection with previous contributors and to widen the perspectives available to inform the potentially substantial public investment programme. Through a series of targeted conversations, the team therefore reconnected with national institutions and aimed to canvass the opinions of stakeholders in smaller institutions, principally based in the regions. It was considered important also to consider the views of individuals who belonged to organisations that can be understood to represent large swathes of the GLAM sector. With over 1800 museums in the UK, surveying the entire sector in the time available was impossible, so opinions were sought from the Museums Association, the Collections Trust, and others. Similarly, the views of organisations with important national oversight in the DIGILAB field, such as the Archaeological Data Service (ADS) and Historic England were also approached for specific comment.

A series of small group workshops were held online during 2 weeks in May 2021 to capture stakeholder perspectives on a range of issues pertinent to RICHeS' potential remit. Hour-long workshop conversations were structured to make best use of consultees' time. The interactive whiteboards for each workshop, which enabled consultees to leave anonymous comments, remained open to contributions after the workshops and were viewed by the project team as part of compiling the project evidence.

The core structure for workshops outlined the RICHeS proposal, invited consultees to envisage how the RICHeS programme might unleash the potential of HS and to identify relevant barriers and enablers. Consultees were also invited to discuss governance functions and principles. The workshops also began articulating how and where heritage science has created public value. Following the workshops, Preservation Matters was contracted to compile a set of case studies for the public value created by heritage science. As necessarily interim, the case study compilation has not been published here but has instead been shared with the National Heritage Science Forum for further development.

The targeted conversations and workshops identified areas which would benefit from a wider set of insights than had hitherto been possible. AHRC therefore conducted an online survey using the Jisc online survey platform[26] which closed on 21 June. The survey was publicised widely to reach as widely as possible within the time available.

179 people responded to the online survey and their insights and comments have been incorporated into the thematic reports compiled by Rebecca Stacey (Annex A), Ben Edwards (Annex B) and Freya Horsfield (Annex C). Although the targeted conversations, workshops and survey have provided a richer picture of the opportunities and challenges facing RICHeS, the limitations of the underpinning data should be emphasised. Specifically, more cross-sectoral quantitative data may be needed to capture a baseline for RICHeS' planning and delivery stages. Overall, the work reported here represents one stage in the ongoing process of collaborative programme design. Further work would be necessary if the RICHeS bid were to process to the next gateway.

[26] https://www.onlinesurveys.ac.uk/

4. Results: snapshot of UK Heritage Science landscape

4.1 FIXLAB and MOLAB

4.1.1 Technologies

The mapping exercise emphasised well the diversity of technologies that are used in HS in the UK. More than 100 analytical techniques regular use in the sector were inventoried, drawn from the full range of biological, physical, chemical, and medical sciences. These are applied in more than 20 recognised HS sub-disciplines and the survey data enabled preliminary mapping of the interconnections between sub-disciplines as well as capturing the diversity of technological application within this landscape. Advanced analytical facilities are accompanied by wider use of more general scientific tools, applied in both research and routine practice.

It should be noted that not all HS uses advanced scientific equipment for data acquisition. Given a robust scientific methodology, data acquired by other methods are equally suitable for high level statistical analysis and thus can be viewed within the scope of the RICHeS ARCHLAB and DIGILAB platforms. Advanced technologies all require specialist technical knowledge for their productive use and/or data interpretation and different expertise is required for applying specific technologies to different kinds of materials and problems. Moreover, meaningful interpretation of HS data demands a nuanced understanding of the complexity of heritage contexts. People, therefore, are fundamental and vital components of the of HS technical infrastructure – at least as crucial as the technologies they deploy.

4.1.2 Host organisations / facilities

Specialist and high-tech facilities for HS broadly fall into five types: HEI-based; IROs with stewardship of specific heritage collections; STFC facilities; other national infrastructure facilities; commercial facilities. There is considerable difference between these in terms of their organisation, remit, funding structure, staffing, types of technologies that are hosted and accessibility to the wider heritage community. Some of these variables were captured by the consultation activities, others are exemplified by the extent of engagement with these and earlier consultations and highlight areas where the RICHeS could generate beneficial change. Regionally, the facilities are distributed throughout the UK. An apparent bias to the south of England needs to be considered in terms of the different types of organisations represented in the infrastructure.

Portable national collections tend to be held by national institutions located in capital cities, thus associated IRO facilities are more likely to be concentrated in these locations, whereas HEI facilities have a much broader regional presence. IROs that steward nationally distributed collections apply their research beyond the location of their lab premises. Many commercial operations specialise in mobile technologies enabling their services to be delivered across the full national heritage landscape. The extent to which regionally based facilities have research links to their local regional heritage has not been mapped in the study but merits further investigation. Regional HS research networks offer an opportunity for local collections to both benefit from and drive the regional priorities of HS.

4.1.3 Mobile technologies

Portable technologies are an innovation frontier for HS because they have many advantages: they eliminate the risk of moving sensitive objects; buildings and monuments can be studied *in-situ*; heritage sites and landscapes can be investigated at scale; roving facilities have potential to increase HS accessibility. A further attraction is that many are non-invasive, but they are not necessarily so, portability and non-invasiveness should not be conflated. A truly non-invasive technology completely precludes damage, including microscale or chemical alteration. Movement/manipulation of objects to facilitate use of portable technologies may introduce risks equivalent to those of moving the object to a non-invasive 'fixed' technology. Many well-established 'fixed' technologies are available in portable form, but the fixed technology may be of higher specification with enhanced capabilities: portable and fixed versions of a technology are therefore not necessarily equivalent.

A significant risk factor associated with portable technologies is the temptation for use by underqualified personnel. Risk of damage to heritage during data collection is a clear concern, but, more pervasively, the consequences of improper application of a technology, or misunderstanding of the data outputs, can put heritage at risk by generation of erroneous interpretation. This is of particular concern if the results are used to guide practical heritage management, as in the planning process or in conservation. This is an area where RICHeS can play an important role in awareness raising via training.

4.2 ARCHLAB and DIGILAB

4.2.1 Existing definitions of ARCHLAB and DIGILAB

ARCHLAB and DIGILAB refer to the physical and digital archives of technical documentation and data, samples and reference collections concerning heritage science in the UK; and, crucially, the connections between these resources and researchers in the form of advanced digital tools and databases. The definitions of these two areas were drawn from original conceptions by E-RIHS (European Research Infrastructure for Heritage Science) but slightly broadened to include a wider representation for archives held across the GLAM sector.

4.2.2 ARCHLAB and DIGILAB with reference to existing funded initiatives

The RICHeS programme will act to fill important gaps in existing AHRC-funded provision for heritage science in the research, academic and GLAM sectors. Two primary existing initiatives are of relevance here: Towards a National Collection (TANC) and Capability for Collections (CapCo). Both are focused on *creating* new physical and virtual elements for the infrastructure landscape: TANC, an integrated and searchable national database of the objects, collections, and archives that form “samples and reference collections” of ARCHLAB and the “digital archives as research resources” of DIGILAB; CapCo, new or enhanced equipment for generating new ARCHLAB and DIGILAB “data”. The consultation responses identified several areas where these two programmes failed to meet the infrastructure priorities of heritage scientists, which are explored in the Annex B on ARCHLAB and DIGILAB.

4.2.3 Mapping the consultation responses

The responses to the RICHeS online survey and consultation workshops were categorised under FAIR principles, i.e. that all data should be findable, accessible, interoperable and re-usable. Further, it is recognised that these principles can be applied to both ARCHLAB and DIGILAB. Whilst the principles were developed for digital data, exactly the same principles can be applied to the physical archives that form the basis of heritage science research (ARCHLAB), both in terms of physical objects themselves (such as reference collections), and the databases that record the existence of these collections. Thus, the analysis includes problems of access to physical collections by heritage scientists, and problems of accessing the resulting archives of digital data produced by those same scientists.

4.2.4 Themes in the identified priorities

A series of themes can be identified in the priorities for infrastructure investment from the consultees. These are not exclusive to either ARCHLAB or DIGILAB and often crosscut both:

4.2.4.1 Sustainability of digital resources

The most striking result concerning sustainability is that the majority of respondents reported that their digital resources were either presently unfunded or that funding for them was at risk, and a minority reported that their resources were not adequately resourced for ongoing maintenance. If these data sources represent the results of expensive scientific enquiry or other resource-intensive research, then there is a clear risk to the long-term sustainability of these prior investments.

4.2.4.2 Connections

Several consultees spoke to problems of digitally connecting people at different types of institutions (such as HEIs, GLAMS, and national labs) with each other, with digital technology, and with data repositories. These connections are essential to allow meaningful, representative and, by extension, valid scientific investigation, whether on digital data or on physical assets. So, connectivity can be seen to encompass people, data, and technologies.

4.2.4.3 Digital technological infrastructure

A major recurring theme is access to analytical tools that can process and interrogate the range of heritage science data produced from ARCHLAB collections. This priority was seen to operate at several levels. At the most basic it concerns digital connectivity to databases of scientific results, as well as their discoverability and accessibility. At the middle level, there are concerns about access to digital technologies that undertake large-scale analyses, in terms of software, the skills to operate that software and the underlying architectures that support it. Finally, is the highest-level issue of interoperability between different types of data from very different fields within the heritage science ecosystem. This literally encompasses the ability of complementary but divergent data types to 'talk' to one another, either form databases or other forms of repository.

4.2.5 Filling gaps in existing provision

The major gaps in infrastructure provision therefore are as follows: the aggregation of the *results* of heritage science investigations; the discoverability, accessibility, interoperability and reusability of these results, and of localised sample and reference collections beyond the GLAM sector; digital technology to connect curators in the GLAM sector with heritage science technology and expertise to meet GLAM sector priorities; digital technology to foster new and innovative forms of analysis of heritage science data.

5. Common themes from consultations April – June 2021

The consultation workshops invited HS practitioners from across the sector to reflect on the issues of the existing HS ecosystem. Comments collected via discussion and contributions to interactive whiteboards were necessarily anecdotal and need to be tempered by awareness of potential bias in the consultation cohort. Identification of the major challenges to be addressed by the RICHeS infrastructure differ markedly in type based on the characteristic of the stakeholder group. Nevertheless, some consistent themes emerged which characterise the challenges that the RICHeS needs to address.

5.1 People and skills

It is generally acknowledged across UKRI that a focus of many funding programmes to date has predominantly been on investigators, with the role played by other professions arguably under-supported to date and certainly less visible overall.[27] In terms of the RICHeS remit, although some analyses have illustrated the labour market for some sectors (such as archaeology and conservation), it is difficult to distinguish heritage science data from that relating to the wider heritage sector.[28] A unified picture of the likely 'people and skills' needs of heritage science 2023-2033 is therefore difficult to determine at this stage.

The consultations for the current report however suggest that skilled individuals will continue to play important roles in all parts of the heritage science ecosystem. In addition to investigators, technical staff are essential to maintain and use technologies to their full potential, through knowing what techniques do. Supporting staff are also essential to widening access to technology, helping non-specialist users to identify the most relevant technology for their needs and interpreting data correctly.

The workshops and online survey surfaced a widespread perception of a looming skills crisis in some areas of heritage science, with some key individuals scheduled to retire soon with no strategic succession planning for this loss. Another widespread perception is that generally low pay rates have a negative effect for the sector through leaching of talent into other sectors due to lack of career opportunities and low pay. It was suggested that such issues are having a consequent negative impact on the diversity of the workforce and on capability for research. The DIGILAB platform specifically will need to take account of the significant lack of computer science expertise either directly in existence within the heritage science sector or feeding into it.

Qualified and experienced individuals are vital 'human capital' within heritage science, providing a variety of services to a wide range of users. Development and retention of appropriate skills will therefore be key challenges for future UK heritage science. The Smith-Reid review argues for a protection/ stabilisation stage in research and innovation

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[27] https://www.technicians.org.uk/technician-commitment Accessed 12/8/21
https://www.gov.uk/government/publications/research-and-development-rd-people-and-culture-strategy Accessed 12/8/21

[28] Such as reports by the National Heritage Science Forum https://www.heritagescienceforum.org.uk/what-we-do/community and Landward Publications https://landward.eu/publications-2/ and research by ICON into conservation labour market intelligence https://www.icon.org.uk/resource/are-you-able-to-take-part-in-icons-labour-market-intelligence-research.html All accessed 12/8/21

capability, before attempting transitions which depend on that capability.[29] The need for such a protection / stabilisation stage in the RICHeS context is apparent from the consultation results.

5.2 Scope, visibility, and accessibility

Several issues emerged which broadly relate to scope, visibility, and accessibility. In contrast to the broad definitions of 'heritage science' identified at the beginning of this report, it was notable that some consultation comments reflected a lack of recognition of what HS has to offer in terms of scope, expertise, and problem-solving potential. Specifically, the targeted conversations reflected a lack of knowledge in some parts of the wider heritage practitioner community of how HS can address their needs. The wider community of heritage science researchers may also not be aware of the *existence* of data repositories and physical archives (ARCHLAB) of the results of scientific investigation. The *content* of physical and or digital archives of heritage science data (ARCHLAB) also may not be accessible or available. This is a particular concern for sample and reference collections that fall outside the GLAM sector beneficiaries of investments in cataloguing, such as the TANC programme, and are thus not the focus for improvements in findability and accessibility.

The consequences of such issues means that analyses and investigations can be partial, in that they do not take account of the full amount of potential data sources, and therefore that they may be unrepresentative and/or results may therefore be skewed. A further potential consequence is that the costs associated with archive maintenance are not justified by the level of use to which they are put. Several respondents to the consultation remarked that there was an incomplete understanding of the *audience* for their digital data, literally who used the information once it had been made available.

5.3 Cross-cutting challenges

A key challenge therefore is creating and maintaining relevant knowledge connections, conceived as a flow of data and insight, between heritage science practitioners, professionals in the GLAM sector, and the wider heritage research community. Digital connections are increasingly an underpinning of knowledge connections overall. Staff

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[29] Smith, A., Reid, G., (2019). Changes and Choices. Advice on future frameworks for international collaboration on research and innovation, commissioned by the Minister of State for Universities, Science, Research and Innovation. https://www.gov.uk/government/publications/future-frameworks-for-international-collaboration-on-research-and-innovation-independent-advice Accessed 15/8/21

expertise and financial resources are however essential to set up and maintain digital archives and connections. Such resources are often in short supply or non-existent, which hampers accessibility of digital archives and connections, and sustaining usability in the face of rapid technological change. Other issues include that where there is a weak fit with the overall remit of the host institution, this can lead to a lack of support from the host institution. There can also be insufficient recognition (in some quarters) of the importance of context in interpreting HS data. Overall, current funding structures are inadequate to address these interlinked issues.

The effect of existing funding strategies has been a competitive culture which is ill-aligned with the aims of the sector for a collaborative culture. Heritage speaks to fundamental human needs of identity and community. Heritage science therefore must be inclusive and capable of tackling the most pressing questions for the sector, such as the impact of climate change.

6. A vision for RICHeS – what would transformation of UK heritage science look like?

The consultation workshops invited participants to envision how RICHeS might transform the HS landscape. The feedback consistently identified four areas where investment could deliver transformative progress for the sector:

6.1 Connectivity – improved mechanisms enable and encourage:

- Collaborative projects, joint research initiatives, interdisciplinarity.
- Connections, knowledge/data exchange between experts.
- Expertise bridges between specialists, facilities and user communities.
- Improved engagement with beneficiary communities – beneficiary-led research questions.
- Stronger links and more collaboration between academics, IROs and commercial practice.
- Relationships with tech developers and other sciences to develop innovations.
- Well-defined relationships with other UK infrastructures to maximise value
- Connectivity extends across the UK and connects internationally

6. 2 Access – improved mechanisms and resources enable and encourage:

- Full use of the equipment infrastructure
- Access to equipment for a wider community of researchers – e.g. regional museums
- Smaller organisations have logistical support to seek scientific access
- Expertise bridges to support and promote widened access.
- Open access to data for future study.
- Easily discoverable collections available for scientific study.

6.3 Sustainability – creates security to ensure:

- Equipment is used to its full technical potential.
- Equipment is supported by expert technical staff
- Career opportunities keep talent and experience in the sector
- Long-term strategic planning for research and investment is possible
- Long term data storage and accessibility for future researchers.
- Development of technological innovations to address genuine and pressing needs
- Tools and data can be sustained in the face of technological, methodological and structural developments and thus be long-term resources for research and innovation.

6.4 Impact – enhanced visibility and recognition:

- Outputs are monitored to demonstrate the societal value of HS.
- Potential for HS to contribute to solving big problems of society is recognised.
- HS is better understood throughout society, especially by potential beneficiary communities.
- HS is used to full potential as an education tool – a recognised gateway from science to arts and vice versa.
- HS clearly feeds into practice and commercial opportunity.
- International links are recognized and fit with global infrastructure is well understood.

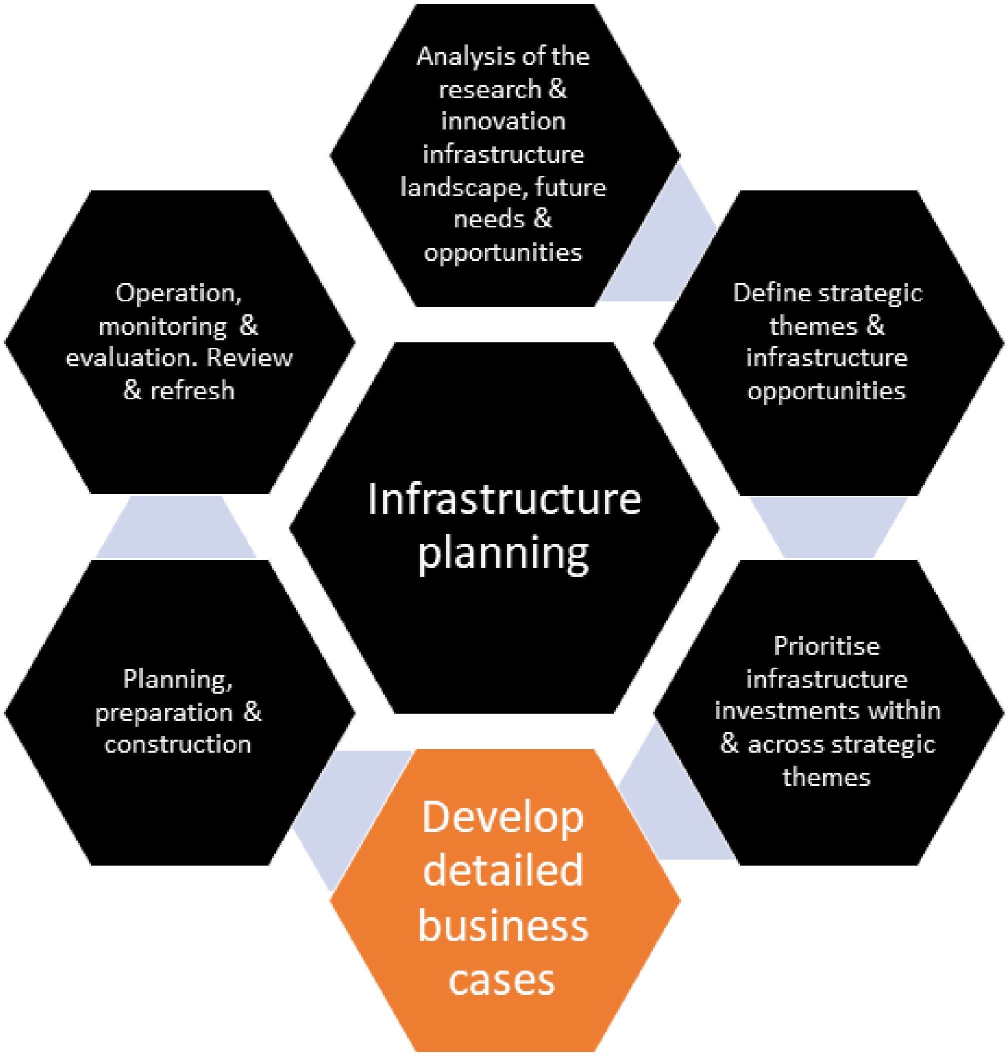

Figure 2: Infrastructure planning. Adapted from UKRI 2020b Figure 3

7. Planning for the proposed infrastructure

7.1 A coherent approach to the transformative potential of heritage science

The scoping and consultations from 2018 onwards identified the need for a coherent approach to the HS ecosystem to achieve the transformative potential of heritage science. The HS community has articulated an ambitious but deliverable vision (previous section). The following section therefore focuses on the potential role of the research funder.

Delivery of the vision for heritage science will depend on research investment with specific characteristics:

Long-term and sustained programmes, to address the issues which have not been tackled by short-term (3-5 years) project grants.

Able to place development of human capital at the heart of planning, from investigators (researchers /scientists) through to the wide array of supporting and professional service roles that make up a modern knowledge enterprise.

Able to support knowledge connectivity to minimise the constraints of current exclusionary definitions such as between physical and digital realms, specific disciplines, the remit of the UKRI family, and organisational affiliation

Can encourage the full spectrum of public value, from growth of knowledge for its own sake to innovation and commercial application

Connect all parts of the UK with the transformative mechanisms

The UKRI Infrastructure Fund supports step-changes in infrastructure capability and/or capacity.[30] The above characteristics therefore endorse the decision by AHRC to submit a bid for RICHeS to the UKRI Infrastructure Fund. Potential infrastructure investments however are subject to a lengthy and rigorous consideration (UKRI 2020c).[31]

Figure 2 illustrates the typical cycle of development, appraisal, and evaluation of an infrastructure project.

RICHeS depends on a successful bid by AHRC bid to the UKRI Infrastructure Fund. The AHRC bid may however not be successful and the potential operational start date for

[30] https://www.ukri.org/our-work/creating-world-class-research-and-innovation-infrastructure/ Accessed 16/8/21

[31] The UK's research and innovation infrastructure: opportunities to grow our capability https://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-UKinfrastructure-opportunities-to-grow-our-capacity-FINAL.pdf Accessed 13/8/21

RICHeS is some time away. It is therefore not possible at present to design the details of specific grant schemes, eligibility criteria, etc.

It is however appropriate and possible at this stage to outline some elements of the infrastructure necessary to address the challenges and opportunities identified through consultations. It is hoped that these outlines might support future cross-sectoral discussions.

7.2 High level concept

The high-level concept of the infrastructure is illustrated in Figure 4. A distributed infrastructure model is the only viable approach for developing a unified national HS infrastructure because:

- It capitalises on the existing long-established specialist infrastructure and expertise in different institutions across the UK.
- It recognises that technology is used differently in different disciplines of HS and that technology demands specific expertise for use in different applications.
- It consolidates and promotes multi-disciplinarity, which is an integral characteristic of HS.
- It provides the most effective means to secure the confidence and engagement of the whole HS community.

It exploits the regional distribution of the existing infrastructure to promote and widen accessibility.

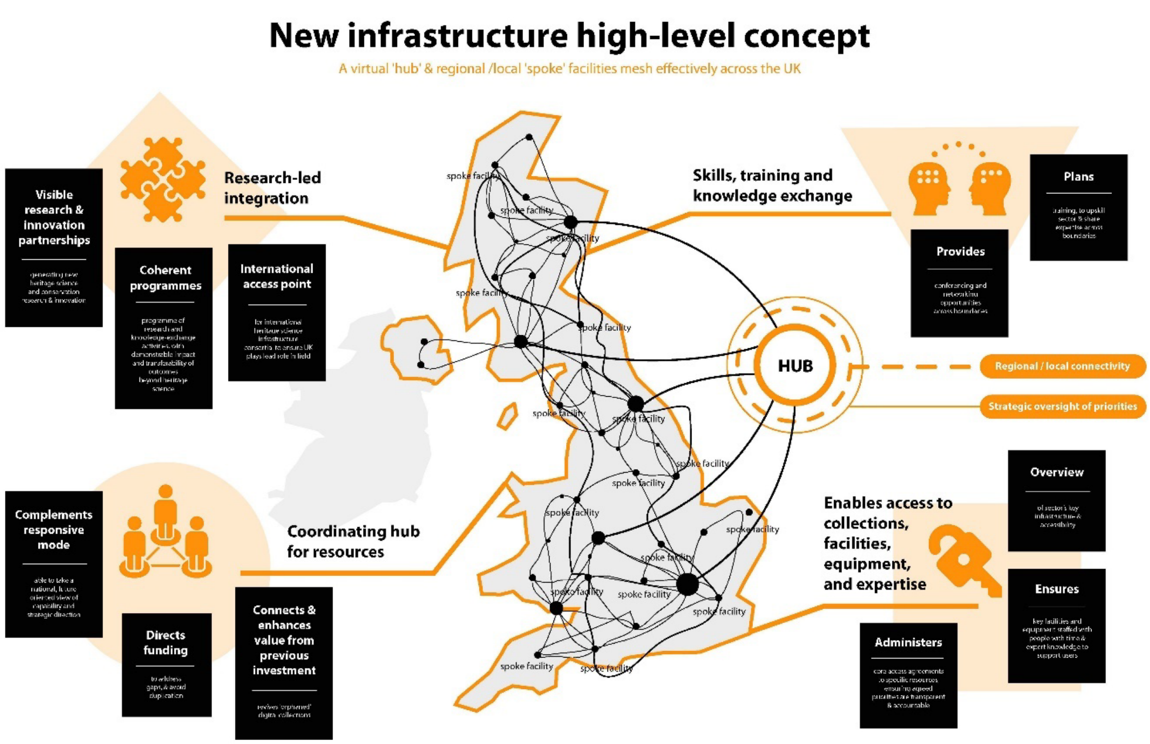

Figure 3: New infrastructure high-level concept. Credit: Monika Flakowska

A ‘functions and principles’ approach to some key governance planning issues was therefore adopted. This used a decision tree approach to test the pre-2021 assumptions for the high-level governance model (Annex C). The decision tree endorsed AHRC’s plan to establish a small strategic hub to perform certain functions, including high-level oversight and overall management of programme funds. The strategic hub would begin life organisationally within AHRC but have the potential to incorporate staff across the UK so thus could be ‘virtual’ to a large degree. The hub would work with AHRC and the heritage science community to provide strategic leadership and co-ordination across the totality of UK publicly funded heritage science facilities. It would map and coordinate the existing and emerging research infrastructure, to enable greater partnership working and reduce inefficiencies caused by duplication and redundancy. This unit would provide a ready structure to engage with international distributed research infrastructures (e.g. E-RIHS.eu), stimulating opportunities for inward investment into UK research capability from Europe and beyond. The strategic hub would work with the HS community and a wide range of stakeholders, to catalyse a step-change in UK HS within the life of the RICHeS programme. Some relevant resources and issues are sketched below.

7.3 Knowledge resources: people

The strategic hub would work with the heritage science community to identify priorities for investment in people. Realising the potential of heritage science depends on putting people front and centre, acknowledging the inherently collaborative nature of much heritage science. Creating a confident and versatile future workforce (including investigators and allied colleagues) equipped with cutting-edge skills and ready access to tools, techniques, data, archives, and collections will require training, knowledge exchange and skills-development opportunities, combined with a sustainable infrastructure. As this report has emphasised throughout, part of the potential of heritage science lies in its definitional fluidity. Being a heritage scientist may therefore evolve into part of a compound identity, allied to a more traditional specialism.

7.4 Knowledge resources: appropriate culture and practices

Coherence of the field may lie instead in shared culture and values. Articulation of such shared culture might usefully begin with articulation of the principles and standards to which heritage scientists work. The consultations for this report began to capture some of the relevant standards and principles, in addition to those which would necessarily be drawn down from UKRI as part of core grant conditions (Annex C). Additionally, this report has foregrounded FAIR principles, of which ‘accessibility’ merits specific mention here. Part of the core mechanism for the success of RICHeS will be that institutions and research areas which have historically had poor access to heritage science infrastructure will be able to apply for investment in infrastructure and skills or access facilities and expertise at other providers. New users of heritage science, including cross-disciplinary consortia of smaller research-active organisations, hi-tech industry and SMEs, will increase collaboration with the heritage science community. The return on investment in existing facilities will be greater, by maximising access to them.

7.5 Knowledge resources: Data

The strategic hub would work with the heritage science community to establish a sustainable infrastructure for data. Aggregation of data and other resources is key and fits well with a decentralised model for the infrastructure. This model also mirrors the work of Towards a National Collection for archives and collections, replicating this model for the results of data derived from heritage science.

RICHeS might therefore:

Develop a central database of scientific archives; of digital databases; of reference collections; and of institutional data repositories containing information derived from UKRI-funded heritage science projects.

- Develop a means of querying these different datasets.
- Develop standards for archive and database metadata.
- Mandate deposition in a securely funded data repository suitable for heritage science data (with deposition free under certain circumstances).
- Make conformity with the above a requirement of capital investment, AHRC awards and fellowships, to make new heritage science data accessible and interoperable.
- Encourage inclusivity across the whole ecosystem, from smaller financially fragile institutions to large, more secure national bodies. Moves towards non-proprietary, open-source software may have a role in this.
- The infrastructure should provide training and resources to enable spoke institutions to maintain and upgrade their digital archiving solutions as technology changes.
- Develop consistent approaches to tracking investment, activity, and outcomes of HS
- Develop an effective approach to computing resilience
- Identify and fund key challenge areas

7.6 Practical resources: methods, techniques, facilities, and equipment

The strategic hub would work with the heritage science community and across UKRI to establish a collaborative, challenge-focussed programme to optimise capability, develop and test new methods and techniques, and connect these widely across and beyond the sector. A programme budget would be allocated competitively to partner institutions, to supply necessary facilities and equipment that meets national infrastructural needs. Provision is currently planned around the LAB categories derived from the E-RIHS definitions, namely FIXLAB: fixed facilities (e.g. laboratories specialising in proteomics, x-ray imaging); MOLAB: mobile instruments for in-situ analyses (e.g. hand-held X-ray Fluorescence Spectroscopy, portable 3D scanners); ARCHLAB: facilities for access to research repositories and reference collections; DIGILAB: software and expertise to host, and enable remote access to, digital data and tools.

8. Conclusions

8.1 The consultations summarised in this report give two clear messages: of the existing and potential public value created by heritage science, and of the need for structural changes in how some aspects of heritage science are supported by research funders. Established funding mechanisms have led to issues such as short-termism, under-use of expensive equipment, and a highly insecure career environment. Left unaddressed, such trends pose a risk to the UK's iconic heritage, such as through the loss of skilled professionals. Reversing these trends will require substantial, extended commitment which is structurally different to existing grants that address discrete aspects of the knowledge ecosystem, such as equipment, individual projects, and knowledge transfer.

8.2 Sustained infrastructure investment of the heritage science knowledge ecosystem will be necessary to mitigate issues inherent in existing funding mechanisms. Investment in people will be necessary, so that UK heritage science can continue to diversify and thus drive new approaches and insights. Greater attention to the full disciplinary span, including social sciences, will form part of this effort. Improved connectivity will be essential. Embedding partnerships, knowledge transfer, and expertise bridges, will need to be mediated by sustainable digital infrastructure and fluid aggregation which supports collaboration at the scale appropriate to the investigative challenge.

8.3 The proposed solution is of a research infrastructure for heritage science, RICHeS. RICHeS would create the conditions necessary for innovative heritage science to be conducted at the scale and pace required to realise the sector's full potential for socio-economic impact and to sustain the UK's role as a global leader in heritage science research and innovation. In a competitive, fast-changing landscape, it is however uncertain that RICHeS will be supported by the UKRI infrastructure Fund.

8.4 This report is therefore offered in service to the heritage science community, to help it prepare for a range of outcomes from the investment decision. The consultations for the programme so far have revealed that, despite the parlous state of many parts of the sector, there is a vision and passion for how heritage science can enable both understanding of our shared past and help shape our shared future.

Annex A: FIXLAB and MOLAB

AHRC infrastructure policy and engagement fellowship in heritage science and conservation 2021 – Report and recommendations

Rebecca Stacey, July 2021

Contents

1. Introduction

This document describes work undertaken between March and July 2021 through the AHRC Infrastructure Policy and Engagement Fellowship (FIXLAB/MOLAB strand) in support of the development of the AHRC's bid for a Research Infrastructure in Conservation and Heritage Science (RICHeS).

The RICHeS proposal emerged from a research and innovation mapping exercise undertaken following the creation of UKRI in 2018. Consultation by AHRC led to identification of heritage as one of three priority areas for investment. Development of a bid for an Institute for Heritage and Conservation Science Research (IHSCR) followed and was submitted to UKRI in 2020. The proposal was well-received, and three Infrastructure Policy and Engagement (IPE) fellowships were created to generate evidence to refine and develop it.

Each fellowship was focussed on a different component of the infrastructure: physical facilities (FIXLAB/MOLAB); digital platforms (ARCHLAB/DIGILAB); and governance. An integrated overall approach however was crucial as there is considerable overlap between the three strands: physical infrastructure generates both data and archives, while investment in and access to these facilities and resources demands governance and administrative activity.

This report describes the landscape mapping research and consultation activities of the IPE Fellowship dedicated to physical facilities and presents the data that have been collected by this exercise. It also makes recommendations for the scope, structure and priorities of the proposed RICHeS infrastructure based on this evidence.

2. Heritage science and conservation research (HSCR) in the UK

2.1 Background

The use of science in support of heritage and conservation research in the UK has a long history, the British Museum for example has housed an in-house science laboratory for over 100 years[32]. The first dedicated heritage science journal was launched from Oxford University in 1958 as the B*ulletin of the Research Laboratory for Archaeology and the History of Art* (now *Archaeometry*) and the subsequent proliferation of journals dedicated to subjects in the field (and its associated disciplines) attests to its growth and development.

Technological advances have diversified and intensified the application of science to heritage questions in recent decades, broadening the opportunities both for new kinds of knowledge generation and for improving our understanding of threats to our heritage assets and new means to protect and preserve them.

[32] https://www.britishmuseum.org/our-work/departments/scientific-research

All branches of science (chemistry, physics, biology, medical, engineering) are used in HSCR and are applied across the full range of heritage types: landscapes, buildings, buried and submerged remains, and our rich collections of cultural objects. The quality of the scientific research developed by HSCR is demonstrated by its publication by the highest profile international science journals.

UK HSCR is outward looking with researchers collaborating internationally across the full remit of the sector. UK HSCR institutions participated in past EU research infrastructure projects[33] for heritage science. These projects paved the way for the current development of the European Research Infrastructure for Heritage Science (E-RIHS)[34] and the contributions of the participating UK institutions have been pivotal shaping the development of this European infrastructure project over the last 20 years.

The UK does not have an integrated or centralised HSCR infrastructure. Centres of expertise have grown organically in different institutions resulting in a fragmented and diverse set of facilities. The RICHeS infrastructure is an opportunity to bring these facilities together to tackle the challenges arising from the existing *ad hoc* structure and, with strategic investment, to secure and grow the vital tools on which the future understanding and preservation of our heritage depends.

Similar moves to bring together heritage science infrastructure on a national basis are underway in other countries. In Italy, the formation of the Instituto di Scienze del Patrimonio Culturale (ISPC)[35] in 2019 brings together cross disciplinary groups working in sciences and humanities, with distributed research centres (in Catania, Firenze, Lecce, Milano, Potenza and Roma) coordinated from headquarters in Naples. The ISPC sits within the Consiglio Nationale delle Richerche (CNR)[36] which leads E-RIHS at EU level and the development of the Italian node of E-RIHS. The developing French node of E-RIHS has been underpinned by two consortium projects under the Foundation des Sciences du Patrimoine comprising mobile and fixed infrastructure access programmes and collaborative research activities[37]. RICHeS will provide an important means for the UK to work with other national infrastructure initiatives as they develop as well as acting as a national link to the E-RIHS ERIC.

[33] EU-ARTECH, CHARISMA and IPERION-CH under FP6 and FP7 programmes 'Integrating Infrastructure Initiatives' and Horizon2020 programmes 'Integrating and opening existing national and regional research infrastructures of European interest'.

[34] http://www.e-rihs.eu/; E-RIHS is a European Research Infrastructure Consortium (ERIC) scheduled to become fully operational in 2022.

[35] www.ispc.cnr.it

[36] http://www.e-rihs.eu/partners/cnr-it/

[37] http://www.sciences-patrimoine.org/; projects PATRIMEX and PATRIMA http://www.sciences-patrimoine.org/equipex-patrimex/

2.2 Value of Heritage science

The importance and value of heritage science to our society is woefully underestimated. This is because the value sits behind the overarching public value of heritage itself (see Heritage Counts reports[38]). Scientific technologies, methods and expertise underpin almost every aspect of heritage-related research and are widely deployed in routine investigative and preservation practice. Thus heritage science underpins, extends and safeguards the value of our heritage as a whole. A snapshot of the public value of HSCR within the specific area of archaeology can be gained from the 'News' section of the latest issue of *British Archaeology*; five out of the 12 stories featured explicitly mention scientific technology (lidar, C14, aDNA, residue & isotope analysis, x-rays/CT), a further three have unreported science behind them (routine geophysics, Treasure/PAS analysis) and one is archaeozoology[39]. Thus together at least 75% of those stories are underpinned by science. All were widely covered by the press, adding beneficial impact for local communities to the wider public interest and heritage protection outcomes.

Heritage materials and problems are testing, presenting unique challenges, both technical and ethical, which have driven innovation and indeed the whole development of the field. The quality, ingenuity and novelty of knowledge and innovation that results from HSCR provides a rich resource for development by fields beyond the heritage sector (as evidenced by case studies in the original IHCSR bid).

The crucial role of HSCR in heritage investigation creates demand for commercial activity where a marketplace can be supported, e.g. driven by the needs of planning policy[40]or the art market[41]. It is further recognized by the requirements of statutory heritage protection in The Treasure Act[42].

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[38] Published by Historic England on behalf of the Historic Environment Forum, Heritage Counts provides research-based evidence for the value of heritage to our economy, society and environment. For reports and regional case studies see https://historicengland.org.uk/research/heritage-counts/

[39] British Archaeology July/August 2021

[40] Evidenced, for example, by the growth in commercial geophysics in commercial archaeology initially through PPG16 and now the NPPF. https://www.gov.uk/government/publications/national-planning-policy-framework--2

[41] https://news.artnet.com/market/the-importance-of-provenance-in-determining-authenticity-29953

[42] As in the Treasure Act Code of Practice (section G56), https://finds.org.uk/documents/treasure_act.pdf

2.3 The UK Heritage science landscape

One of the tasks of this fellowship has been a landscape mapping exercise to reconnoitre the range of scientific technologies used in HSCR, the facilities where they are housed and the types of research they are used in. The mapping draws on personal experience of the sector, data gathered from institutional websites of HSCR active HEIs and IROs, recent AHRC equipment investment data, previous sector research by the National Heritage Science Forum (NHSF)[43], examination of other infrastructures and conversations with research active HSCR practitioners. The results have been drawn together in a database, which, with further development, will allow the gathered information to be searched, interrogated and visualised. The database has potential to be developed as a resource for the future RICHeS infrastructure.

The mapping exercise was supported by two phases of consultation. A series of eight workshops was conducted over a two-week period in May 2021. The consultees were invited HSCR practitioners from across the sector. There were 51 participants, drawn from 33 different organisations representing HEI, IRO, commercial and sector stakeholders. The participants shared their experiences and knowledge of the current HSCR infrastructure, and their expectations of the opportunity represented by the proposed RICHeS model.

Following the consultation workshops a survey was launched in June 2021 to gather further details about the existing landscape and to reach a wider stakeholder community including non-scientist practitioners. Geographic and sector distributions of the different consultee cohorts are presented in Figure 5 and are worth comparing with the overall mapped HSCR landscape data (Figure 6). The workshop participants were geographically slightly biased in distribution, probably as a result of under-representation of the HEI sector and high engagement from national IRO organisations. The survey reach corrects some of this bias, especially for respondents identifying as scientists.

Some key observations from the landscape mapping and consultation exercises are summarised in the sections that follow.

[43] 'Strategic Framework for Heritage Science in the UK 2018-2023' NHSF 2018, https://www.heritagescienceforum.org.uk/what-we-do/strategic-framework; Heritage Science and Societal Challenges: a blueprint for action, NHSF 2020 https://www.heritagescienceforum.org.uk/documents/NHSF_SocietalChallenges_Blueprint.pdf

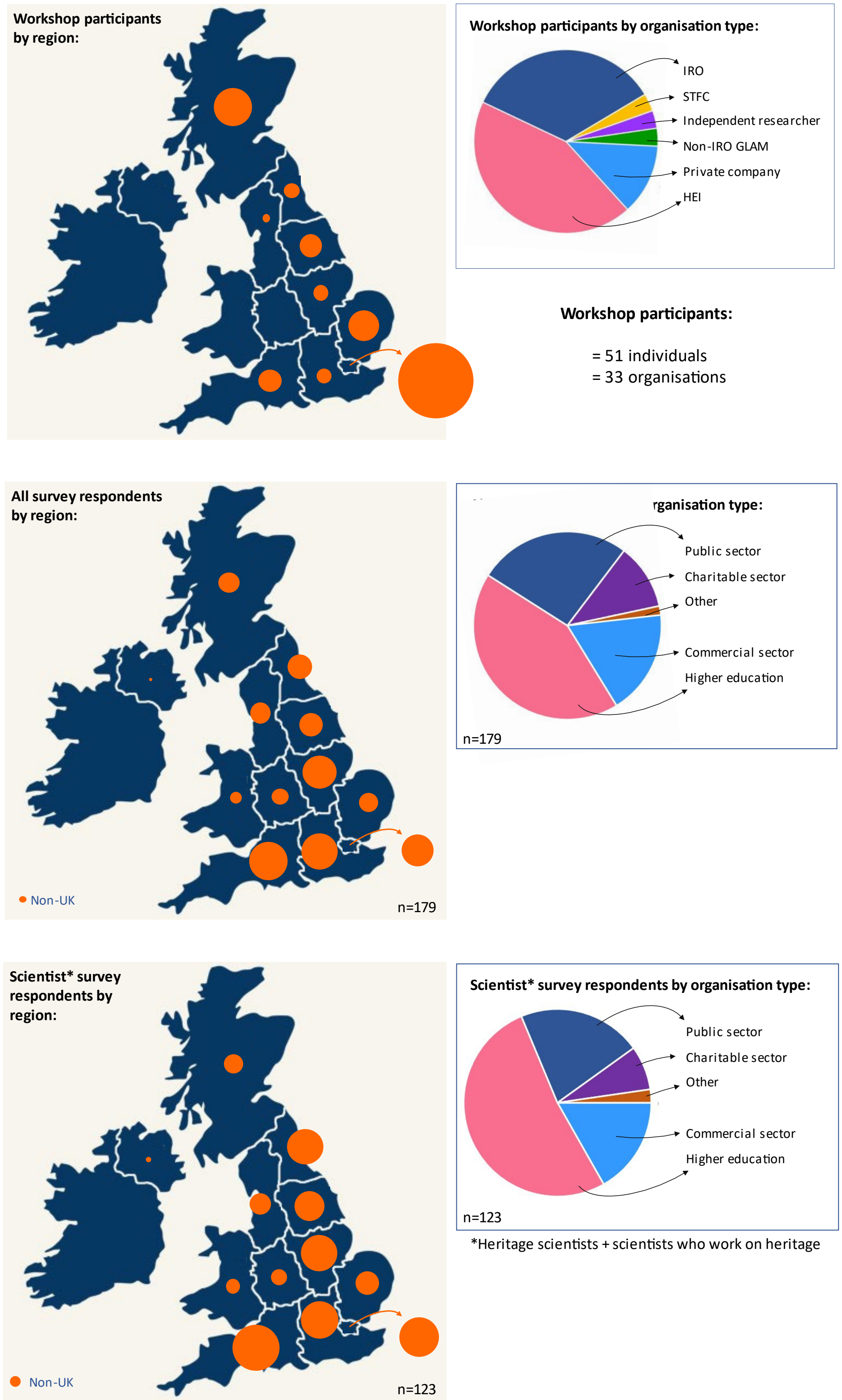


Figure 4: Geographic and sector distributions of the consultee cohorts from the workshops and survey.

2.3.1 Technologies

The technologies used in HSCR are diverse and drawn from the full range of biological, physical, chemical and medical sciences. Over 100 analytical technologies, techniques or tools in regular use in the sector have been inventoried in this exercise (Appendix 1) and there are undoubtedly many more to be captured.

The technologies are applied in more than 20 sub-disciplines of HSCR. The identified sub-disciplines are listed in Appendix 2 and have been selected to reflect well-recognised fields that have established research communities. There are many overlaps between them and other classifications are possible. The survey data enabled capture and visualisation of the interconnections between these sub-disciplines (Figure 6) and the results show how more detailed network analysis by RICHeS could be used to underpin development of these existing sector relationships and the forging of new connections.

The same approach can be used to visualise the diversity of application of different technologies within the sector. The radar plots in Figure 7 demonstrate the wide application of technologies in archaeology and conservation and the more targeted applications in other sub-disciplines. Some technologies are applied in specific research areas (e.g. genomics), while others are widely used across the sector (e.g. x-ray techniques) for a variety of research problems.

Alongside these facilities there is a broader spread of more general scientific tools in use across the sector. These may be applied in research or routine practice. It is important to recognise that not all HSCR uses advanced scientific equipment for data acquisition. Data acquired by other methods, when collected within a robust scientific methodology, is equally suitable for high level statistical analysis and is thus within the scope of the RICHeS infrastructure under the ARCHLAB and DIGILAB platforms.

With the exception of general laboratory tools, all the technologies require some degree of specialist technical knowledge for their productive use and/or data interpretation. In some cases, extensive specialist expertise is required for data acquisition and/or processing. Different kinds of expertise may be required for applying specific technologies to different kinds of materials and problems (e.g. the use of SEM for palynology vs its application in metallography). Moreover, proper meaningful interpretation of HSCR data demands a nuanced understanding of the complexity of heritage contexts. People, therefore, are a fundamental and vital part of the of HSCR infrastructure – at least as crucial as the technologies they deploy.

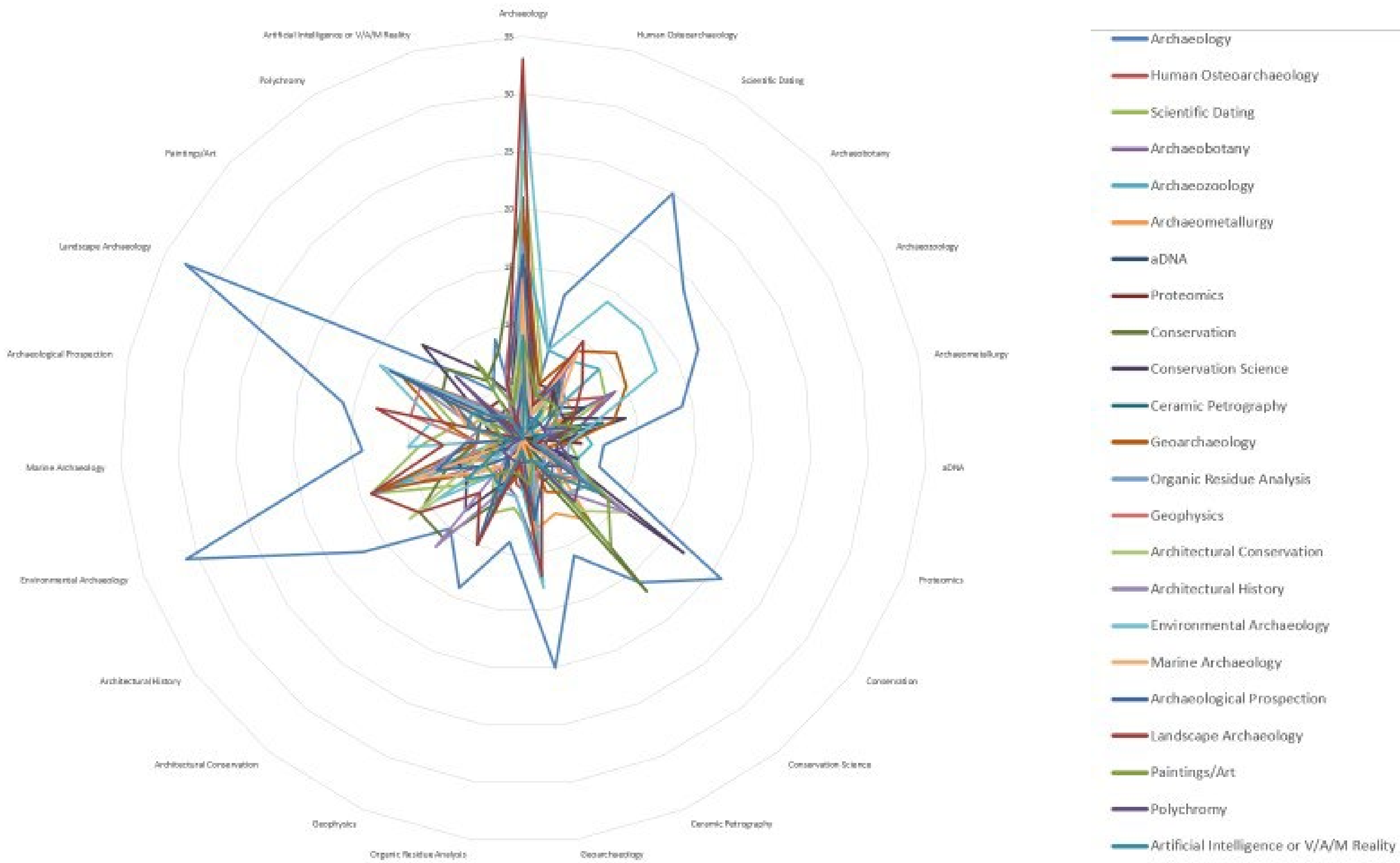
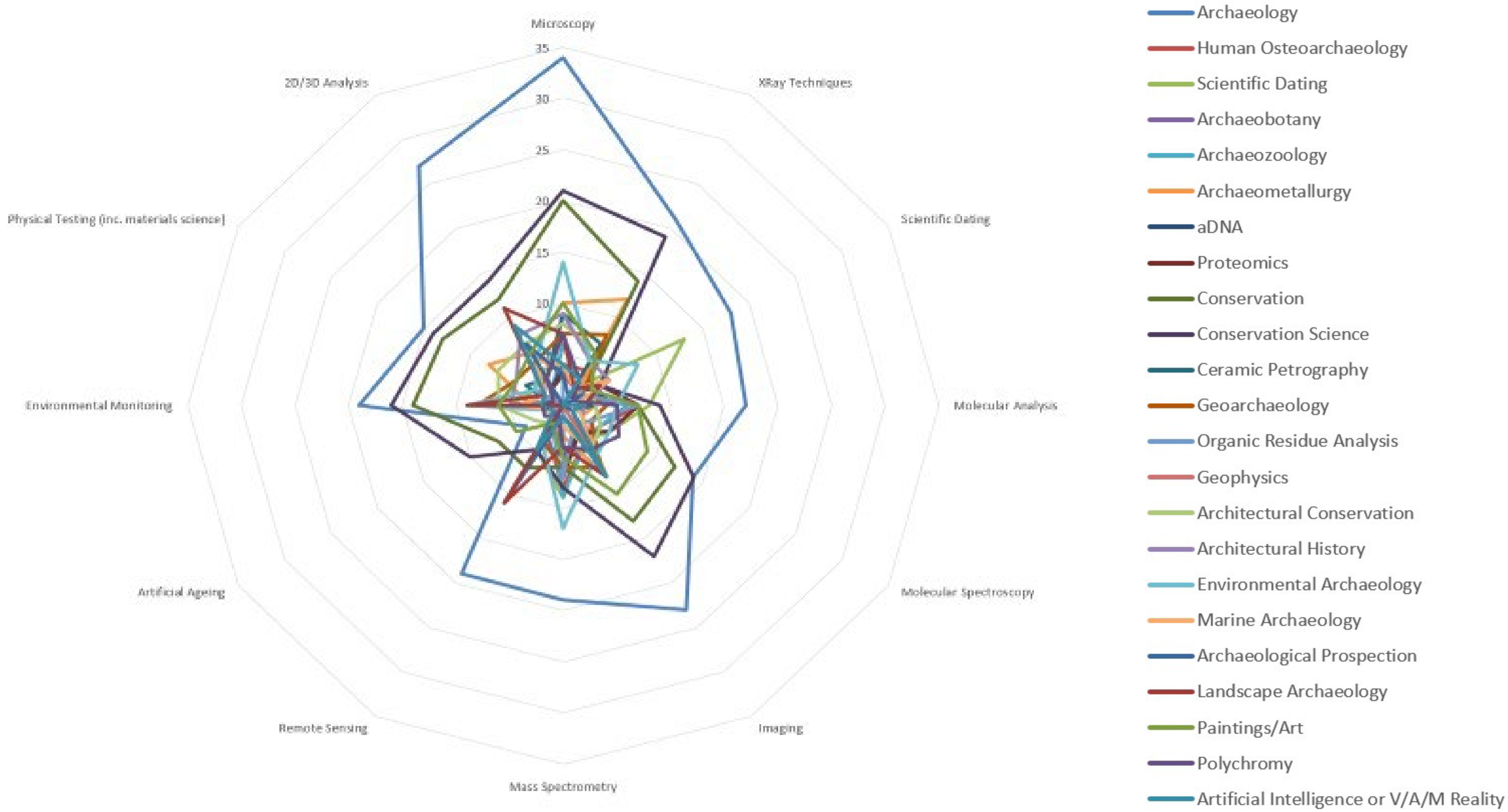


Figure 5: Radar plot showing connections between sub-disciplines of HSCR based on survey responses   Radial axis indicates number of respondents identifying with paired disciplines.


Microscopy
35
30
25
20
15
10
XRay Techniques
Scientific Dating
Molecular Analysis
Molecular Spectroscopy
Imaging
Mass Spectrometry
Remote Sensing
Artificial Ageing
Environmental Monitoring
Physical Testing (inc. materials science)
2D/3D Analysis
Archaeology
Human Osteoarchaeology
Scientific Dating
Archaeobotany
Archaeozoology
Archaeometallurgy
aDNA
Proteomics
Conservation
Conservation Science
Ceramic Petrography
Geoarchaeology
Organic Residue Analysis
Geophysics
Architectural Conservation
Architectural History
Environmental Archaeology
Marine Archaeology
Archaeological Prospection
Landscape Archaeology
Paintings/Art
Polychromy
Artificial Intelligence or V/A/M Reality

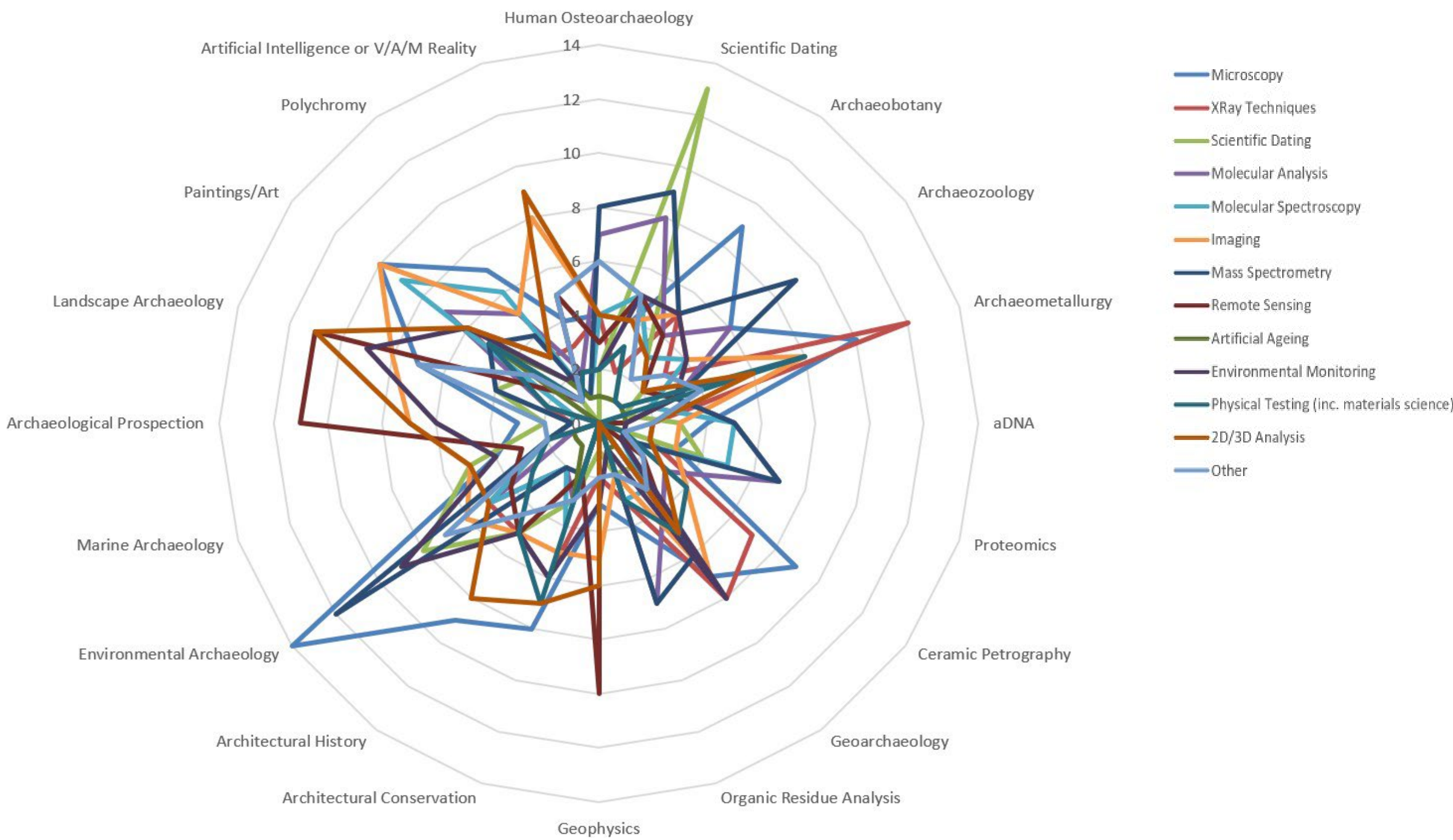


Figure 6a & 7b: Radar plots correlating scientific technology classes (see Appendix 1) with sub-disciplines of HSCR.

Based on survey responses: radial axes indicate number of respondents identifying with discipline/technology pairs. Archaeology and conservation are omitted in second plot to enhance the detail of other sub-disciplines.

2.3.2 Types of facility

Specialist and high-tech facilities for HSCR broadly fall into five types with the following characteristics:

University-based

- Facilities may be based within heritage departments (e.g. archaeology/art/humanities) or within science departments (e.g. chemistry/physics/geography).
- May serve non-heritage research activity as well.
- May be highly specialist in focus or more general.
- Some group together related specialist areas within the field (e.g. Bioarch at York[44]).
- May be strongly associated with specific academics and their personal research interests (risk factor for sustainability).
- May have formalised research links with local heritage institutions to form research clusters (e.g. CHERISH[45] at Cambridge).

Within National Institutions that steward specific heritage collections.

- IROs that maintain laboratory facilities and employ scientists to support their curatorial function.
- Tend to serve focussed research related to type of collection held/managed (buildings, paintings, manuscripts etc.).
- May be strongly conservation/conservation science led (depending on remit).

STFC facilities

- Cutting edge technologies with bespoke technical infrastructure.
- Expert technical staff.
- Deliver analysis across wide science applications, not just heritage.

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[44] https://www.york.ac.uk/archaeology/centres-facilities/bioarch/

[45] The Cambridge Heritage Science Hub (CHERISH), https://collectionsresearch.lib.cam.ac.uk/research-growth-networks/materiality/cambridge-heritage-science-hub-cherish

Other national infrastructure facilities

- Well-equipped facilities with supporting technical staff.
- Remit can be broad range or directed to specific non-heritage field (though may be well aligned).
- Heritage activity may be low priority or subservient to wider strategic remit.

Commercial facilities

- Deliver analysis on a commercial basis.
- May also do research and technical innovation.
- Focus is driven by marketplace demands – principally linked to planning/development process.
- Mobile technologies are well represented.

Differences in the extent of technology housed by different types of organisations and remit for application to HSCR were captured by the survey, see Figure 8. The distribution of research activity in different sub-disciplines and using different technologies across the organisation types is also telling (Figure 9). These charts highlight some recognised features of the landscape, for example that remote sensing is a strong area for commercial activity. They also show the kinds of activity that are concentrated in HEIs and draw attention to some of the specific concerns of IROs related to managing collections, e.g. environmental monitoring. There is considerable scope to add nuance and detail to this picture with further sector consultation.

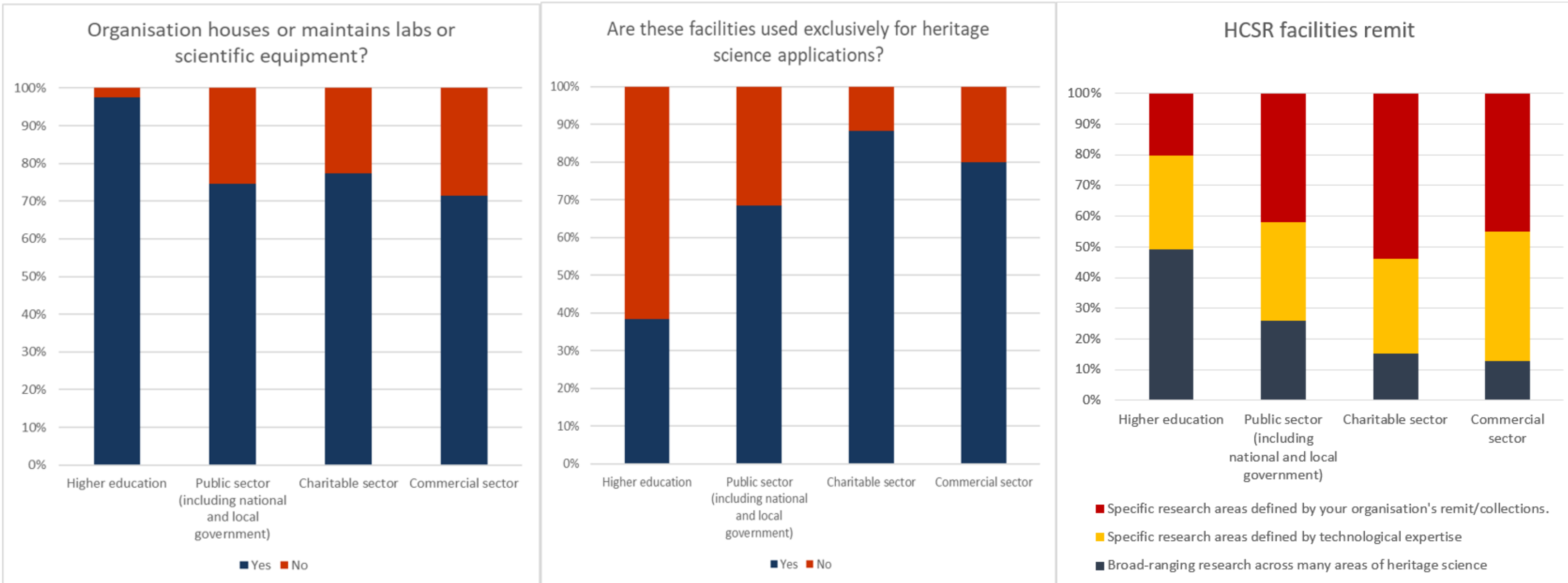

Figure 7:Survey data describing the types of organisations where HSCR is housed and the remit of the facilities with respect to HSCR.

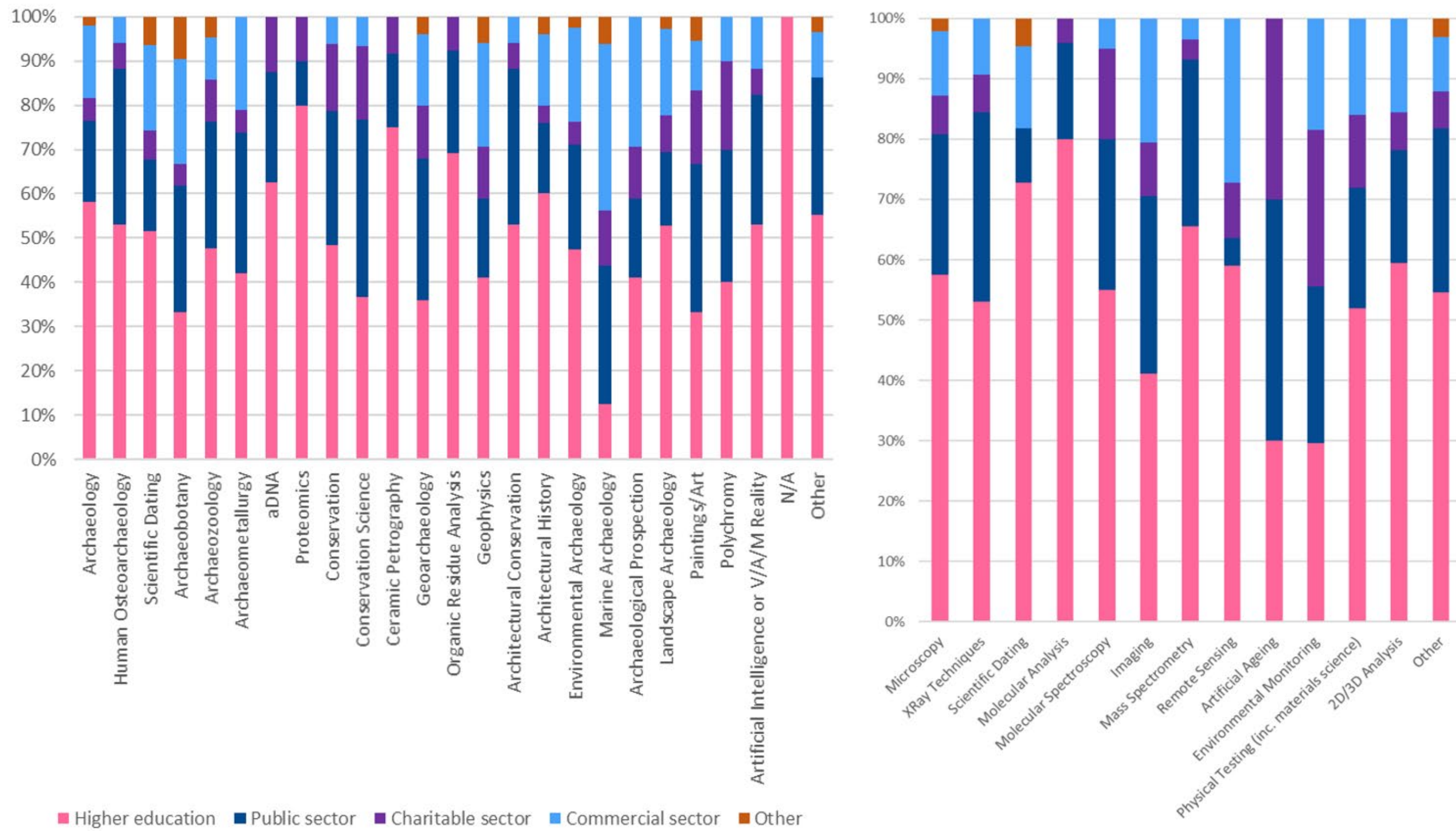

Figure 8: Distribution of sub-disciplinary research activity (left) and technology (right) across different types of HSCR organisation (from survey data)

2.3.3 Regional distribution of HSCR facilities

HSCR is carried out at locations throughout the UK. A visualisation of the regional distribution is presented in Figure 10. Superficially the distribution appears concentrated towards the south of England, however the landscape needs to be considered in terms of the different types of organisation represented. The tendency of portable national collections to be held by national institutions located in capital cities means that IRO facilities are more likely to be concentrated in these locations, whereas HEI facilities have a broader regional presence. In addition, the collections of some HSCR active IROs are nationally distributed (e.g. Historic England) meaning that their work extends beyond the location of their laboratory base. Indeed, this is true of all facilities where the heritage that is the subject of scientific study is regionally located.

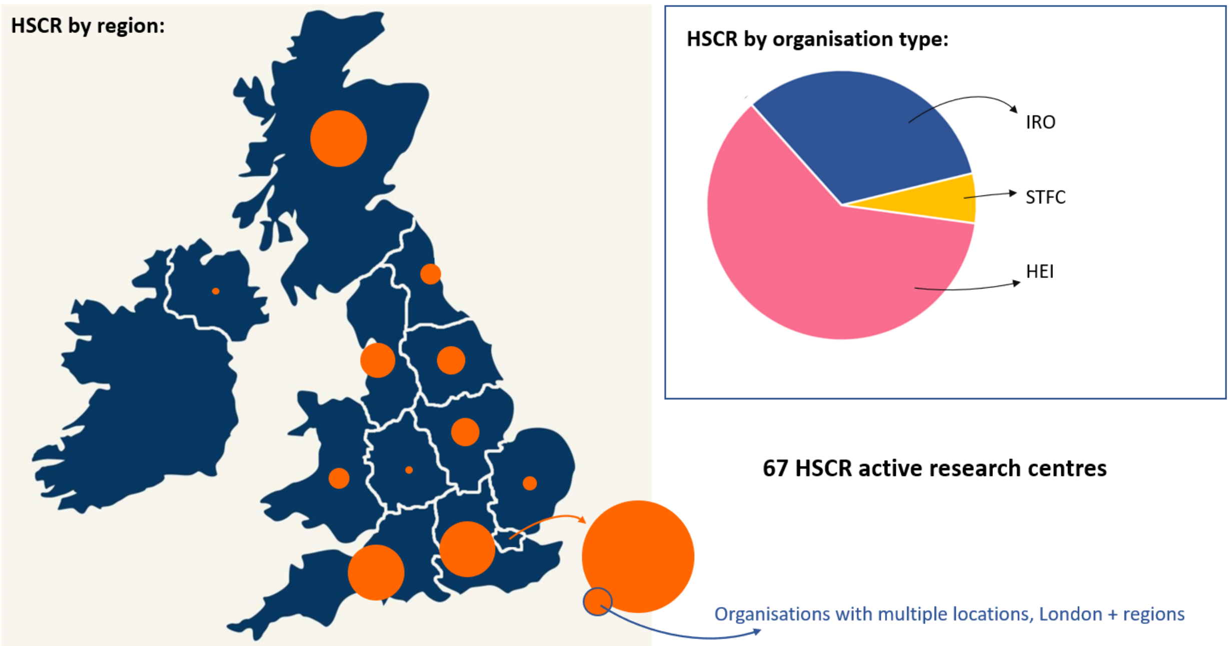

Figure 9: Regional distribution of HSCR active research centres in the UK and breakdown by type of organisation.

This distribution does not capture commercial entities except where they are hosted within the mapped research centres.

The mapping does not capture the location of specific technologies by institution, so the regional presence of technologies listed in Appendix 1 cannot be visualised in this way. At this stage there is little benefit in attempting to map this technology landscape, which is both dynamic and complex, and demands a high degree of sector engagement and confidence to collect. The impact of the events of the last 18 months (Covid-19 and departure from the EU) is yet to unfold and may lead to alterations in the overall picture. Any detailed mapping attempted now would be likely to be quickly outdated. Mapping of this kind will be an important early and ongoing function of the RICHeS infrastructure (see 3.4). The different types of facility can nevertheless be examined through a regional lens. The STFC facilities are primarily based at the Harwell campus and the technologies have to be accessed on location there. Many commercial operations specialise in mobile technologies enabling their services to be delivered across the full national heritage landscape.

The extent to which regionally based facilities have research links to their local regional heritage has not been mapped in the study but is worthy of further investigation. Regional HSCR research networks offer an opportunity for local collections to both benefit from and drive the regional priorities of HSCR.

2.3.4 Fixed and mobile technologies

Classification of technologies as ‘fixed’ or ‘mobile’ primarily describes the mode of access anticipated via the RICHeS access platforms (see 3.2.2), but crucially also the capacity of a technology to be applied *in-situ*.

Portable technologies are an innovation frontier for HSCR because they have many advantages: sensitive objects do not need to be moved for analysis with all the risks thus entailed; immovable objects, buildings and monuments can be studied *in-situ*, heritage sites and landscapes can be investigated at scale, roving facilities have the potential to increase awareness and accessibility of HSCR capability.

Another attractive feature of portable technologies is that many are non-invasive, but they are not necessarily so, and the question of portability and non-invasiveness should not be conflated. A fully non-invasive technology should completely preclude damage to the object/site studied at every scale. This goes beyond removal of the requirement for sampling and includes damage at the microscale and/or chemical alteration arising from the intervention. Movement or manipulation of objects to facilitate use of portable technologies may introduce risks equivalent to those of moving the object to a non-invasive ‘fixed’ technology.

Many well-established ‘fixed’ technologies are available in portable form and it is important to note that the fixed technology may be of higher specification with enhanced capabilities, portable and fixed versions of a technology are therefore not necessarily equivalent.

A significant risk factor associated with portable technologies is the increased tendency for use by underqualified personnel. This may risk damage to heritage during data collection for all the reasons noted above, but, more pervasively, the consequences of improper application of the technology, or misunderstanding of the data outputs, can put heritage at risk by generation of erroneous interpretation. This is of particular concern if the results are used to guide practical heritage management, as in the planning process or in conservation.

2.4 The scope of RICHeS

It is important to define the scope of the proposed RICHeS infrastructure in relation to the equipment/facility landscape. Three principles describe the scope, and the RICHeS model recommended in this report is based on these:

1) Technologies/facilities that are used for ***scientific research*** on heritage (i.e. all built, buried, submerged or portable heritage, including natural history collections but excluding the living natural environment.

2) Equipment (and access to equipment) is for ***scientific research*** not routine practice.

3) The technologies are those used to generate data ***for research*** (extending knowledge and understanding) not generating data to facilitate access or create a research resource (although the data once generated may do that subsequently, falling then within the scope of ARCHLAB). Digitisation would therefore be excluded unless it is applied as a research tool.

2.5 Challenges to be addressed by the RICHeS infrastructure

The consultation workshops invited HSCR practitioners from across the sector to reflect on the shortcomings of the existing infrastructure and barriers within the HSCR ecosystem more generally.

Comments collected via discussion and contributions to interactive whiteboards were necessarily anecdotal and need to be tempered by awareness of potential bias in the sector demographic of the consultation cohort (see 2.3 above). Nevertheless, some consistent themes emerged which characterise the challenges that the RICHeS needs to address.

- Lack of recognition of what HSCR has to offer in terms of scope, expertise and problem-solving potential.
- Conflicting definitions of 'heritage science' create division in the sector.
- Technologies require technical staffing to maintain and use them to full potential.
- Widening access depends on supporting staff roles to facilitate.
- There is an expertise barrier that limits widening of access – knowing what techniques do, interpreting data correctly.
- Lack of knowledge in wider heritage practitioner community of how HSCR can address their needs.
- Leaching of talent into other sectors due to lack of career opportunities and low pay.
- Loss of career expertise from retirement – no strategic succession planning for this loss.
- Impact of low pay on diversity of workforce and associated impact on priorities, research interests and scope for community-led research.
- Lack of support from host institutions if the fit with the overall remit is perceived as weak.
- Insufficient recognition of the importance of context in interpreting HSCR data (in some quarters)
- Inadequacy of current funding structure to address these challenges.

Consistent messages emerged from the survey which consulted a broader cross section of stakeholder community.

2.6 A vision for RICHeS – what would transformation of UK HSCR look like?

The consultation workshops also invited participants to reflect on how RICHeS might transform the HSCR landscape. The feedback consistently identified four areas where investment could deliver transformative progress for the sector:

1. Connectivity – improved mechanisms to enable and encourage:

- Collaborative projects, joint research initiatives, interdisciplinarity.
- Connections, knowledge/data exchange between experts.
- Expertise bridges between specialist facilities and user communities.
- Improved engagement with beneficiary communities – beneficiary-led research questions.
- Stronger links and more collaboration between academics, IROs and commercial practice.
- Relationships with tech developers and other sciences to develop new innovations.
- Relationships with other UK infrastructures are well-defined

2. Access – improved mechanisms and resources to enable and encourage:

- Full use of the equipment infrastructure
- Access to equipment for a wider community of researchers – e.g. regional museums
- Smaller organisations have logistical support to seek scientific access
- Expertise bridges to support and promote widened access.
- Open access to data for future study.
- Easily discoverable collections available for scientific study.

3. Sustainability – creates security to ensure:

- Equipment is used to its full technical potential.
- Equipment is supported by expert technical staff
- Career opportunities keep talent and experience in the sector
- Long-term strategic planning for research and investment is possible
- Long term data storage and accessibility for future researchers.
- Development of new technological innovations to address genuine and pressing needs.

4. Impact – enhanced visibility and recognition:

- Outputs are monitored to demonstrate the societal value of HSCR.
- Potential for HSCR to contribute to solving big problems of society is recognised.
- HSCR is better understood throughout society, especially by potential beneficiary communities.
- HSCR is used to full potential as an education tool – a recognised gateway from science to arts and vice versa.
- HSCR clearly feeds into practice and commercial opportunity.
- International links are recognized and fit with global infrastructure is well understood.

3. The RICHeS model

3.1 A dispersed infrastructure

The RICHeS model proposed in the original bid envisaged a dispersed infrastructure comprising a hub and numerous (n=50+) spokes. The role of the hub in the model is to provide strategic oversight of the infrastructure, coordinating activities, leading and administering the access and investment programme, maintaining links to other national and international infrastructures, and delivering robust governance. The role of the spokes is to deliver scientific activity (research and innovation), house the expertise and technical resources of the infrastructure, and to provide access for the heritage researcher community to these resources.

The model is distinct from the investment route provided by AHRC CapCo (World Class Labs) because it addresses not only equipment needs but also the staffing and expertise that is vital to support it, the connectivity needed to invigorate the community, sustainability to safeguard the scientific needs of our heritage for the long-term, and a widening of access to ensure that the resource is used to maximum potential.

International distributed infrastructure models are explored in detail (with recommendations for their operation and governance) in an OECD report[46]. RICHeS will follow these principles on a national scale to link geographically dispersed independent research organisations with specialist expertise and equipment for HSCR. The UK infrastructure landscape is already home to other distributed infrastructure models e.g. Royce Institute[47], ELIXIR-UK[48]. A distributed infrastructure model is the only viable approach for developing a unified national HSCR infrastructure because:

- It capitalises on the existing long-established specialist infrastructure and expertise in different institutions across the UK.
- It recognises that technology is used differently in different disciplines of HSCR and that technology demands specific expertise for use in different applications.
- It consolidates and promotes multi-disciplinarity, which is an integral characteristic of HSCR.
- It provides the most effective means to secure the confidence and engagement of the whole HSCR community.
- It exploits the regional distribution of the existing infrastructure to promote and widen accessibility.

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[46] 'International distributed research infrastructures: issues and options' OECD 2014, https://www.oecd.org/science/international-distributed-research-infrastructures.pdf

[47] The Henry Royce Institute is the UK National Institute for Advanced Materials, a partnership of nine institutions (universities of Cambridge, Imperial College London, Liverpool, Leeds, Oxford, Sheffield, the National Nuclear Laboratory, and UKAEA) with an operational hub at the University of Manchester. It is funded by the EPSRC/UKRI. https://www.royce.ac.uk/

[48] The UK Node of ELIXIR, an interdisciplinary international cooperation for life sciences data management. ELIXIR-UK is a distributed infrastructure across 19 UK organisations providing training and resources to support the bioinformatics and broader research community. The organisations work together via a 'Hub and Nodes' model. https://elixiruknode.org/

3.2 Spokes, access platforms and activities

These sections describe a recommended approach to deliver the vision and priorities that have been described above. The recommendations should be viewed as a starting point which can be tested by further consultation and refined in development of the strategic business case.

3.2.1 Component facilities

RICHeS spokes will be AHRC eligible HEIs and IROs, category 1 and 2 in list (2.3.2) above. Two kinds of spoke facility are recommended:

Specialist centres – centres of specialist expertise with specific technology for particular kinds of analysis (e.g. proteomics, x-ray imaging)

Bespoke/cluster facilities – well established centres for HSCR which house a broader range of analytical facilities. In an IRO these may be tailored to the collection that the facility serves, in an HEI they may be associated with the sub-disciplinary research strength(s) of the department.

An organisation might identify both as a cluster facility *and* a specialist centre if they meet the criteria for both. There is scope for multiple organisations to join together to from a consortium spoke; this might have advantages where closely located regional organisations can increase their strength by working together or where pooling of equipment/expertise resource makes more effective use of existing or new infrastructure. Ineligible facilities, such as STFC facilities, will still be recognised as components of the HSCR landscape and will have a relationship with the hub to ensure they are included in the collective cohesion it delivers for the sector. However, they should continue to operate through their existing access routes and would not obtain infrastructure funding from the hub.

Commercial entities will benefit from the hub in raised awareness of the sector, more access to newly developing innovations, and a closer relationship with the research community. Commercial entities may choose to partner with spokes to develop new marketable scientific innovations.

The sector-wide engagement activities of the hub will ensure that low-tech HSCR is recognised in the landscape and that opportunities for collaboration are developed in this area.

3.2.2 Access platforms

Increasing access to the national HSCR infrastructure is central to the RICHeS vision. The UK heritage research community will be able to access the spoke facilities set out above via four access platforms: FIXLAB, MOLAB, ARCHLAB and DIGILAB. The first three of these relate to physical infrastructure:

- FIXLAB – technologies housed and used within laboratories ('fixed' infrastructure).
- MOLAB – technologies that portable and can be used in fieldwork or on objects at their home site ('mobile' infrastructure)
- ARCHLAB – the archived resources associated with FIXLAB and MOLAB infrastructures – i.e. archived scientific data from previous studies on heritage/reference material, physical reference collections of samples, comparison specimen materials, the proprietary software platforms that allow archive data to be read and re-processed.

Spoke facilities may offer access through more than one of these platforms depending on the kind of the infrastructure they host. The access platform describes the nature of the access rather than the spoke facility, thus:

- FIXLAB – Heritage objects or samples are brought to a spoke facility by researchers, for analysis using the facilities and expertise at that spoke.
- MOLAB – An expert or expert team brings portable technologies to work with a researcher on location with a heritage asset.
- ARCHLAB – Researchers visit the spoke facility to work with archives and data, supported by the expertise of the spoke.

3.2.3 Sector development

Alongside investment in the physical infrastructure and its accessibility, the RICHeS must address sustainability and tackle the current challenges of fragmentation. Initiatives to promote cross-sector collaboration and to nurture technical innovation are therefore important components of the programme.

Spokes can be encouraged to work with each other and with the wider heritage research community by participating in 'joint research initiatives' (JRIs). These JRIs would be designed as collaborative programmes focused on sector-wide challenges for research and innovation. They should tackle the most pressing research priorities of the sector by pooling expertise and technological resources, fostering new collaborations and fuelling innovation. Knowledge exchange events, thematic workshops and cross-sector meetings organised via the hub will provide the opportunity for JRI challenges to be identified and defined by the HSCR community in consultation with wider heritage practitioner stakeholders.

Knowledge exchange events will also be a crucial means to bring different elements of the sector together to share knowledge, build relationships and raise awareness of HSCR in the heritage community. Events organised by the hub should be structured to achieve these aims and to include the wider heritage sector to promote community and practice-led research.

RICHeS also offers a means to address the lack of recognition of HSCR in the UK and the public value generated by the sector. Work of the hub to survey and monitor the extent and development of the infrastructure, its activities and outputs, will deliver new data by which the impact of HSCR in the UK can be measured and promoted.

3.2.4 Training and professional development

As noted in section 2.3.1 people are key to the successful delivery of the RICHeS. Knowledge and expertise are crucial for advances in research and technical innovation and vital to underpin the vision of infrastructure accessibility. The future of the sector depends on nurturing talent, improving access to skills development in HSCR and strengthening career pathways. The RICHeS programme and functions of the hub can address these issues the following ways:

- **Training for access**. For potential users of the infrastructure, whether HSCR practitioners or heritage professionals who seek access to the capabilities of spoke facilities, bootcamp training events will raise awareness of the applications of different technologies and their limitations, provide basic understanding of the scientific principles that underpin them and the fundamental aspects of data interpretation. This training should be delivered by the relevant spoke organisations (or consortia thereof) coordinated by the hub.
- **Knowledge exchange**. Professional development opportunities for HSCR practitioners to widen their technical experience and forge broader links within the HSCR community. This could be achieved through themed workshop events, technical masterclasses and placement exchange opportunities between spoke providers.
- **Data skills**. Although primarily a concern of the DIGILAB strand, data management and data interpretation tools are inextricably associated with the physical infrastructure from which the data originate and are crucial for ensuring that maximum benefit is extracted from scientific intervention and the accrued data resource. Skills development workshops in statistics, data archiving and FAIR[49] principles will lead to cross-sector strengthening in expertise, and much needed consistency of approaches to data treatment and management.
- **Diversifying career paths.** Investment in technical roles to support the physical infrastructure will offer new employment opportunities in the sector. Increased connectivity within the sector will deliver more flexibility in workforce expertise, providing more options to early career reserachers for developing their career paths and opportunities for developing new cross-sector expertise portfolios.

3.3 Participation and investment

Details of the specific equipment investment needs cannot be set out at this stage (see 3.4). An early function of the hub should be a comprehensive sector engagement exercise to map the detail of the physical infrastructure in terms of equipment and staffing. The strategy for investment needs to be managed through the hub with an application process designed to deliver the evidence to ensure the most transformative interventions that capitalise on existing capacity.

3.3.1 Spoke eligibility criteria

To be recognised as a RICHeS spoke and to receive infrastructure investment a facility should meet certain criteria. All spoke types (specialist centres or bespoke/cluster facilities) would need to demonstrate:

- an established track record for excellence in their identified specialism or area;

[49] https://www.go-fair.org/fair-principles/

- an existing collaborative network delivering expertise to the wider HSCR community;
- an internal strategic plan for consolidating and developing the facility which includes an analysis of the sector demand for extending/widening access for the HSCR community;
- mechanisms for cooperating with other aligned centres.

Physical infrastructure costs available to spokes must include staff costs as well as equipment, in recognition of the specialist expertise required to run and maintain equipment and to correctly process and interpret the data acquired. Equipment costs in scope should include:

- additional equipment needed to extend access;
- replacement/upgrade of aged/outdated/failed equipment;
- equipment required to develop new technologies/applications to benefit the sector;
- equipment maintenance costs.

Staff costs should include:

- expert technical personnel to support an accessible facility;
- researchers to participate in JRIs;
- programme management/administration at spoke level.

3.3.2 Access mechanism

The access platforms provide the route through which researchers in the wider heritage community can gain access to facilities and expertise at the spokes. Regular calls enable researchers to apply for facilitated access via a peer-reviewed application process.

Facilitated access means spokes providing access to equipment and expertise at the spoke site (FIXLAB), or bringing the expertise and equipment to heritage on location (MOLAB), or hosting researchers to work with archive resources at the spoke site (ARCHLAB). All overhead, staff and analytical costs for the spoke are covered, as are travel/subsistence and insurance costs for researchers or spokes. Limited resources of smaller organisation are a significant barrier to demand for HSCR access, thus, to promote accessibility for infrastructure users it is recommended that costs of their time in accessing RICHeS are met.

The hub and the spoke facilities will both provide guidance and advice to ensure the most appropriate technologies/expertise are sought for given research problems. As outlined above (3.2.4), training programmes and knowledge exchange events will be designed to address the knowledge gaps that create a barrier to accessing HSCR expertise.

3.3.3 Dissemination and data ownership

Open access publication of results and data will be an obligation of all RICHeS participants, resourced and facilitated via the hub. Terms of data ownership for data acquired via access platforms will need to be defined within the terms of access. Primary data generated from heritage assets is likely to belong either to the custodian of the heritage asset or the spoke facility that generates it, depending on the type of asset and its stewardship status. Secondary data (arising from processing or reinterpretation of the primary data) is more appropriately the intellectual property of the researcher. Access agreements will also need to define co-publication arrangements. It is important to recognise that publication represents an important motivation for organisations to participate in RICHeS as spoke providers. Where interpretive outputs of the research are contingent on expertise provided by the spoke via

FIXLAB or MOLAB platforms it is proper that co-publication of research outputs ensues. Where researchers work independently with the resources of spokes, as via ARCHLAB access, co-publication would be inappropriate.

3.4 Further work needed to deliver project

This exercise has identified a number of areas where information that will be important for the development of RICHeS is lacking. Some of this data is likely to be needed for development of the strategic business case but there may also be early work here for the hub in oversight of the RICHeS and certainly a longer-term role in maintaining this evidence to support future planning.

Staffing. The current state of staffing in HSCR, in terms of roles, distribution across sub-disciplines/organisation types, pay and career trajectories is not well documented. For archaeology, the Landward Research 'Profiling the Profession' reports have surveyed the labour market in terms of demographic composition, geographic distribution, qualifications and salaries, capturing changes to the employment landscape in this sector over the last 20 years through successive censuses[50]. This record is a helpful resource for the RICHeS but it captures only one component of the HSCR sector and does not address the specific details that are most relevant to the HSCR infrastructure challenges. A 2019 NHSF report[51] examined the demographics and motivations of students entering the HSCR profession, but not the wider workforce.

Staffing is crucial to underpin the physical infrastructure of RICHeS, both for technical support of equipment and specialist expertise for its appropriate application to HSCR problems. The innovation and accessibility that the RICHeS seeks to develop is reliant on the staffing element of the infrastructure and this challenge was consistently identified in consultation, both via the workshop and the survey responses. To address the problem with investment a better understanding of the staffing landscape is necessary, including a measure of trends that are potentially detrimental to the future of the sector: the tendency for ECRs to depart for alternative professions due to lack of opportunity in HSCR, consequent impact on cumulative career expertise and recognition of the importance of this for sustainability within the infrastructure, manifest in impact of retirement and associated lost expertise.

Accessibility and demand. Organisations have adopted individual approaches to providing access to their scientific infrastructure which may be via for-profit commercial activity, at cost services, project collaboration, or via outreach programmes. Anecdotal evidence suggests that underuse of equipment is widespread and that the primary limit on increased access for wider users is staff time. However, we have little data with which to test this.

Questions about how access is currently managed, how often equipment is accessed, who the external users are and the extent of unfulfilled demand need to be answered if the RICHeS

[50] https://profilingtheprofession.org.uk/

[51] Careers in Heritage Science: Opportunities and Constraints, NHSF/CS 2019, https://www.heritagescienceforum.org.uk/documents/Careers_in_Heritage_Science.pdf

programme is be effective in its ambition to extend access. The pressures on staff time in the potential user community must not be overlooked as this is a significant check on demand, as is lack of knowledge of technologies in the wider community. Navigation of the infrastructure is currently heavily dependent on word-of-mouth recommendations which do not necessarily result in the appropriate techniques being applied. Further research is needed to understand the current access dynamic from both the supply and the demand perspectives.

Equipment mapping. Detailed mapping of equipment (specific equipment items hosted by organisations) has not been attempted in this stage of the RICHeS scoping. The landscape is complicated, equipment may be held and used across multiple departments and for the benefit of stakeholders outside of HSCR. Age and maintenance status of equipment are integral to its utility and sustainability so the mapping requires more than a simple inventory. Facilities are hard to map at this level without extensive consultation and, crucially, high levels of stakeholder confidence and buy in. Equipment holders want to understand the benefit sharing their equipment inventories delivers to them and the that the consequences in terms of demand and competition are going to be manageable.

Connectivity. The landscape mapping reported here provides some baseline insights into the connectivity of the HSCR community but there is more that could be achieved with collection of further data. Network analysis based on consultation to probe existing collaborative relationships, infrastructure access arrangements, regional networks and relationships between different organisation types would highlight weaknesses where the RICHeS investment could make a difference.

4. Conclusions

The task of this fellowship was to gather evidence to develop the RICHeS model that was proposed in the original IHSCR bid. That has been achieved through a combination of landscape mapping and consultation, the results of which have been presented here. The landscape mapping provides an evidence base to underpin the dispersed infrastructure model that is at the heart of the RICHeS vision. The mapping has examined the regional spread, interdisciplinary scope and technological diversity of the HSCR sector in the UK. The consultation has identified key challenges the sector faces in terms of staffing, sustainability, expertise and interconnectivity, as well defining the opportunities for RICHeS to address these and transform the sector.

The recommendations made in this report are based on an analysis of the evidence collected and describe an approach to the delivery of the RICHES vision that is aligned with the identified priorities. They should be viewed as a starting point that can be refined in development of a strategic business case and tested by further consultation. Specific areas where further data are needed have also been identified, some of this will need to be gathered to advance the business case but maintaining and evaluation this evidence will be an ongoing function of the RICHeS hub to support delivery of the vision.

5. Appendices

5.1 Appendix 1: Scientific technologies used in HSCR

(Excludes techniques housed in STFC facilities (e.g. Synchrotron X-ray techniques, ion beam experiments and neutron techniques) as outwith scope of RICHeS investment).

X-ray techniques X-radiography X-ray computed tomography (CT) Micro-computed tomography (micro-CT) X-ray fluorescence (XRF) Micro X-ray fluorescence (micro-XRF) Energy dispersive X-ray spectroscopy (EDS)	**Imaging** Magnetic resonance imaging (MRI) Macro X-ray fluorescence (MA-XRF) imaging 2D micro XRF scanner IR/NIR hyperspectral imaging Multispectral imaging Multispectral luminescence microscopy
Microscopy Optical/light microscopy Metallurgical Microscopy Fluorescence microscopy Immunofluorescence microscopy (IFM) UV microscopy Petrographic microscope High resolution digital microscopy Variable pressure SEM (VP-SEM) Field emission SEM (FE-SEM) Atomic force microscopy (AFM) Nonlinear optical microscopy (NLOM)	**Molecular analysis** aDNA Enzyme-linked immunosorbent assay (ELISA) Amino acid racemization analysis (AAR) High-pressure liquid chromatography (HPLC) LC - mass spectrometry (LCMS) Gas chromatography mass spectrometry (GC-MS) Pyrolysis-GCMS Zooarchaeology by ZooMS High resolution MS:- FT-ICR-MS High resolution MS: Orbitrap Ion chromatography Size exclusion chromatography
2D/3D analysis Acoustic tomography Digital holographic speckle pattern interferometry (DHSPI) High resolution digital microscopy NMR depth-profiling/relaxometry Optical coherence tomography Optical microprofilometry Terahertz imaging	**Dating** AMS radiocarbon Electron spin resonance (ESR) Optically-stimulated Luminescence (OSL) Thermoluminescence dating (TL) Palaeomagnetism Uranium series Dendrochronology Tephrochronology
Mass Spectrometry Inductively coupled plasma mass spectrometry (ICP-MS) Multicollector-inductively coupled plasma mass spectrometry (MC-ICP-MS) Isotope ratio mass spectrometry (IRMS) Thermal ionisation mass spectrometry (TIMS)	**Artificial ageing** Spectrophotometry Micro-fading
Molecular spectroscopy FTIR FTIR micro-imaging Raman/micro-Raman Nuclear magnetic resonance (NMR) **Environmental monitoring** Air exchange rate/ventilation Vibration RH recording Light metering **Physical tests** Viscometry Tensile testing	**Remote sensing/analysis** Magnetometry Ground penetrating/synthetic aperture radar Multibeam and sidescan sonar Laser scanning and LiDAR Magnetic susceptibility Soil conductivity and electrical resistivity tomography Remote LIBS system Remote Raman/LIF Remote SWIR hyperspectral imaging Remote UV LIF spectroscopy Remote VIS/NIR hyperspectral imaging Aerial photogrammetry and multispectral models

5.2 Appendix 2: Sub-disciplines of HSCR

aDNA
Archaeobotany
Archaeological Prospection
Archaeological Science
Archaeology
Archaeometallurgy
Archaeozoology
Architectural conservation
Architectural history
Artificial Intelligence or V/A/M Reality
Ceramic petrography
Conservation
Conservation Science
Environmental archaeology
Geoarchaeology
Geophysics
Human osteoarchaeology
Isotope analysis
Landscape Archaeology
Marine Archaeology
Organic residue analysis
Paintings/Art
Polychromy
Proteomics
Scientific Dating

Annex B: ARCHLAB and DIGILAB

AHRC infrastructure policy and engagement fellowship in heritage science and conservation 2021: Report and recommendations

Ben Edwards, July 2021

Contents

1. Introduction

1.1 Background

1.1.1 The following document reports on the IHSCR (Institute for Heritage and Conservation Science Research), now known as RICHeS (Research Infrastructure in Conservation and Heritage Science), consultations and online survey with reference to ARCHLAB and DIGILAB (see section 1.2). The aim of this report is to summarise the results of the online survey, consultation workshops and individual conversations with stakeholders in the heritage science sector, focusing on responses particularly pertinent to the ARCHLAB and DIGILAB strands of the Heritage and Conservation Science infrastructure bid in preparation by the AHRC. The focus of the report will be on the challenges facing the sector identified by consultees, with a view to shaping the eventual infrastructure to meet these needs. Crucially important is identifying the 'place' and role of the proposed infrastructure with reference to existing strategic programmes being undertaken by the AHRC in partnership with other national institutions and funding bodies. Important also, is the secure definition of ARCHLAB and DIGILAB, but with the recognition that the two strands are so closely related that their separate identification must be seen as artificial. With the above in mind, this report will examine the definition of the two strands, the place of the RICHeS in the infrastructure and funding landscape, the challenges identified by consultees, and potential remedies that could be provided by the proposed infrastructure investment.

1.2 Existing Definitions of ARCHLAB and DIGILAB

1.2.1 The origin of the ARCHLAB and DIGILAB definitions are to be found in the E-RIHS (European Research Infrastructure for Heritage Science) documentation, which defines the two strands with reference to *access* to heritage science data from physical and digital resources in a broad sense.[52] The two strands are defined in the following manner:

- E-RIHS ARCHLAB

  Access to specialised knowledge and organized scientific information – including technical images, analytical data and conservation documentation – in datasets largely unpublished from archives of prestigious European museums, galleries and research institutions.

- E-RIHS DIGILAB

  Virtual access to scientific data concerning tangible heritage, making them FAIR (Findable-Accessible-Interoperable-Reusable). It includes searchable registries of multidimensional images, analytical data and

[52] http://www.e-rihs.eu/access/

documentation from large academic as well as research and heritage institutions.

1.2.2 These two definitions were reproduced in the initial Institute for Heritage Science and Conservation Research (IHSCR) bid with minor changes leading to a slight broadening of the original emphasis on 'access':

- IHSCR (RICHeS) ARCHLAB:

  Physical and digital archives of technical documentation and data, samples and reference collections accessed at a facility (data flowing to DIGILAB after investment).

- IHSCR (RICHeS) DIGILAB

  Digital archives as research resources and advanced digital tools (remote access).

1.2.3 The important development between these two definitions is an addition to, and a broadening of, the ARCHLAB strand. In the E-RIHS definition, ARCHLAB was envisaged as access to the results of heritage science investigations held in the archives of 'prestigious' European institutions. The RICHeS definition broadens this to physical samples and reference collections, and drops the focus on the 'prestigious', which by implication therefore allows the inclusion of the collections, data and archives of the UKs very decentred, regional and specialised GLAM landscape. DIGILAB is conceived in similar terms between the two definitions.

1.2.4 These definitions are pertinent because they draw the boundaries around elements of infrastructure that are, or are not, to be included in any consultation and the final scope of the bid. The underlying elements of 'infrastructure' in the heritage science field include both physical and digital collections, *and* the means of accessing and analysing those collections. Thus, the addition in the RICHeS ARCHLAB definition of "samples and reference collections" significantly broadens the potential elements that can be included in the infrastructure: from "images", "data" and "documentation" in E-RIHS, to the *underlying* physical collections that these data are drawn from. It is also important to note that "samples and reference collections" of the ARCHLAB definition does not necessarily encompass all museum and archive collections. A distinction should be made here: reference collections are not always kept or accessioned in traditional museums or archives; they are frequently collections held by universities or research organisations in order to inform ongoing scientific work. For example, reference collections of plant macrofossils, of animal skeletal remains, or of dyes and pigments, would all fall within the RICHeS definition. The consequences of this are explored below with reference to other funded initiatives (1.3.2).

1.2.5 A broader definition has both positive and negative effects. Positively, this allows a more *forward-looking* infrastructure that can respond to the priorities of institutions that curate physical collections and archives, with a view to the production of *new* analyses, techniques and, therefore, data. This may be of particular benefit to smaller institutions, such as local museums that, nevertheless, hold collections of national importance that are in need of heritage science or conservation support. On the other hand, a problem of this definition is that it makes the boundary between the proposed RICHeS infrastructure and other, pre-existing, programmes and initiatives somewhat difficult to clearly discern. This is particularly the case with two ongoing AHRC-supported initiatives: 'Towards a National Collection' (TANC) and Capability for Collections (CapCo). This is also true for the definition of DIGILAB, where these existing initiatives are already supporting digital programmes, such as the digitisation of collections and the interconnection of GLAM catalogues through common metadata standards. It is therefore essential to clearly define the boundaries of the RICHeS infrastructure in support of this bid, and how it will enhance existing initiatives without duplicating or wasting effort and resources.

1.3 ARCHLAB and DIGILAB with Reference to Existing Funded Initiatives

1.3.1 Some of a more broadly defined ARCHLAB and DIGILAB infrastructure are, in part, already being developed by existing funded initiatives. TANC is developing nationwide search and cataloguing tools to benefit the GLAM sector to create an interconnected collection. This aims to address the fragmentation of the UK's digital access to archival information and collections catalogues. Clearly therefore, ARCHLAB and DIGILAB in the RICHeS bid need not be concerned with the basic priorities of digitising catalogues, archives and collections and making them accessible to the public and heritage science research community. There may, however, be a role for a ten-year RICHeS infrastructure in ensuring the *sustainability* and legacy of any resources created by the TANC programme.

1.3.2 However, there are types of collections that fall outside of the scope of the TANC programme. Scientific samples and reference collections held outside the GLAM sector, such as within university labs or other research bodies undertaking scientific work (see 1.2.4) are not accessioned in the traditional manner. There is the risk, therefore, that the very existence of such collections remains little known, before even considering a broader knowledge of what these collections contain. The role of ARCHLAB here could be important: creating and maintaining a record of these collections would widen accessibility, knowledge and understanding, but also potentially prevent the duplication of effort and resources. If a reference collection already exists this should be exploited before considering the destructive sampling of heritage assets to create a new one.

1.3.3 CapCo had a similar capacity-building focus to TANC but was aimed at equipment to support ARCHLAB and DIGILAB infrastructures – the significant crossover with FIXLAB and MOLAB should also be noted here. This programme invited small to multi-million-pound bids to invest in the purchase or upgrade of heritage science and conservation equipment across GLAM sector. Crucially, this included analytical equipment (hence the FIX/MOLAB relevance) and also digitisation equipment, creating a potential overlap with RICHeS in the field of digital archives.

1.3.4 For the purposes of the RICHeS bid it may be helpful to summarise the areas in which TANC and CapCo are likely to have the most impact on infrastructure, in order to define their boundaries. Both, it appears, are focused on *creating* new physical and virtual elements for the infrastructure landscape: TANC, an integrated and searchable national database of the objects, collections and archives that form "samples and reference collections" of ARCHLAB and the "digital archives as research resources" of DIGILAB; CapCo, new or enhanced equipment for generating new ARCHLAB and DIGILAB "data". In both cases, these existing initiatives allow for scalar approaches to their priorities, designed to benefit both large national institutions and improve the capabilities of smaller regional or local players in the GLAM sector.

1.3.5 Before moving on, a final project is of relevance to the context of the RICHeS infrastructure. The HIAS project, led by Historic England, is both an important complementary initiative, and also serves to demonstrate the *need* for infrastructure investment in the heritage ecosystem.[53] The 'Heritage Information Access Strategy' (HIAS) seeks to simplify and improve access to Historic Environment Records (HERs), primarily held by local councils and consulted as part of the planning and development process, but with a wide variety of other public and research users. A major part of this project is to improve the aggregation function of Historic England's national search engine of important heritage assets. Whilst HIAS is not primarily aimed at heritage science collections or archives, it is clear that the physical heritage assets recorded in HERs are the subject of heritage science research, particularly surrounding conservation practice.

1.3.6 Rather than create an *a priori* boundary for the RICHeS ARCH and DIGILABs with respect to existing initiatives at this stage, this report will now move on to examine the priorities for investment identified through consultation with stakeholders in the heritage science and conservation sector. A definition for the role of RICHeS in this area will therefore be responsive to the priorities of the sector. The RICHeS definition of its role in ARCHLAB and DIGILAB will be thereby informed by two factors: 1) the provision provided by existing initiatives, and 2) the needs of the sector not fulfilled by these existing initiatives.

[53] https://historicengland.org.uk/research/support-and-collaboration/heritage-information-access-strategy/

2. Results of the consultation and online survey

2.1 Consultees and Survey Respondents

2.1.2 A range of consultees contributed to the workshops designed to identify strategic priorities for infrastructure investment. The majority of these belonged to larger national institutions, though not exclusively. In order to canvass the opinions of ARCHLAB stakeholders in smaller institutions, principally based in the regions, a series of targeted conversations were also undertaken. It was also important to consider the views of individuals who belonged to organisations that can be understood to represent large swathes of the GLAM sector. With over 1800 museums in the UK, surveying the entire sector was impossible, so opinions were sought from the Museums Association, the Collections Trust and others. Similarly, the views of organisations with important national oversight in the DIGILAB field, such as the Archaeological Data Service (ADS) and Historic England were also approached for specific comment.

2.1.3 The online survey of those involved or connected with heritage science research was less targeted and sought to gather broader metric information on FIXLAB/MOLAB, ARCHLAB/DIGILAB, and access and governance themes. This survey was publicised to the sector via the original workshop consultees, professional associations and academic networks, and through social media. The ARCHLAB and DIGILAB components of this survey sought to capture information on physical and digital archives and reference collections, with particular foci on sustainability, and on the realisation of the FAIR principles (see 2.2) by the sector.

2.2 Categorising Responses – FAIR Principles

2.2.1 In 2016 the 'FAIR Guiding Principles for scientific data management and stewardship' were published, primarily aimed at ensuring that the digital data resulting from scientific investigations were 'Findable, Accessible, Interoperable and Reusable'. Importantly, one must note the following coda to the four principles:

> "The principles refer to three types of entities: data (or any digital object), metadata (information about that digital object), and infrastructure. For instance, principle F4 defines that both metadata and data are registered or indexed in a searchable resource (the infrastructure component)."[54]

2.2.2 This quote provides a useful means of categorising the responses to the stakeholder consultation, in that it unifies data and metadata with the infrastructure to 'find' these data. Moreover, it is arguable that far from being limited to the DIGILAB element of the infrastructure, FAIR principles can also be applied to physical collections and archives that provide the basis of ARCHLAB. Thus, two areas that crosscut ARCHLAB and DIGILAB can be scrutinised under FAIR principles: 1) physical resources for

[54] https://www.go-fair.org/fair-principles/

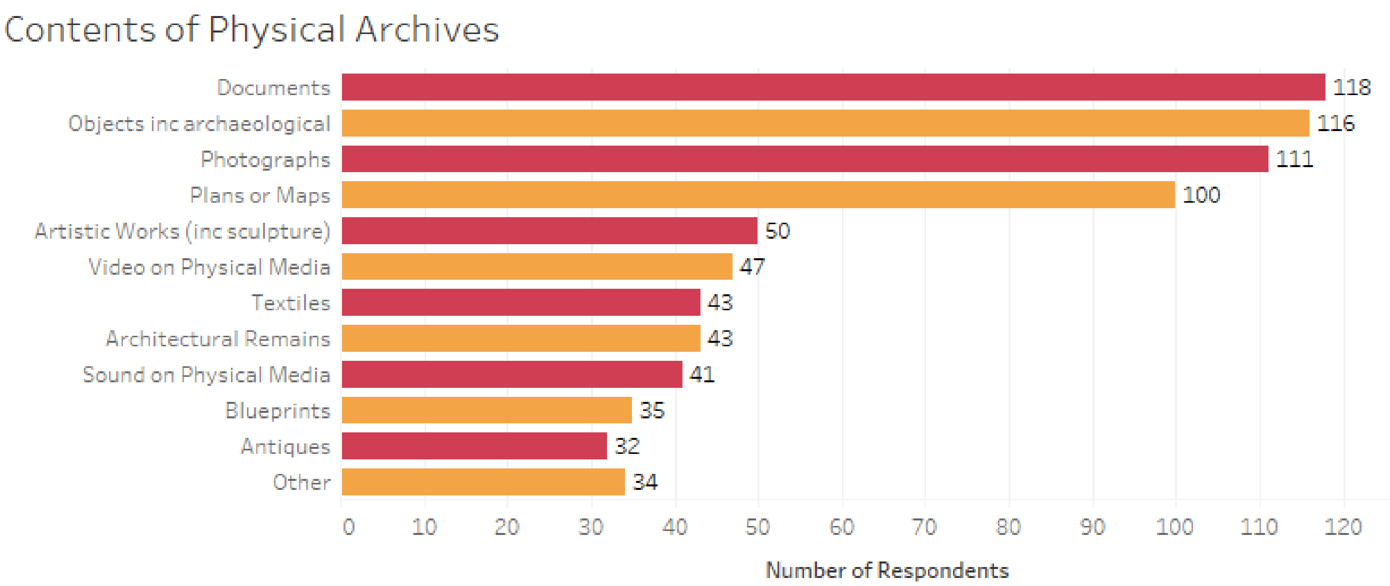
heritage science and conservation (collections and archives held by GLAMs); 2) the data derived from science undertaken on these heritage collections, either specific to an individual asset, across a collection/archive, or studies that draw data from a variety of sources across the entire sector. One can replace the 'digital' in the above quote with 'physical' and principles are equally compatible.

2.2.3 All of the responses to the consultation, whether regarding problems with the physical infrastructure of ARCHLAB, or the digital infrastructure of DIGILAB, can be categorised through the FAIR principles. This equally includes those concerned almost entirely with problems of access to physical collections by heritage scientists, and those with accessing archives of digital data produced by heritage scientists.

2.3 Analysing the Online Survey Responses

2.3.1 This section considers the responses to the online survey that are of relevance to ARCHLAB and DIGILAB. The survey was undertaken using JISC Online Surveys, was anonymous, and was compliant with GDPR regulations. There were 179 respondents to the survey. There were two main foci addressed in the questions, the first relating to physical archives and reference collections, and second relating to digital databases and their accessibility.

2.3.2 *Physical Archives and Heritage Science Reference Collections*
The survey aimed to take a snapshot of the types of physical archive and/or heritage science reference collection that respondents' organisations hold. There were a wide variety of job roles held by respondents to the survey, reflecting the diversity of attendants to the workshops and their professional networks. As a result, the types of collection listed include both those held as the result of, or for the use of, heritage science work, and also those that could be the subject of scientific investigation – the 'raw material' for heritage science researchers. Figure 11 displays the variety of types of physical archive held and the level to which their catalogues are searchable online. Note: may archives held several types of resource.



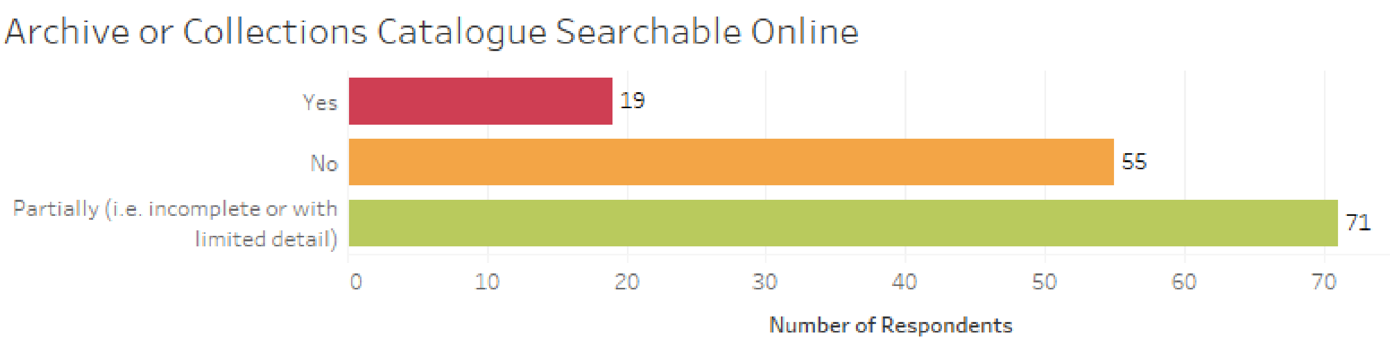


Figure 10: The contents of physical archives and collections, and their searchability online

2.3.3 It is clear from Figure 11 that the major problem for heritage science researchers and practitioner is identifying and searching for information in archives and reference collections. If the majority of collections are either not, or only partially catalogued for remote access, there is clearly an issue with their *findability*. Raising the prospect of duplication of effort and underused resources, simply because scientist may *not know* what is available to them.

2.3.4 *Digital Archives for Heritage Science*

The survey aimed to take a similar snapshot of digital archives and collections that are available for heritage science research or hold the results of such research. The results are displayed in Figure 12.

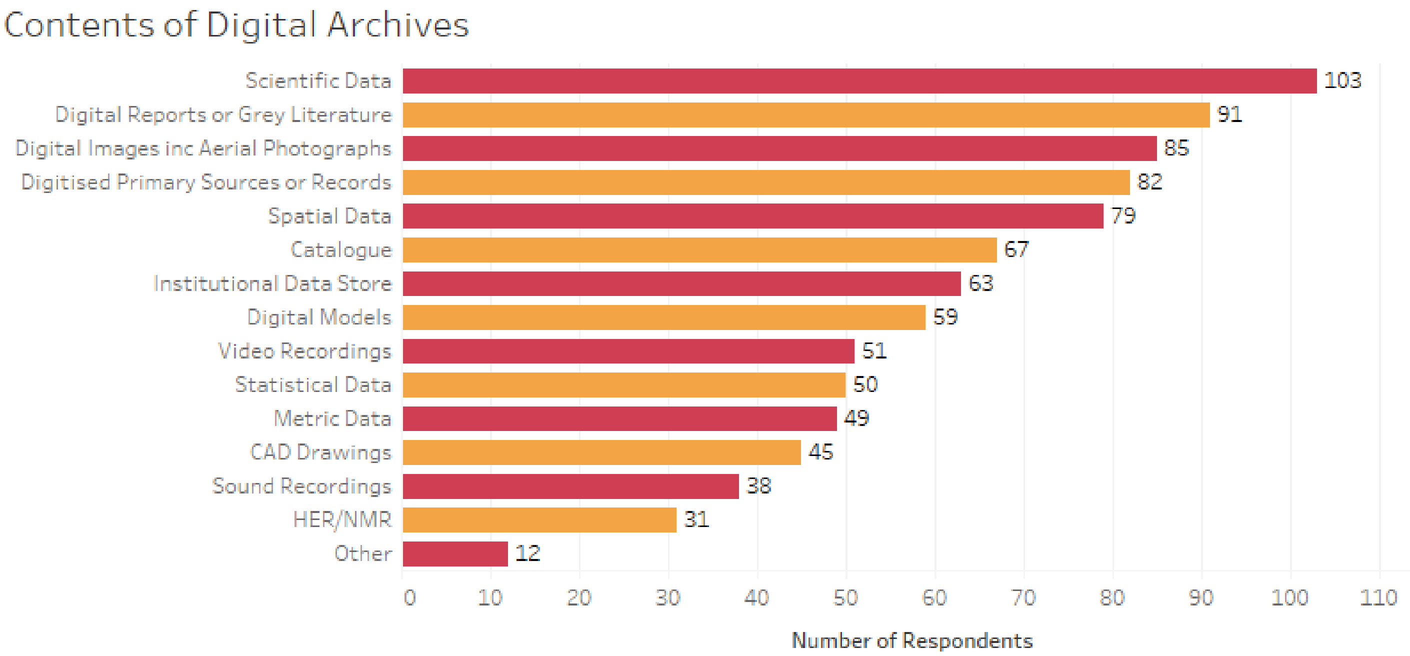
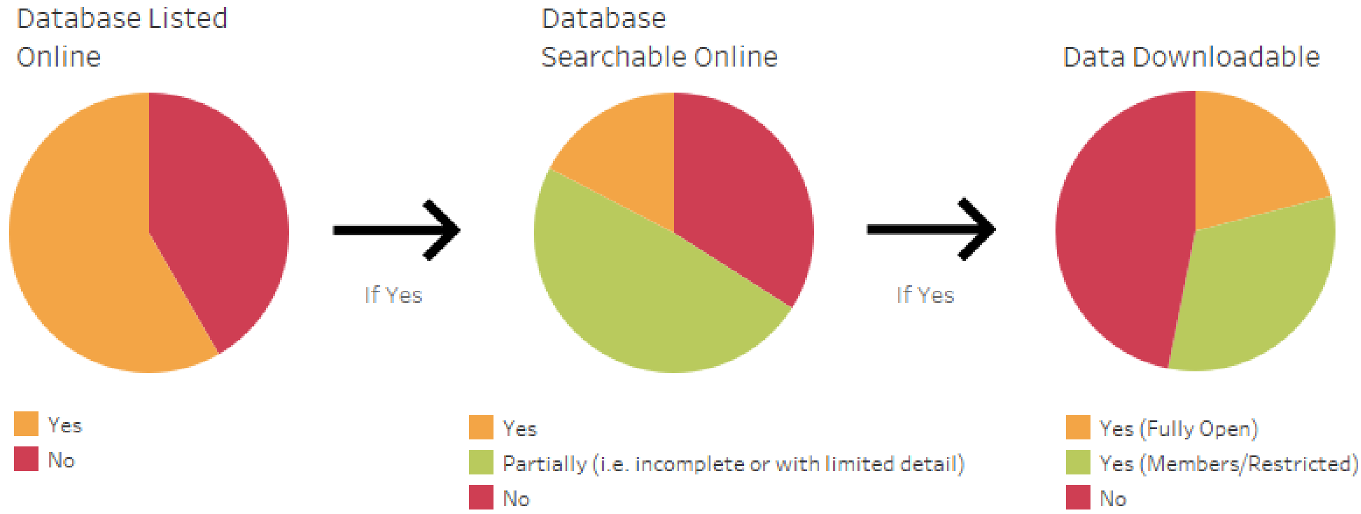


Figure 11: The contents of digital archives and collections

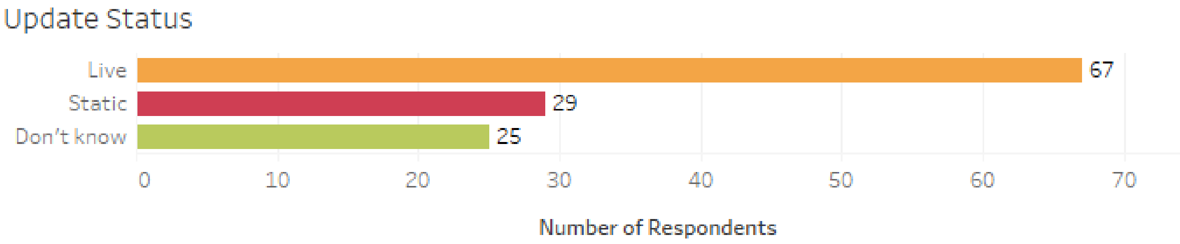
2.3.5 The most striking result here is the preponderance of 'scientific data', followed by digital reports and literature, which are likely to contain the result from the analysis of scientific data. These data represent the results of expensive (often publicly funded) research, and thus are a resource that requires accessibility to realise its full value.

2.3.6 The importance of recognising the place of scientific data in the heritage science ecosystem is brought into sharp focus by the results displayed in Figure 13 (following page). Note how the databases that hold scientific results are inconsistently compliant with FAIR principles. The existence of a significant minority of data sources are not known to the whole sector because they are not listed online. Of those that are listed online only a small minority have full search functions, with the majority being partial or unsearchable. Finally, of those that are online only a small minority provide open data access. The fact that most of the databases that do exist online are 'live', in that they are regularly updated, is encouraging. However, there is a clear issue with aggregation – the majority of data sources stand alone and thus must be individually consulted, rather feeding into efficient aggregator services.

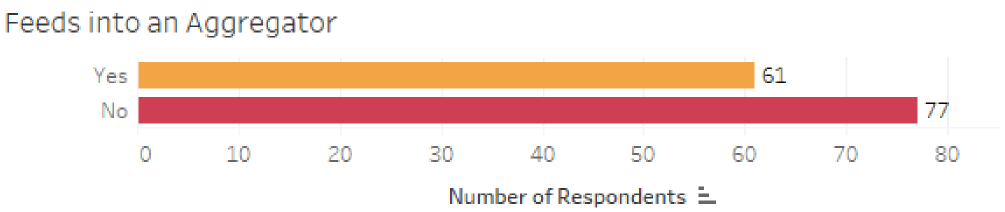
Digital Databases



Note the increasing proportion of negative returns on the survey when the 'findability' and 'accessibility' of online databases are considered.



In some cases databases that are accessible online are regularly updated, either manually or through a direct link to a backend server: these are described as 'live'. Databases that are published but then not updated are termed 'static'.



Some online databases also feed into other search engines, which combine the results of several different online resources: these are described as 'aggregators'.

Figure 12: Amalgamated results of the digital heritage databases questions on the survey

2.3.7 The final consideration for these online data sources is their sustainability. A database is only useful to the extent that its existence is assured, or that its 'live' status can be maintained. The survey questioned respondents as to the long-term sustainability of their digital archives, see figure four. It should be noted that this question applied to both locally hosted and databases available for online access.

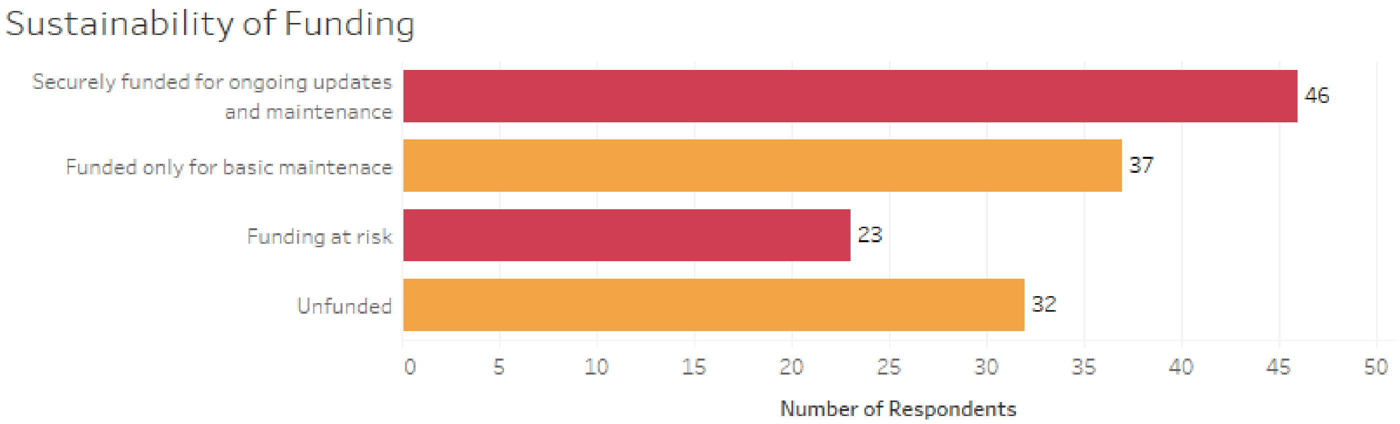


Figure 13: Sustainability of funding for digital databases and collections

2.3.8 The most striking result here is the majority of respondents (n=55) reported that their digital resources were either presently unfunded or that funding for them was at risk, and a minority (n=46) of the total reported that their resources were not adequately resourced for ongoing updates. If these data sources represent the results of expensive scientific enquiry or other resource-intensive research, then there is a clear risk to the long-term sustainability of these prior investments.

2.4 Mapping the Consultation Responses

2.4.1 The following reports the responses to the consultations undertaken through online workshops and individual conversations. In addition to outlining the infrastructure priorities identified by consultees, this section maps them against three sets of criteria: 1) whether falling principally within the remit of ARCHLAB or DIGILAB; 2) which of the FAIR principles under which the priority can be categorised; and 3) whether the priority is already being targeted by an existing strategic funded initiative, such as CapCo or TANC.

2.4.2 Table 1 displays the responses to the workshops regarding priorities for infrastructure investment. **Note**: the entries are not individual responses, but represent common areas identified by one or more respondent – many comments spoke to similar priorities across the various workshops and could be grouped as such.

Priority Identified	ARCH or DIGILAB	F.A.I.R.	Addressed by Existing Initiative
Lack of 'digital representation' of collections	DIGILAB	F.A.	Yes: TANC
Lack of digital skills in science community	DIGILAB	F.A.I.R.	No
Need for contacts between collections and scientists	ARCHLAB DIGILAB	F.A.R.	No
Lack of sustainable digital repositories	DIGILAB	F.A.I.R.	Partial: TANC
Archives closed to new accessions	ARCHLAB	F.A.I.R.	No
Funding for Historic Environment Records	DIGILAB	F.A.I.R.	Partial: HIAS
Disconnect between local and national priorities	ARCHLAB DIGILAB	F.A.I.R.	No
Collections data not online or not aggregated	DIGILAB	F.A.	Yes: TANC
Support required pre-digitisation of collections	ARCHLAB	F.	Unknown
Open-source software needs recognising as infrastructure	DIGILAB	I.R.	No
Resources for regional museums	ARCHLAB DIGILAB	F.A.	Yes: TANC, CapCp
Data should be Open	DIGILAB	A.I.R.	No
Need to cross the divide between different collections management systems	DIGILAB	I.	Yes: TANC
AI and machine learning require real-world validation	ARCHLAB DIGILAB	I.R.	No
Address barriers of proprietorial data formats	ARCHLAB DIGILAB	I.R.	No
Existing digital repositories need maintenance funding	ARCHLAB DIGILAB	F.A.	Partial: TANC, HIAS
Lack of IT capability at smaller institutions	ARCHLAB DIGILAB	F.A.I	No
Address problem of legacy digital file formats	ARCHLAB DIGILAB	A.I.R.	No
Access to distributed computing for analysis	DIGILAB	I.R.	No
Cloud-based resources for data storage and processing	DIGILAB	I.R.	No
Central database of expertise not just data	ARCHLAB DIGILAB	F.A.	No
Training in industry standard software	DIGILAB	A.I.	No
Accessibility of digital expertise for online presentation and programming	DIGILAB	A.I.	No
Lack of knowledge about the audience that actually uses digital resources	DIGILAB	A.	No
Support for big-data science that is online rather than using physical scientific equipment	DIGILAB	A.I.R.	No

Projects to address important databases that have become 'static' i.e. no longer updated	DIGILAB	R.	No
Robust links between national and international data repositories	DIGILAB	A.I.	No
Recognition that the results of scientific analysis (as data) are as important as basic data on collections	ARCHLAB DIGILAB	F.A.I.R.	No
Digital expertise not uniformly distributed nationally	ARCHLAB DIGILAB	F.A.I.	No
Intellectual property of heritage science data need addressing	ARCHLAB DIGILAB	A.R.	Partial: UKRI
Heritage science researchers do not know what collections digital/physical *exist*	ARCHLAB DIGILAB	F.	Partial: TANC

Table 1: ARCHLAB and DigiLAB – priorities and existing initiative coverage

2.5 Themes in the Identified Priorities

A series of themes can be identified in the priorities for infrastructure investment from the consultees. These are not exclusive to either ARCHLAB or DIGILAB and often cross-cut both:

2.5.1 Sustainability of Digital Resources

Referring to any form of database or digital repository, whether online or local, there was a concern with sustainability. This can be conceived in terms of financial resources for hosting or maintenance, but just as importantly as futureproofing against changes in technology or file formats; and the skills and expertise to maintain and update digital resources, particularly smaller institutions with a limited staff base. Questions of intellectual property also affect sustainability in the long term.

2.5.2 Connections

A number of priorities speak to problems of digitally connecting people at different types of institutions (such as HEIs, GLAMS, and national labs) with each other, with digital technology, and with data repositories. This is deemed essential to undertake meaningful, representative and, by extension, valid scientific investigation, whether on digital data or on physical assets. So, connectivity can be seen to encompass people, data and technologies.

2.5.2 Digital Technological Infrastructure

A major recurring theme is access to analytical tools that can process and interrogate the range of heritage science data produced from ARCHLAB collections. This operates at a number of levels. At the most basic it concerns digital connectivity to databases of scientific results, as well as their discoverability and accessibility. Interoperability becomes problematic between databases of scientific results produced through different processes or techniques. At a higher level, there are concerns about access to digital technologies that undertake large-scale analyses, in terms of software, the skills to operate that software and the underlying architectures that support it. This covers access to specific programmes, but more importantly, dedicated distributed computing and/or cloud-based services that can be relied upon to process and analyse very large datasets. Allied to this issue is the limited existence of accessible digital repositories for very large (in terms of file size) data types that result from scientific analyses, such as three-dimensional data and high-quality visual data. Finally, is the highest-level issue of interoperability between different types of data from very different fields within the heritage science ecosystem. This literally encompasses the ability of complementary but divergent data types to ‘talk’ to one another, either form databases or other forms of repository. An example of this would be the ability of the researcher to combine synchrotron data with SEM or other 3D modelling information.

3. The role of Archlab and Digilab in RICHeS infrastructure

3.1 Filling Gaps in Existing Provision

3.1.1 Section 1.3 identified complementary funded initiatives that RICHeS must complement but not duplicate, particularly the CapCo and TANC programmes. Respectively, these cover the upgrade or development of technical equipment, and the connectivity and development of collections databases. The major gap in infrastructure provision therefore are as follows:

i. The aggregation of the *results* of heritage science investigations
ii. The discoverability, accessibility, interoperability and reusability of these results, and of localised sample and reference collections beyond the GLAM sector
iii. Digital technology to connect curators in the GLAM sector with heritage science technology and expertise to meet GLAM sector priorities
iv. Digital technology to foster new and innovative forms of analysis of heritage science data

3.1.2 It becomes increasingly difficult to clearly separate ARCHLAB and DIGILAB in this landscape. However, they can be conceived in the following manner: ARCHLAB is the physical and/or digital infrastructure that holds and makes available the expertise, technology and data of heritage science, whilst DIGILAB is the connections that allow the interoperability of the all the stakeholders and resources within the heritage science ecosystem, see Figure 15.

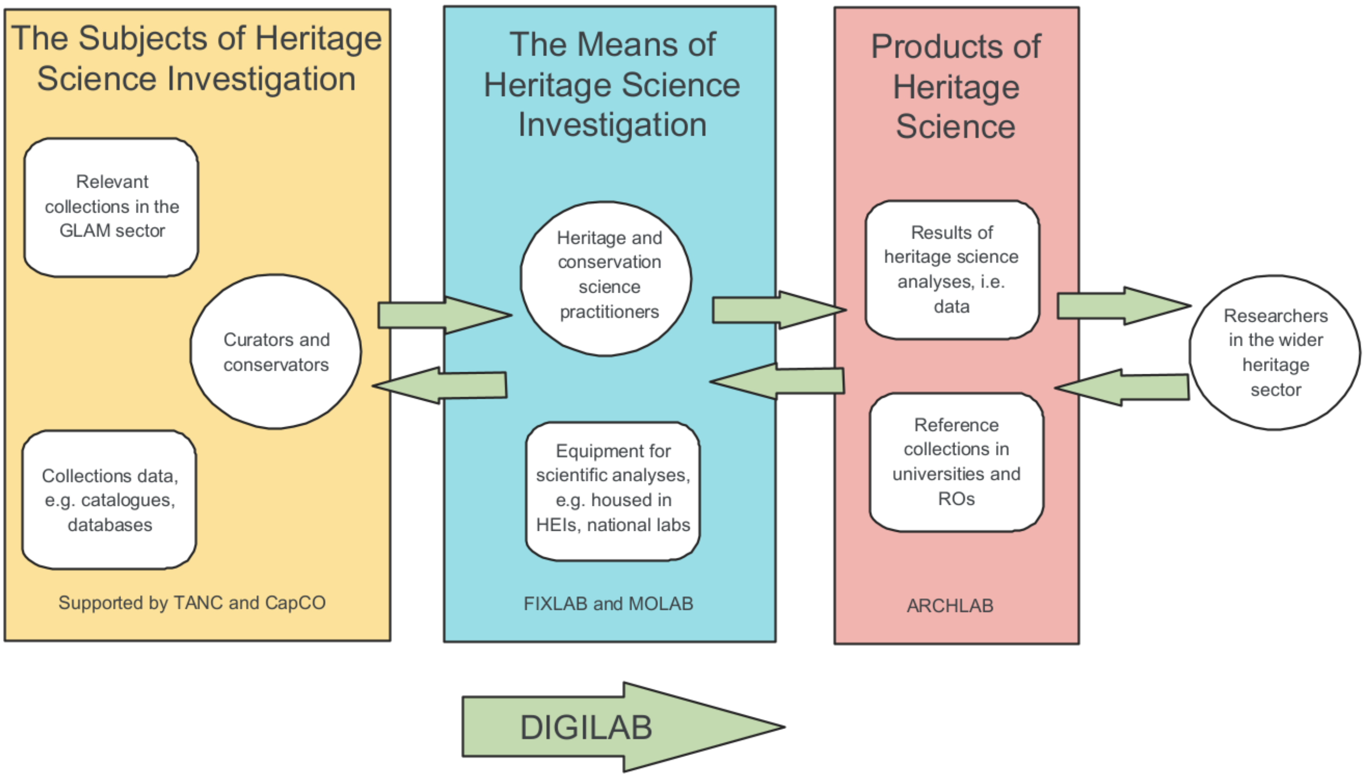


Figure 14: The place of RICHeS ARCHLAB and DIGILAB within the heritage science ecosystem

3.2 Major Challenges for RICHeS ARCHLAB and DIGILAB to Address

3.2.1 The major challenges to be addressed by the RICHeS infrastructure differ markedly in type based on the size of the stakeholder group and/or institution undertaking heritage science and/or maintaining an archive of the results of heritage science. They can be summarised in terms of FAIR, but the specific details are also important.

3.2.2 The *existence* of data repositories and physical archives (ARCHLAB) of the results of scientific investigation may not be known to the wider community of heritage science researchers. This is a particular concern for sample and reference collections that fall outside the GLAM sector beneficiaries of investments in cataloguing, such as the TANC programme, and are thus not the focus for improvements in findability and accessibility. This means that analyses and investigations can be partial, in that they do not take account of the full amount of potential data sources, and therefore that they may be unrepresentative and/or results may therefore be skewed. A further potential consequence is that the costs associated with archive maintenance are not justified by the level of use to which they are put.

3.2.3 The *content* of physical and or digital archives of heritage science data (ARCHLAB) may not be accessible or available. Research is therefore inefficient because archives need to be classified or catalogued before used as a resource. Data standards also differ widely between heritage science archives. This can be as broad as primary means of cataloguing data/objects, but also right down to the specifics of field names and field data types in databases, or file types used for storage. Data must therefore be 'cleaned' before use, an inefficiency requiring time and resource. Differences can mean that data is unusable for certain scientific applications or analyses.

3.2.4 Resources, both in terms of finance and staff expertise, often do not exist to maintain digital archives in order to make them accessible and usable in the face of rapid technological change. This can be due to physical technological obsolescence, but also changing data and access standards in wider heritage/computing ecosystem, e.g. changing industry standard file types, deadlinking, software compatibility.

3.2.5 There is a significant lack of computer science expertise (DIGILAB), either directly in existence within the heritage science sector, or feeding into it. This means the sector is ill-placed to take advantage of advances in cloud-computing, distributed computing, digital citizen science, artificial intelligence and machine learning. At its worst this problem also manifests itself in scientific data that is not archived to a common standard, not interoperable, and/or the victim of proprietary file formats, and/or at risk of becoming obsolete due to changing technological standards in both hardware and software.

3.2.6 A key challenge is creating and maintaining relevant digital connections, either conceived as a flow of data or of information and advice, between heritage science practitioners, professionals in the GLAM sector, and the wider heritage research community. This can be as simple as knowing what expertise is available to answer certain questions or meet certain priorities, to as complex as feeding three-dimensional data from a variety of different providers into distributed computing networks to undertake detailed analyses.

3.2.7 Several respondents to the consultation remarked that there was an incomplete understanding of the *audience* for their digital data, literally who used the information once it had been made available. There was often an appreciation of core users of a given dataset, for example, heritage professionals using Historic Environment Records, but then a lack of clarity about the large number of other users, whose priorities are unknown, perhaps only recorded as website 'hits'. A consequence is that the full value of heritage science archives may not be being realised if only a core demographic of users is fully understood. A number of important corollaries also flow from this observation: data may not be available in a format most suited to large cohorts of potential users (for example, some data is still only available in legacy *.ascii format); the financial sustainability of many digital resources is reliant upon demonstrable use-value, if this is not captured across all user groups these resources may be at risk (for example, the closure of local HER resources); finally, in a research environment increasingly valuing inter-disciplinary collaboration, resources need to be accessible and intelligible to audiences beyond the core audience of heritage scientists, but the requirements of these users is only tangentially appreciated.

3.3 Recommendations for the Role of the RICHeS Infrastructure

3.3.1 The centralisation of data and the results of heritage science is **not** the answer. Data and archives are too heterogenous in type and, critically, in their purpose. *Aggregation* is therefore key and fits well with a decentralised hub and spoke model for the infrastructure. This model also mirrors the work of Towards a National Collection for archives and collections, replicating this model for the results of data derived from heritage science (broadly defined). This RICHeS can provide:

- A central database of scientific archives; of digital databases; of reference collections; and of institutional data repositories containing information derived from UKRI-funded heritage science projects.
- A development of the above would be a means of querying these different datasets – this would be a further goal.
- Standards for archive and database metadata could be made requirements of AHRC awards and fellowships, and capital investment in order to make new heritage science data accessible and interoperable.

3.3.2 Long term sustainability of digital archiving is a major problem, and thus the infrastructure, probably central or regional hubs, should provide training and resources to enable spoke institutions to maintain and upgrade their digital archiving solutions as technology changes.

- This will prevent technological obsolescence.
- Investment in technical skills and expertise will allow spokes to maintain their infrastructure in a manner suited to their own needs, rather than conformation to arbitrary or unrepresentative central standards.

3.3.3 Allied to the above is the problem of project-orientated funding for research that creates data but may not ensure its long-term archiving. This is less a problem for large projects, or for large spoke institutions, but is an issue for smaller and shorter-term projects, or projects undertaken by less well-resourced bodies.

- A central AHRC heritage science data repository would overcome this issue. This could be designed around the same principles as the ADS, or indeed be hosted within it, but be focused on open access to data generated by publicly funded projects.
- This would ensure long term sustainability and fulfil open-data requirements.
- The existence of such a data repository would also be a tangible and measurable output of the infrastructure's success and value to ecosystem of heritage science, and thereby self-justify continued investment in the infrastructure.
- Such a repository would not dictate the form or nature of digital archives but would demand certain standards of metadata and compatibility with the aggregation functions of the hub (3.3.1). This would ensure heritage science data was interoperable and available for later research, particularly as big-data approaches using AI and machine learning become increasingly important methodologically.

3.3.4 Basic investment in computing resilience could be undertaken through ring-fenced bidding to infrastructure providers, either a central or regional hub(s). A function of the infrastructure will be to connect much-needed computer-science expertise with the creators and practitioners undertaking heritage science research. This will fulfil a number of important priorities: specific, immediate and practical; and broad and forward-looking.

- The results of heritage science need online means of access, either through web-based APIs, or via direct connections to data repositories for researchers – this relates, again, to 3.3.1 and 3.3.3.
- Projects require input at pre-application stages to build in support for legacy access to resulting data, and stronger advice on long-term storage and access through accessible data repositories.
- Specific hypothecated funding could be made available for advances in the application of AI and machine learning approaches to aggregated heritage science data if the priorities identified in 3.3.1 and 3.3.3 are addressed by the infrastructure.
- There will need to be a move toward non-proprietary, open-source software to ensure inclusivity across the whole ecosystem, from smaller financially fragile institutions to large, more secure national bodies.

3.3.5 The TANC programme is supporting the GLAM sector with digital cataloguing and recording, and this will doubtless open up the potential of previously unknown collections across the UK to heritage science and conservation practitioners. However, it become increasingly important to *feed-back* the results of any heritage science into the digital catalogues containing the basic details of the collection(s) or object(s) studied. In short, the RICHeS infrastructure will create a virtuous circle that will see the providers of raw research material (GLAM sector) directly connected to the results of the science that their collections have made possible.

- Compatibility will be ensured between the data standards of GLAM catalogues and databases, and the data standards of heritage science archives via liaison with TANC and the HIAS programmes.
- Linkages will be made between GLAM catalogues and heritage science data repositories through consistent metadata and primary record numbers (PRNs).

3.3.6 A role of the infrastructure should be to more thoroughly survey and understand the different users and creators of digital heritage science data. Beyond a core group of heritage scientists and the national science infrastructure, the landscape needs more accurately mapping (3.2.7). We need an understanding of the myriad smaller and regional bodies producing heritage science data; who the primary audience of this data is, if it shared in any way; who other potential users may be; and what the specific requirements of user groups are, from the very general (data subjects), to the very specific (file formats, technological limitations, etc). Thus, the infrastructure should provide funding for:

- A landscape-scale survey of heritage science creators and their core users.

- A study focused on the non-traditional users of heritage science data in higher education and related sectors, for example: architects, sustainable tourism practitioners, app and other software developers.
- The data and technological needs of these non-core users in order to integrate the results of heritage science into their research and/or practice.

3.4 Strategy for the Delivery of the Infrastructure Recommendations

3.4.1 The proposed ten-year timescale for the creation and delivery of the RICHeS infrastructure allows a once-in-a-generation opportunity to build a genuinely responsive research ecosystem for heritage science, moving beyond short-term interventions or fragmented individual initiatives.

3.4.2 The current heritage science landscape is fragmented, and as a result we lack a full understanding of what resources, connections and users are already in existence. Therefore, the first stage of any infrastructure investment into ARCHLAB/DIGILAB must (note the specific use of FAIR terminology):

Phase 1: Undertake a full landscape map to identify

a) What heritage science archives and reference collections, both digital and physical (ARCHLAB), exist and at what level of cataloguing and availability – a qualification of the findability of archives. This will become the SUPPLY-SIDE of the infrastructure.
b) What core (heritage science researchers) and other users' priorities are for accessibility, interoperability and reusability of heritage science data, both generally (hardware requirements) and specifically (software/formats etc). This will become the DEMAND side of the infrastructure.

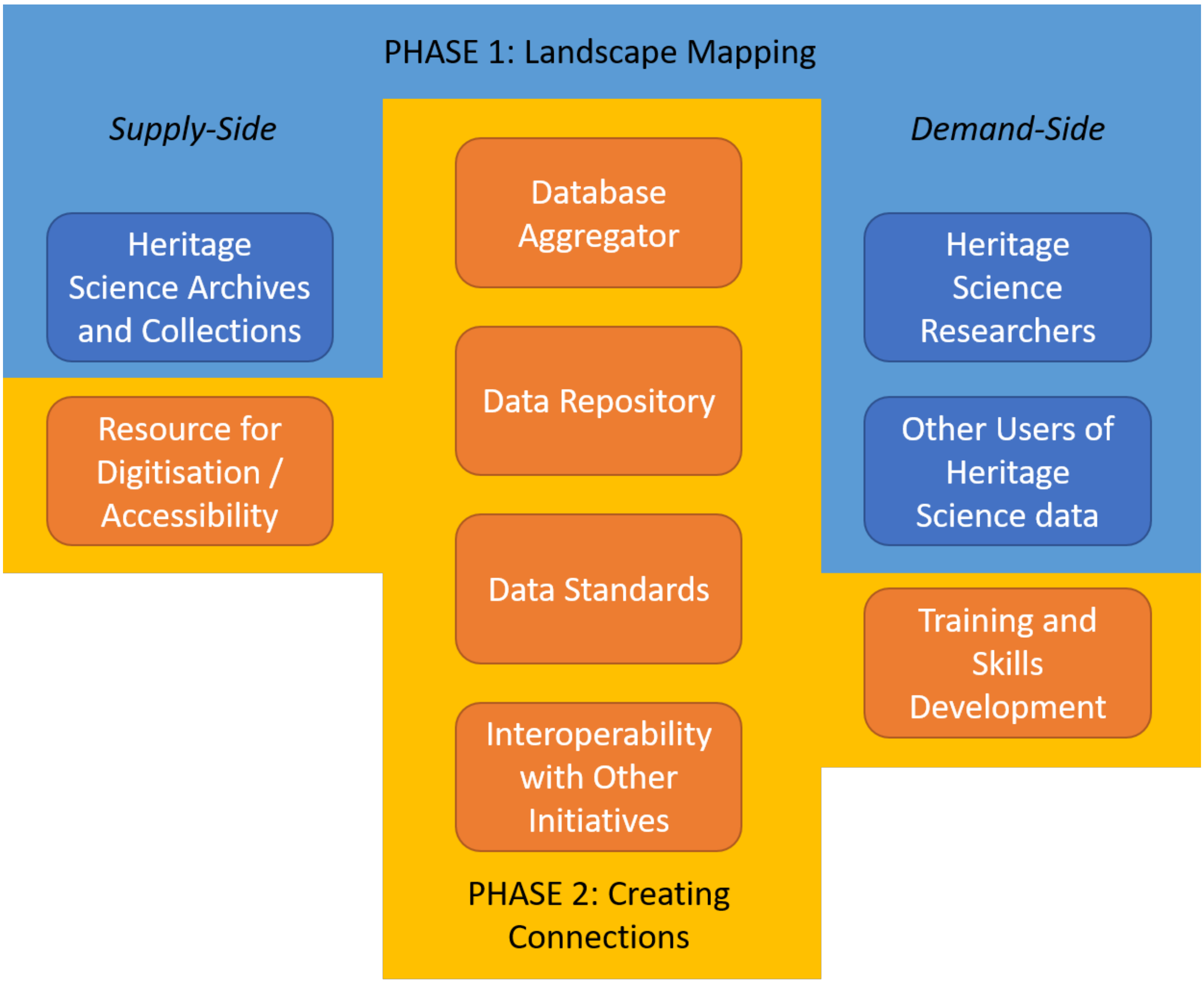
3.4.3 Having identified supply and demand priorities, the necessary technological infrastructure must be created – this will form the connections between the different parts of the ecosystem.

Phase 2: The creation of connections

a) Establish an aggregation function to list heritage science digital databases and physical archives – these are the results of heritage science undertaken across the UK. Simply put: a database of databases.
b) Provide resource for the digitisation or transformation of heritage science collections to enable compatibility with the above.
c) An aggregated search function of the above.
d) Establish a heritage science data-repository for the results of publicly funded research via UKRI.
e) Establish metadata and recording standards to align heritage science data with ongoing efforts in the HIAS and TANC programmes.
f) Enforce open-data and non-proprietorial software standards on heritage science projects benefiting from AHRC funding.

g) Create a network of advice and expertise, connecting heritage scientists with computer scientists, to enable a more resilient and forward-looking infrastructure, capable of adaptation to technological change.
h) Hypothecate funding for ongoing training in, and maintenance of, the above.

3.4.4 These phases can and should run concurrently to a degree, as the results of the RICHeS consultation exercise have already identified themes around gaps in capacity. It is already established that database aggregation, standards and repositories are required, and these can be development alongside the landscape mapping that will determine their eventual final form and function. See Figure 16 for a visualisation of the scheme.



Key: phase 1 = blue; phase 2 = yellow

Figure 15: The phases of infrastructure development and the relationships between constituent elements

4. Future directions

4.1 Summary

4.1.1 The realisation of an integrated ARCHLAB/DIGILAB infrastructure will be of significant importance in securing the future sustainability of the heritage science work undertaken through the FIXLAB and MOLAB elements of the RICHeS bid. Fundamentally, digital connections between people, technologies and objects of study ensure the maximum value is realised from major publicly funded research projects. In terms of FAIR: sustainable long-term accessibility, interoperability and reusability of scientific results that are findable, not only justifies the expense of research, but provides for future, as yet un-realised opportunities for down-stream value-added outcomes. Future-proofing the digital existence of heritage science data will enable research using techniques and technologies yet to be developed. There is also a *moral duty* on researchers and research councils to preserve the results of heritage science, particularly if analyses are destructive or compromise the material under study. This is particularly true when heritage and scientific reference collections are considered. Given that these are usually held outside GLAM sector beneficiaries of other funded programmes, such as TANC, there is a risk that their potential is not fully realised, leading to duplication of destructive analyses on the finite resource of heritage assets.

4.2 Use, Value, Sustainability

4.2.1 The most valuable contribution of the RICHeS infrastructure may not lie with benefits experienced by the largest institutions or higher education providers. In times of financial hardship, it is often smaller collections, archives or university research departments that face existential threats; whilst economic restrictions can limit the activities of larger organisations, they can threaten the existence of already marginal ones. Unfortunately, the *size* of a heritage organisation, collection, archive or research department is not a predictor of the *importance* of their contents to the future of heritage science: the landscape is traditionally fragmented and no size of organisation has a monopoly over nationally or internationally important collections or research.

4.2.2 The RICHeS infrastructure could have an important role to play in this fragile ecosystem and demonstrate significant value-added to its core activities and initial investment. New infrastructure will connect heritage science collections and archives with technologies and with researchers; make smaller collections *findable*; and feedback the results of research to the curatorial community. All these activities act to stimulate the **use** of heritage science collections and data in the broadest sense – they are studied. Use of a resource can be a metric for its **value** – if something has a purpose it is inherently of some worth. If a resource is of ongoing value it is worthy of **investment,** crucially from sources external to the infrastructure. Ongoing investment ensures long-term **sustainability** – archives are maintained, collections continue to be curated. If the resource is sustained it is available for future **use**, and thus the cycle repeats.

4.2.3 It should be noted that this is equally applicable to ongoing sustainability of digital resources as it is to physical collections. Indeed, as the cost of archiving larger and more complex digital datasets, such as three-dimensional and high-quality photographic data, grows ever higher, there will be increasing pressure on the cost of the resource for making this data open and accessible to contemporary and future researchers. Digital data repositories also need to be more light-footed in the context of use-value-investment-sustainability than physical collections: rapidly changing technology, software and analytical techniques require greater investment in compatibility and accessibility. Training and support from the ARCHLAB/DIGILAB strands of RICHeS will be essential in this regard.

Annex C: Governance

AHRC infrastructure policy and engagement fellowship in heritage science and conservation 2021: Report and recommendations

Freya Horsfield, July 2021

Contents

1. Introduction

The following is an interim report on design of specific elements of governance for the RICHeS programme. It incorporates the consultations to June 2021 and the AHRC's critical success criteria (above). The model proposed in the original RICHeS bid envisaged a distributed infrastructure. The following endorses that model, with additional nuances. It suggests an incremental approach to governance design in support of the RICHeS vision. The articulation of governance functions is begun through considering functions of the proposed strategic hub. Identification of a set of agreed core principles is also begun. The recommendations should be viewed as a starting point which can be refined through development of the strategic business case and continued engagement with stakeholders.

The text throughout uses a metaphor of the UK heritage science landscape as a complex (eco)system. The definition of a complex system used here includes characteristics such as being diverse, interconnected, interdependent, dynamic, and to some degree emergent.[55] Each of these descriptors illustrates the challenges and opportunities associated with the intention to support transformative change in the UK heritage science ecosystem.

2. A distributed infrastructure

Immoveable tangible heritage across the UK is highly dispersed overall, as reflected in catalogues of heritage assets.[56] Such records reflect the different ways in which different places have developed over thousands of years. Moveable tangible heritage is also highly dispersed across the UK. Many heritage objects are however not portable, for reasons of size or fragility. Moving these to central facilities is therefore not feasible, hence portable equipment has been developed enabling *in situ* analyses.[57] The modern communities who make decisions affecting heritage are also dispersed across the UK. Of these communities, the distribution of specialist heritage scientists, researchers, and allied practitioners, is a blend of dispersal and concentration.[58] Anecdotally, this distribution has been shaped substantially by factors such as the priorities and grant capture of specific institutions.

[55] Page, S., 2010. Diversity and Complexity. Princeton University Press, Princeton. https://doi.org/10.1515/9781400835140 Retrieved 4/8/19. This definition relates to organisational diversity. Diversity in the characteristics of people involved with heritage science merits further attention.

[56] Such as the catalogue of England's historic sites and buildings https://www.heritagegateway.org.uk/gateway/ Retrieved 4/8/21

[57] For example: Mulholland, R., Howell, D., Beeby, A., Nicholson, C.E., Domoney, K., 2017. Identifying eighteenth century pigments at the Bodleian library using in situ Raman spectroscopy, XRF and hyperspectral imaging. *Heritage Science* 5, 43. https://doi.org/10.1186/s40494-017-0157-y Retrieved 4/8/21

[58] Reports by Dr Rebecca Stacey and Dr Ben Edwards, above

The UK infrastructure landscape is already home to other distributed infrastructure models e.g. Royce Institute[59], ELIXIR-UK[60]. A distributed infrastructure model is the only viable approach for developing a unified national HS infrastructure because:

- It capitalises on the existing long-established specialist infrastructure and expertise in different institutions across the UK.
- It recognises that technology is used differently in different disciplines of HS and that technology demands specific expertise for use in different applications.
- It consolidates and promotes multi-disciplinarity, which is an integral characteristic of HS.
- It provides the most effective means to secure the confidence and engagement of the whole HS community.
- It exploits the regional distribution of the existing infrastructure to promote and widen accessibility.

Distribution was therefore considered as the first issue in a decision tree for RICHeS' governance development.

2.1 Centralised v distributed governance of heritage science infrastructure

Option A: centralised model of governance

A wholly centralised model of governance is superficially attractive. In this model, an existing research organisation, such as a centre of excellence, would be funded through a programme grant, directing all infrastructure funding. In the context of UK heritage science, consultations to date however suggest that wholly centralised governance would face specific challenges.

A centralised model of governance is likely to *reproduce* the structures, and therefore issues, that the RICHeS programme aims to address. Specific voices and perspectives have been structurally privileged in the processes feeding into the proposed infrastructure development. This structural privilege creates a potential tension in terms of setting funding priorities and agendas. Priorities and agendas need wide buy-in and involvement to achieve the transformative potential of the proposed investment. Such potential tensions emerged as recurring themes in the consultations for the RICHeS bid April – June 2021.

In a competitive funding environment, an existing research organisation could struggle to convince peers of its independence in distributing funds. A wholly centralised model of governance therefore makes this option a poor fit to AHRC's critical success factors 3 and 6. This is emphatically *not* an argument against centres of excellence, simply that such centres needs to be considered as parts of a wider ecosystem in terms of governance.

[59] The Henry Royce Institute is the UK National Institute for Advanced Materials, a partnership of 9 institutions (Universities of Cambridge, Imperial College London, Liverpool, Leeds, Oxford, Sheffield, the National Nuclear Laboratory, and UKAEA) with an operational hub at the University of Manchester. It is funded by the EPSRC/UKRI. https://www.royce.ac.uk/

[60] The UK Node of ELIXIR, an interdisciplinary international cooperation for life sciences data management. ELIXIR-UK is a distributed infrastructure across 19 UK organisations providing training and resources to support the bioinformatics and broader research community. The organisations work together via a 'Hub and Nodes' model. https://elixiruknode.org/

Option B: distributed model of governance

In contrast to a wholly centralised governance model, hybrid, distributed governance would encourage the diversity and dynamism of the heritage science ecosystem while mitigating the tendency of the sector to form silos. The operation and governance of international distributed infrastructure models are explored in detail in the report from an OECD Global Science Forum project.[61] Relevant parts of the high-level taxonomies described by OECD are reproduced here as Table 2. Category B (Co-ordination, facilitation or integration of research based on a common scientific theme), and C (Data infrastructures and e-infrastructures) are most relevant to the challenges and opportunities of establishing a governance infrastructure for UK heritage science.

B. Co-ordination, facilitation or integration of research based on a common scientific theme	
B1. Design, implementation and co-ordination of a set of large infrastructures	* ELI: European Light Infrastructure * GEOSS: Global Earth Observation system of systems
B2. Co-ordination/integration of diverse (sometimes multidisciplinary) projects/programmes	* SIOS: Svalbard integrated Arctic Earth Observing system * GEM: Global Earthquake Model
B3. Provision of resources/services (often involving research: instrumentation, software, etc.)	* EMMA: European Mutant Mouse Archive * CLARIN: Common Language resources and Technology infrastructure * CESSDA: Council of European Social Science Data Archives
C. Data infrastructures and e-infrastructures	
C1. Data-oriented infrastructures for federation, management, storage, and curation of large data sets (including development of standards and data-oriented products)	* GBIF: Global Biodiversity Information Facility * INCF: International NeuroInformatics Co-ordination Facility * Lifewatch: E-sciences and technology infrastructure for biodiversity data and observatories * ELIXIR: European Life-science infrastructure for biological information
C2. High performance computing, networking, data storage, provision of services	* GEANT: a pan-European network for research and education * PRACE: partnership for advanced computing in Europe

Table 2: Excerpt from OECD taxonomy of International Distributed Research Infrastructure (IDRIS)

Adapted from OECD 2014:9

[61] 'International distributed research infrastructures: issues and options' OECD 2014, https://www.oecd.org/science/international-distributed-research-infrastructures.pdf Retrieved 4/8/21

The OECD report illustrates the diversity of distributed research infrastructure models, in terms of distribution and connection of nodes. The OECD taxonomy was developed to describe distribution between countries, but the logic is transferrable to places or regions within the UK. It should be noted however that none of the OECD examples relate to infrastructures of the diversity of data types and disciplinary range of heritage science.

A key purpose of the governance model will be to support, equip and challenge UK heritage science to grow in self-organising capability (AHRC critical success factor 6). There is no clear single option for this within the models identified by OECD. Of the models described, OECD's loose connection (1) approximates to the current UK infrastructure, on whose under-performance the RICHeS investment is predicated. OECD's central co-ordination model (2) is at the opposite extreme, whereby one node supports different distributed nodes. Options for the UK context may also fit aspects of model 3 (a co-ordinating mechanism supported by one or several facilities or by an independent organisation) or 4 (multiple operational hubs, themselves being organised as network at the national level with a co-ordinating mechanism that can be supported by one (or several) nodes(s) or by an independent organisation).

RICHeS will need to devise bespoke arrangements for the UK, which could include a hybrid of some of the models identified by OECD, namely a blend of centralised and distributed functions. Given the complexity of the ecosystem, governance design could proceed incrementally, beginning with identifying those functions which are best performed centrally. Consultations in April -June 2021 therefore focussed on two questions: the additionality and remit of a possible strategic hub and the high-level principles to be embedded in governance design. These are considered successively next.

3. Strategic hub additionalities

3.1 Functional scope

A new unit would require justification of need and clear functional scope. The current fragmented nature of UK HS was a consistent 'soft' message from consultees. This fragmentation is longstanding.[62] Part of the RICHeS architecture to help address such fragmentation was proposed by AHRC prior to 2021, in the form of a strategic 'hub.' In April - June 2021 consultees were invited to comment on the high-level functions which a strategic hub could perform. Some clear messages emerged from this material overall (Tables 3 -4 and Figure 17).

The consultations identified a need for resource to deliver specific functions. There was a strong positive response for the suggestion that the hub should **direct funding**. This was to be expected considering the complicated patchwork of funding arrangements for the sector. The AHRC remit and budget do not represent the disciplinary reach of heritage science, which makes use of techniques and technologies across the whole of UKRI's responsibilities. Survey results and workshop comments provided a similarly strong message of the importance of a coherent approach to supporting **retention and upskilling**. There was clear appetite also for

[62] Fragmentation in heritage science was described as 'extraordinary' and as being responsible for 'the lack of any organisation able to identify research needs' by the 2006 House of Lords inquiry into heritage science (section 6.4.1)

the suggested leadership support functions (**catalysing, convening, and supporting the ecosystem**, and **co-ordinating strategic thinking**).

• Very strong support (higher than 70%) for supporting retention & upskilling and providing directed funding • Strong support (higher than 60%) for catalyse convene & support ecosystem; addressing shared challenges through strategic thinking, co-ordination • Medium support (higher than 50%) for advocacy; data management & resilience, strategic connection to wider priorities & mechanisms • Support (above 40%) for resolution of cross-RC issues; visibility and soft power functions • Relatively low (33%) support for oversight of heritage science as an emerging profession. This figure may be confounded by a generally low levels of self-identification as a heritage scientist, and a tendency among some respondents to conflate heritage science with a specific discipline such as archaeology

Table 3: Main messages from survey about hub functions

• Specialisation to reflect the different community needs and audiences for the data • Advocacy and tools and funding streams to help make data FAIRer • Enable the UK node of E-RIHS • Focus on developing new methods and technologies for recording and analysing cultural heritage • To act as a centre for public engagement with cutting edge heritage science • Share equipment/instrumentation across Research Councils (for example with NERC)

Table 4: Free-text comments directly pertinent to survey question on hub function but not otherwise represented in Figure 17 responses

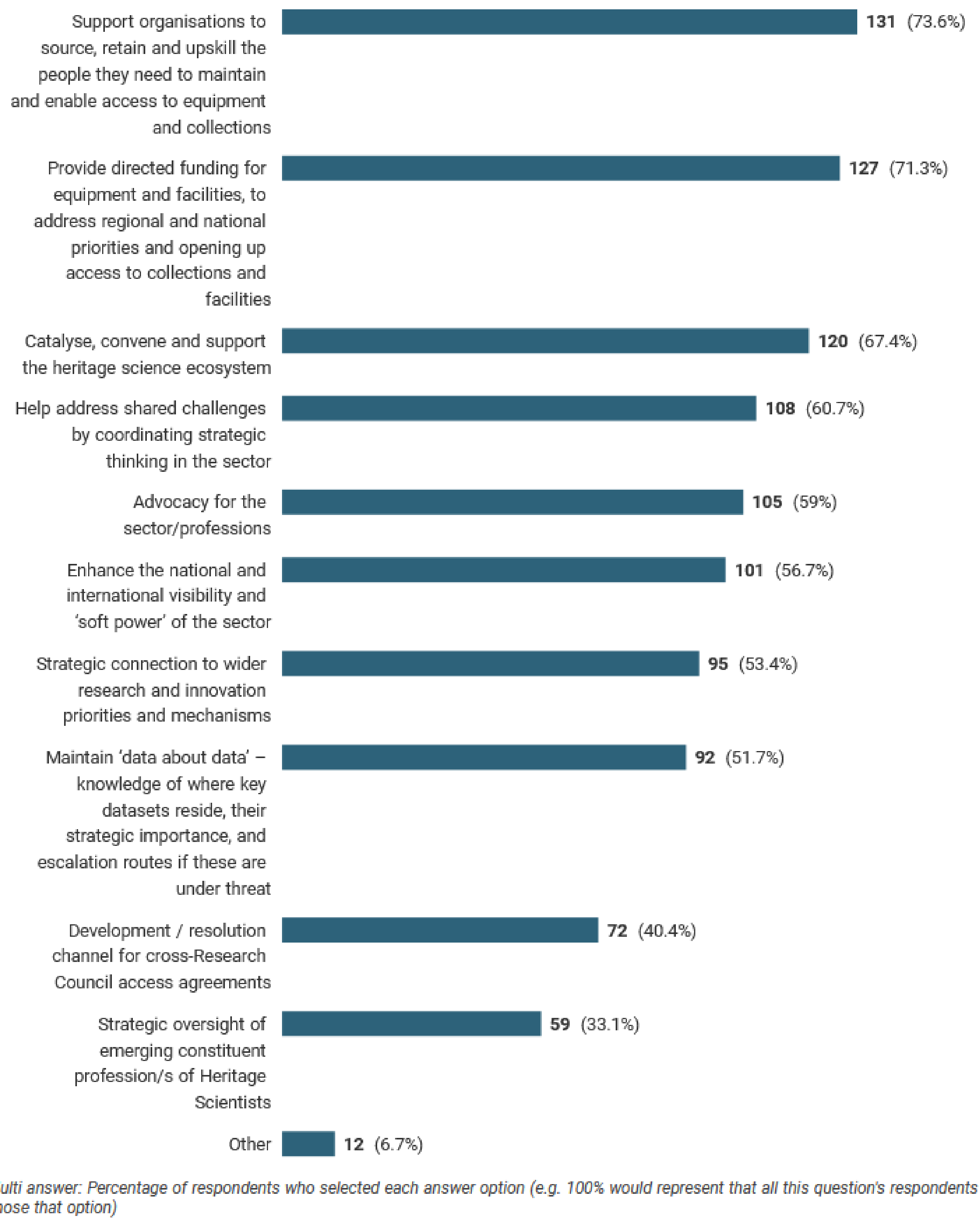


Figure 16: Responses to survey question 'What are the most important functions a strategic hub could perform?'

3.2 Function delivery

The next branch of the decision tree was whether the resource to deliver the identified functions should be established within an existing HEI/RO, perhaps building on an existing centre of excellence, or be separate from existing research institutions. The targeted conversations, workshops, and survey comments gave a clear message of the need for funding, strategic and oversight functions to be separate from an existing HEI / RO. Visible independence of the 'strategic hub' will thus be an important pillar for the functions identified. Avoiding over-identification with specific disciplines also emerged as a theme in discussions.

4. Operational issues

4.1 Strategic hub location

The next decision is whether to establish such a unit as an entirely independent entity with its own staff and governance bodies (**Option A**), or (at least initially) within AHRC (**Option B**). The diverse and dynamic nature of the heritage science ecosystem was emphasised above, and operational requirements are likely to evolve during the life of the infrastructure. These factors argue for the need to retain a degree of organisational flexibility in the early years of the investment, to allow the new arrangements to bed in and adapt. Of the two options, the second (Option B) is therefore recommended here. This mitigates set up costs and retains flexibility to adapt as infrastructure develops. This would not preclude a later move to Option A, whereas a move between A to B would be more cumbersome and expensive.

Setting up in AHRC need not constrain the Hub to be in the Golden Quadrangle.[63] Indeed, it might be a powerful signal of transformative intent if staff were to be located *outside* these areas. Consultees repeatedly made the point that pandemic adaptations had demonstrated the viability of virtual, distributed teams. The pandemic is also prompting consideration of other factors which may be pertinent to the role and delivery model of the strategic hub for RICHeS.[64] The strategic hub will require a defined remit and operating relationships with key partners, as well as resources and processes to ensure that it can meet applicable legal, regulatory, and institutional requirements, and appropriate ethical, scientific, and operating standards. The hub could maintain lateral connections with developments in the wider research and innovation landscape, supporting key relationships such as with UK and international policy and governance contexts. A dedicated strategic hub for RICHeS would also offer enhanced visibility of UK heritage science to the international community, able to support, convene and connect research and innovation partners, visibly independent of institutional affiliations.

[63] London, Swindon, Cambridge, Oxford

[64] Guest, K., 2021. Heritage and the Pandemic: An Early Response to the Restrictions of COVID-19 by the Heritage Sector in England. The Historic Environment: Policy & Practice 12, 4–18. https://doi.org/10.1080/17567505.2020.1864113 Retrieved 4/8/21

4.2 Clear articulation of principles

The hub would need to ensure strategic direction is guided by a clear set of governance principles to underpin operation in a diverse landscape. Workshop and survey participants were asked what principles should be embedded, in addition to those which would be drawn down from UKRI.[65] Respondents were offered three options: FAIR (which 62% endorsed), ethical sampling and non-invasive analysis (which 72% endorsed) and other (endorsed by 14%) (Figure 18). Twenty respondents offered further suggestions as to what other principles should be embedded. These comments are recorded at Appendix A, including principles which are broader than governance but excluding comments which did not directly translate to specific principles pertinent to a research context.

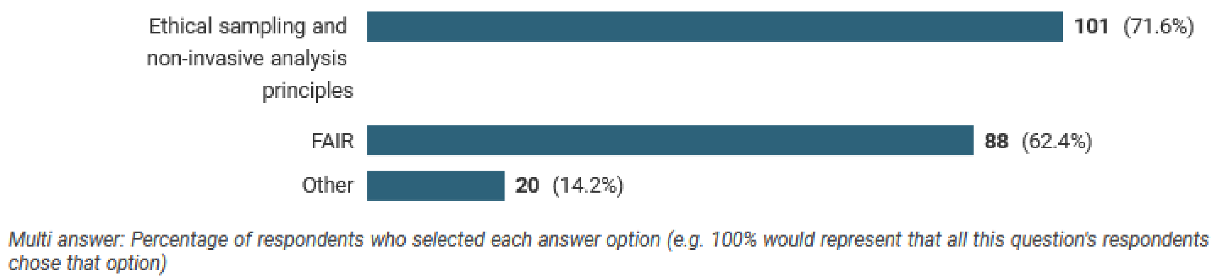


Figure 17: Responses to question 'what principles should be embedded, in addition to those drawn down from UKRI'

4.3 Accessibility

Heritage science is inherently a collaborative enterprise.[66] Part of the case for RICHeS is that it should 'optimise value for heritage science, the wider Research and Innovation sector, and society as a whole' (AHRC success criterion 2). Accessibility is an important part of value optimisation in this context. Put simply: value optimisation depends partly on the research infrastructure being accessible to those beyond the organisation which holds the funded asset, whether the asset is a person, a piece of equipment, or a heritage asset. In many instances, both systematic and *ad hoc* access already occurs, by other research organisations, voluntary and commercial organisations.

RICHeS offers the opportunity to increase such access. To do this, it will be necessary to address barriers to accessibility, including structural factors. The principle of stewardship should be seen as being an embedded in HS and no part of this text should be read as arguing for unfettered access likely to damage the asset.

The team therefore identified accessibility as a key principle for the infrastructure, as a necessary precursor to strategic and operational decisions such as priorities and funding. Two extremes of hypothetical user, characterised respectively by high specificity and high heterogeneity, were used to test assumptions. Individual heritage scientists may possess skills which are so specialist that s/he may be the only such scientist in the country. In respect of the high heterogeneity characteristics, good practice in civic service design is guided by the

[65] https://www.ukri.org/our-work/supporting-healthy-research-and-innovation-culture/ Retrieved 4/8/21

[66] House of Lords Science and Technology Committee (2006) Ninth Report of Session 2005–06. Science and Heritage. https://publications.parliament.uk/pa/ld200506/ldselect/ldsctech/256/25602.htm Retrieved 4/8/21

principle that designing for disability (i.e., high heterogeneity) enables design for everyone. This principle can be extrapolated to infrastructure design, swapping in the concept of citizen science. Citizen science is a type of scientific enquiry which is highly heterogenous. It has further been argued that citizen science has an important role to play in open science innovation.[67] Designing around these two extremes therefore should help address accessibility issues for as wide a range of potential users as possible. It will be an important aspect of the future governance arrangements to set priorities necessary to manage and fund the demand for such access.

4.4 Fluid aggregation

It is not appropriate to determine here specific access arrangements or programmes. Based on consultations thus far, it is however possible to identify some general principles which may be helpful as the RICHeS programme is developed. One principle is that access arrangements pay regard to the potential for aggregation and partnership while supporting a high degree of specialism where there is a case for this. The UK benefits from a diverse range of research / investigative facilities presently used in HS (Stacey, Annex A above). A purpose of research governance in this landscape will therefore be to sustain the ecosystem within which such diversity can flourish, as being an important necessary but not sufficient condition for research excellence.

The strategic hub could therefore work with the HS community to explore aggregation potential where there is appetite for this approach, while ensuring that individual facilities can continue to be funded as standing alone where that is most appropriate. The potential for ‘spokes’ to facilitate access to their resources is outlined elsewhere in this report (Stacey, Annex A above). This section therefore merely notes that various mechanisms for aggregation and access exist. For example, a research consortium is a well-understood mechanism which enables organisations to aggregate, often simultaneously under different arrangements with different partners, for purposes reflecting one or more of their multiple roles.[68]

The flexibility and scalability of aggregation options may also be attractive to potential partners. A consortium arrangement could potentially act as an ‘umbrella’ arrangement, facilitating access to expertise and facilities for a wider set of stakeholders than those eligible to receive UKRI funding directly. Such an arrangement would therefore address a

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[67] Hecker, S., Haklay, M.E., Bowser, A., Makuch, Z., Vogel, J., Bonn, A., (2018). *Citizen Science*. UCL Press, London. Citizen science is also a useful accessibility proxy for other categories. Many conservation professionals operate as Small-Medium Enterprises, for example.

[68] Consortia may come together for specific purposes: 1) a provider consortium, bringing together group facilities, either on a regional basis (like the CHERISH hub in Cambridge) or to consolidate local facilities for specific research (such as BioArchaeology at York University) or for a specific technical/application which could involve dispersed facilities with well-aligned expertise 2) research consortia – a typical collaboration for joint research, including to address overarching challenges 3) access support – consortia to support training and standards for specific technologies.

longstanding concern.[69] The arrangements for match-funding and Accountable Officer assurance of the various aggregation models may require specific attention.

5. Conclusions

The model proposed in the original RICHeS bid envisaged a distributed infrastructure. This interim report endorses that model, with some additional nuances. It recommends that governance design proceed incrementally, be underpinned by a clear articulation of the functions to be performed by specific structures, and by a set of agreed core principles. The recommendations may be refined through development of the strategic business case and continued engagement with stakeholders.

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[69] The issue of direct eligibility for Research Council funding was signalled by the House of Lords Science and Technology Committee inquiry into Science and Heritage in 2006: Recommendation 11

"We acknowledge that there is an issue for those organisations which are unable to access funding because of their ineligibility for Independent Research Organisation (IRO) status. We encourage organisations within the heritage science community who would like IRO status to explore whether it would be possible to develop consortia, perhaps on a regional or thematic basis, to apply as a collectivity for IRO status and bid for funding. The research councils should offer assistance to any group of organisations intending to form a consortium to help them achieve IRO status"
https://publications.parliament.uk/pa/ld201012/ldselect/ldsctech/291/29107.htm Retrieved 4/8/21

Appendix A Additional principles suggested by survey respondents

- Stewardship
- Transparent and accountable governance of resources
- DORA – San Francisco Declaration on Research Assessment
- FAIR
- CARE Principles for Data Governance [70]
- Some draft principles for sharing collections data from recent project with the Open Data Institute[71]
- Ethical sampling and non-invasive principles
- Building on ethical sampling, many frameworks don't appear to recognize likely loss of information without improved conservation for both individual objects and collections. ICON framework is clearly biased towards researcher not 'owner'
- Equitable interactions with stakeholders, especially in the global South but all historically marginalized groups
- UN SDG alignment
- UNESCO and other conventions against illicit trade of antiques
- In CH setting we need to be more specific about threats to cultural heritage tangible and intangible. For example, stronger opposition to damage to the cultural heritage by one community/or interests at the expense of another.
- Advocacy on its use within a wider framework (e.g., archaeology as part of the National Planning Framework)
- External engagement, collaboration between academia and commercial partners
- To ensure that pay levels are adequate to attract people
- Gender equality and support for early career and independent researchers
- Standards issued by professional bodies, e.g., CIfA, IHBC, ICON
- Standards and guidance published by national bodies e.g., Historic England, Historic Environment Scotland, CADW and DoE (NI)

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[70] https://www.gida-global.org/care Accessed 16/8/21

[71] https://collectionstrust.org.uk/tapping-our-collections-potential/guiding-principles/ Accessed 16/8//21

Annex D: Development of the RICHeS concept and earlier consultations – a note by AHRC

UKRI Infrastructure Opportunities and Landscape Analysis

Following the creation of UK Research and Innovation (UKRI) as an entity in 2018, programmes were set up to drive collaborative working among the constituent Councils, to address jointly large-scale interdisciplinary challenges, and to better serve the research and innovation communities by harmonising strategy, communications and service provision. All Councils support research infrastructure, in the form of equipment, facilities and expertise, and many techniques and resources are relevant to the remit of more than one Council. So UKRI, in 2019, launched an initiative to map the research infrastructure landscape and needs of the UK research and innovation community, commissioning each Council to conduct stakeholder engagement and consultation with their researchers and other end users (see also Figure 1 above).

AHRC approached this through a three-tiered survey exercise (see Box A), and a series of follow-up conversations with senior stakeholders, undertaken by AHRC's then Director of Partnership and Engagement, Professor Roey Sweet, and through four open discussion workshops located around the country, for the wider community. The outcomes of this consultation were incorporated into the UKRI Infrastructure Opportunity Report[72] and Landscape Analysis.[73]

AHRC also identified, from the consultation outcomes, three priority areas for investment:

- Creative industries
- Heritage
- Digital and data

These priority areas have formed the basis for AHRC's first three bids to the UKRI Infrastructure bid, respectively:

- Convergent Screen Technologies and Performance for Access in Real-Time (CoSTAR)
- Research Infrastructure for Conservation and Heritage Science (RICHeS)
- Infrastructure for Date Curation and Innovation in the Arts and Humanities (iDAH)

The commitment to infrastructure funding was written into AHRC's 2019 Delivery Plan (see Box B), and these programmes throughout their development have been informed by AHRC's past related strategic initiatives (see Box C).

[72] https://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-UKinfrastructure-opportunities-to-grow-our-capacity-FINAL.pdf
[73] https://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-LandscapeAnalysis-FINAL.pdf

Consultation and Development of the RICHeS concept to Spring 2021

Data collected during the consultation on arts and humanities research infrastructure throughout 2019, and two key publications from the European Research Infrastructure for Heritage Science (E-RIHS, 2016)[74], and its UK national counterpart (UK-RIHS, 2019)[75], formed the basis for the concept of a networked, dispersed heritage science and conservation infrastructure programme.

AHRC convened a workshop which was chaired by Lord Browne, and attended by the Executive Chairs of AHRC, EPSRC and STFC, plus representatives from universities, museums and galleries, archaeology, and the build heritage sector. The wide-ranging discussion explored ways in which UKRI investment could grow heritage science research and identified follow-up actions towards the development of a national programme. The concept was further developed through two focussed conversations with a Heritage Science Steering Group, comprising representatives of the heritage science and conservation research community, with links to the UK national node of E-RIHS (UK-RIHS), and the NHSF, universities, libraries, museums, and galleries.

At a relatively early stage in 2020, the concept was presented to UKRI's Infrastructure Working Group, to ensure it complements and does not substantially duplicate plans under development by other Councils, and to invite input into the programme's fit to UKRIs' Infrastructure funding strategy. The idea was warmly received, and AHRC was invited to participate in the cross-UKRI Imaging Working Group. AHRC also conducted follow-up discussions with the managers of large scientific facilities that are used by heritage science and conservation researchers, including the Diamond Light Source and ISIS Neutron and Muon Source at Rutherford Appleton Laboratory. While the proposal was under consideration by UKRI's Infrastructure Advisory Committee, the RICHeS concept was presented to the wider research community at two open, virtual Town Hall discussion events in November and December 2020.

At the IAC meeting in November 2020, the Committee agreed that the RICHeS programme is strategically important and timely and should be prioritised for funding. The Committee requested further detail as to the specific impacts and additionality that the programme seeks to achieve, and the governance functions and structures that will ensure successful cooperative working among the programme's many stakeholders. AHRC allocated resource to address the issues raised by the IAC, including funding three Fellowships. The present report is part of the output of the AHRC-funded Fellowships.

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[74] https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiO4vLmn4HzAhXLgP0HHYxMDBUQFnoECAUQAQ&url=https%3A%2F%2Fhal.archives-ouvertes.fr%2Fhal-02138538%2Fdocument&usg=AOvVaw32XuKqaYLGS2YnM0Oo7ODu

[75] https://docplayer.net/187267332-Report-on-uk-heritage-science-research-capabilities-carried-out-for-the-uk-research-infrastructure-for-heritage-science.html

A – AHRC Infrastructure Opportunities Survey

To inform the UKRI Infrastructure Opportunity Report, and its own infrastructure funding strategy, AHRC invited institutions (individually or in consortia) to submit their ideas for infrastructure funding projects that would significantly improve their core capacity or allow them to expand to address new challenges. The survey invited opportunities at three stages of development:

- Stage 1: early-stage idea
  A description of the ambition or problem to be solved, the strategic drivers, and the actions that need to be undertaken to progress towards a solution.
- Stage 2: strategic options analysis
  A summary of the vision and how it will produce a step-change for the organisation, and description of the options for delivery, with high-level costings.
- Stage 3: project and concept
  A description of the project and its stage of implementation, the organisations involved in delivery, costings and dependencies.

Seventy-seven responses were received from a range of organisations, including universities, museums, libraries, galleries, and heritage policy bodies (e.g. Historic England, National Trust). Fifty-four of these responses outlined opportunities directly relevant to heritage science and conservation research, many of which have been subsequently funded through the first Capability for Collections fund.

B - AHRC Delivery Plan

AHRC's Delivery Plan was published in winter 2019 after wide-ranging consultation on the UKRI Infrastructure Landscape Analysis. The plan embedded AHRC's commitment to support research infrastructure, with the overarching objective to "contribute to the development of the UK's world-leading cultural research infrastructure, including research e-infrastructures". Specifically, this objective committed AHRC to:

- "establish a research infrastructure for the creative industries to match that available to the biomedical, manufacturing and engineering sectors";
- "make major new investments in the sphere of heritage science, in order to:
    - provide the equipment and facilities to undertake interdisciplinary heritage science research;
    - build capacity within the sector;
    - design and develop systems and modules to incorporate heritage science data into our collections management systems."
- "create a 21st-century research infrastructure that fully meets the needs of the arts and humanities research, both at local institutional and at national level. This will:
    - make effective use of aggregated collections;
    - establish harmonised standards for data, cataloguing and metadata to facilitate interoperability across collections;
    - create the institutional support to bring small collections, archives and museums into a networked environment where they can be shared and used effectively;
    - create the storage systems and capability for the complex data that will be generated in the future;
    - resolve issues around intellectual property and copyright so the UK can become the global leader in this area;
    - work towards the creation of an integrated 'national collection' that will set global standards in the field'."

C - Related AHRC Strategic Programmes

- **Science and Heritage (2007 – 2012)**

The Science and Heritage Programme was funded by the AHRC and the Engineering and Physical Sciences Research Council (EPSRC). It took forward recommendations made by the House of Lords Science and Technology Select Committee report on science and heritage of November 2006 which concluded that there was a compelling need for a comprehensive national strategy for heritage science which covered both immoveable and moveable heritage.

- **Connected Communities (2009 – 2014)**

This £30m AHRC-led cross-Council programme studied the changing nature of communities in their historical and cultural contexts, and the role of communities in sustaining and enhancing quality of life. During the lifetime of the project, around 280 awards were made under themes including: health and wellbeing; participatory arts; civil society and social innovation; diversity and dissent; creative and digital; culture and heritage; and environment and sustainability.

- **Collaborative Doctoral Programme (2013 – present)**

Funding awards to support doctoral studentships with one university supervisor, and one from an Independent Research Organisation (IRO), to support research in the IRO and using its collections and facilities. Award-holding institutions include the British Museum, Tate, The National Archives, Glasgow Life, and English Heritage.

- **Heritage Priority Area (2017 – 2020)**

AHRC made additional funding available for highlight notices on existing funding schemes, studentships (through the Heritage Consortium) and a coordinating Heritage Priority Area Leadership Fellow, Professor Rodney Harrison, University College London.

- **Towards a National Collection (2019 – present)**

A five-year, £18.9m programme to support research into the use of digital technology to dissolve barriers between disparate collections, opening them to greater access for research and engagement. To date, the TaNC has funded eight small-scale Foundation projects, to map the challenges facing this objective, and three Urgency projects,[1] in response to the COVID-19 lockdown, to research guidance for cultural institutions on preparing for digital access while physical presence is impossible. A further round of larger-scale Discovery projects is currently under preparation, which will work cooperatively to develop the physical, digital and organisational solutions needed to address barriers and fragmentation.

- **Capacity for Collections (2020)**

A £15M fund established following a one-off £300M uplift from government to UKRI's World Class Labs programme. It supported a series of targeted, capital investments to renew and upgrade research facilities within UK galleries, libraries, archives and museums (GLAMs), including university collections, focusing on conservation and heritage science facilities, digital capture equipment and specialist study spaces and reading rooms.

Annex E: Glossary and further reading

CapCo	Capabilities for Collections
ERIC	European research infrastructure consortium
GLAM	Galleries, libraries, and museums
HS	Heritage Science
NHSF	National Heritage Science Forum
RICHeS	Research Infrastructure in Conservation research and Heritage Science
TANC	Towards a National Collection

House of Lords Science and Technology Committee (2006) 9th Report of Session 2005–06. Science and Heritage. Report with Evidence. Published by the Authority of the House of Lords. London: The Stationery Office Limited. HL Paper 256. http://www.publications.parliament.uk/pa/ld200506/ldselect/ldsctech/256/256.pdf Accessed 16/8/21

House of Lords Select Committee on Science and Technology (2007) 8th Report of Session 2006–07. Science and Heritage: an update. Report with Evidence. Published by the Authority of the House of Lords. London: The Stationery Office Limited. HL Paper 168. https://publications.parliament.uk/pa/ld200607/ldselect/ldsctech/168/168.pdf Accessed 16/8/21

House of Lords Select Committee on Science and Technology (2012) 5th Report of Session 2010–12 Science and Heritage: a follow-up. Report. Published by the Authority of the House of Lords. London : The Stationery Office Limited. HL Paper 291. http://www.publications.parliament.uk/pa/ld201012/ldselect/ldsctech/291/291.pdf Accessed 16/8/21

NHSF website https://www.heritagescienceforum.org.uk Accessed 18/9/21

NHSF National Heritage Science Strategy https://www.heritagescienceforum.org.uk/what-we-do/national-heritage-science-strategy Accessed 18/9/21

NHSF 2018 Strategic Framework for Heritage Science in the UK 2018-2023 https://www.heritagescienceforum.org.uk/what-we-do/strategic-framework Accessed 16/8/21

Peach, C. 2019. UK Research Infrastructure for Heritage Science (UKRIHS). Report on heritage science capabilities. Preservation Matters Ltd https://docplayer.net/187267332-Report-on-uk-heritage-science-research-capabilities-carried-out-for-the-uk-research-infrastructure-for-heritage-science.html Accessed 18/9/21

NHSF 2020 Societal Challenges and heritage science research
https://www.heritagescienceforum.org.uk/what-we-do/societal-challenges-and-heritage-science-research Accessed 16/8/21

UKRI 2020a The UK's research and innovation infrastructure: Landscape analysis
https://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-LandscapeAnalysis-FINAL.pdf Accessed 16/8/21

UKRI 2020b UK's research and innovation infrastructure: opportunities to grow our capability
https://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-UKinfrastructure-opportunities-to-grow-our-capacity-FINAL.pdf Accessed 13/8/21

UKRI 2020c Creating world-class research and innovation infrastructure
https://www.ukri.org/our-work/creating-world-class-research-and-innovation-infrastructure/
Accessed 16/8/21

UK Government's Research and Development Roadmap 2020
https://www.gov.uk/government/publications/uk-research-and-development-roadmap
Accessed 16/8/21

UKRI technician commitment
https://www.technicians.org.uk/technician-commitment Accessed 12/8/21