# D17.1 Report on E-Archaeology Frameworks and Experiments


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Ariadne is funded by the European Commission's 7th Framework Programme.

## About this document

This document is the “Report on E-Archaeology Frameworks and Experiments”, a contractual deliverable (D17.1) of the project ARIADNE - Advanced Research Infrastructure for Archaeological Dataset Networking in Europe. The research leading to these results has received funding from the European Community’s Seventh Framework Programme (FP7-INFRASTRUCTURES-2012-1) under grant agreement nÅã 313193.

Version: 1.0 (*final*) **28th January 2017**

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# Table of Contents

# 1 Executive Summary

## E-Archaeology

In this study e-archaeology basically means the use of web-based digital data, tools and services for research purposes. E-archaeology may be subsumed under the so called digital humanities, however has its own disciplinary challenges and some different characteristics. The study includes an analysis of significant differences which should be taken account of when developing environments for e-research of humanities scholars or archaeologists.

## Enabling Multi-Disciplinary E-Archaeology

Archaeology is a multi-disciplinary field of research that involves researchers, especially find experts, with different disciplinary backgrounds and research questions. They all contribute to the interpretation of archaeological sites, but their work requires different knowledge, methods and tools. Therefore, the study sees a need of two types of collaborative e-research solutions:

- An environment that allows bringing together, integrate and interpret (synthesise) the results of the different investigations on a site, of the core team of archaeologists/excavators and of the different finds experts who work at the site and/or remotely.
- Environments for researchers in specialities (e.g. physical anthropology, archaeobotany and others) that are specialised for their particular data and terminology and include services/tools for the identification, description and analysis of their finds.

Both environments are essential for collaborative generation of research results, in the context of archaeological excavations and the research of archaeological specialities. The environments should be developed in view of wider range investigations (i.e. beyond individual sites) based on sharing of the collected data through the ARIADNE e-research infrastructure.

## ARIADNE and Virtual Research Environments

Virtual Research Environments (VREs) are web-based environments that provide research communities with tools, services and data resources which they need to carry out research work online. The ARIADNE data infrastructure currently allows discovery of and access to data across distributed digital archives. One next step could be to provide VREs that enable carrying out also other, more specific research tasks online. Such VREs may range from loosely coupled services/tools and data resources to tightly integrated workbenches and databases for specific research communities.

The study looked into the development of VREs for various disciplines, including taxonomies of different types of VRE and research activities they may support. The investigation found that there have been many VRE projects for humanities scholars who study textual content, but few attempts to build VREs for archaeology. But, archaeological researchers use various tools to carry out, analyse and present research results. Today the main variant of an archaeological e-research environment arguably is the Web GIS of an excavation project; also 3D models are increasingly being used to present research results.

## Case Studies

The case studies describe exemplary current digital practices in the respective area, recent progress and/or existing shortcomings, and outline how the area could advance, or contribute to advancing, toward innovative e-archaeology. A common perspective of the studies is the potential development of VREs in the context of the ARIADNE e-infrastructure. The case studies cover a wide range of e-archaeology topics and subject matters:

- *Archaeological methodology*
- *Archaeological ontologies*
- *E-infrastructure VRE at the national level*
- *3D archaeology*
- *Geo-physical surveying*
- *Physical anthropology*
- *Archaeobotany*

The conclusions and recommendations of the case studies with regard to potential advances in e-archaeology concern adoption of novel approaches, standards, methods, tools or other means, depending on the subject area covered. The results are summarised in the final section of the case studies chapter and have been incorporated in the overall conclusions and recommendations.

## Main Conclusions and Recommendations

The ARIADNE e-infrastructure helps to overcome a situation of high fragmentation of archaeological data in Europe (and elsewhere). At the same time, it is a step towards the even more ambitious goal of providing a platform capable to support web-based research aimed to create new knowledge. Thus a major next step could be to implement virtual research environments (VREs) that, in addition to data access, provide services and tools which allow archaeological researchers carrying out research tasks online.

### General Recommendations for Data, Tools/Services and VREs

VREs are web-based collaboration environment that provide a set of integrated tools and services as well as data resources as needed by research communities to carry out research tasks online. With regard to data, tools/services and VREs the general recommendations of this study are:

- ARIADNE should focus on major archaeological data resources, in particular field survey and excavation data, including data of research specialties.
- Concerning data of research specialities ARIADNE will have to consider which fields should be focus areas of future incorporation of additional data resources.
- With regard to research tools the focus should be on tools/services of particular relevance to archaeologists. One area already present in ARIADNE's portfolio is online services for the generation, visualization and exploration of 3D models (Visual Media Service and Landscape Factory).
- Other priority areas of future additional tools/services should be investigated. These could focus on certain types of data (e.g. remote sensing data) and/or tasks (e.g. collaborative building of online reference collections). In general types of data and tasks that are relevant for broad segments of researchers are preferable, at least in a first phase of extension of the ARIADNE service portfolio.
- The main challenge for ARIADNE to support e-archaeology is the multi-disciplinary of archaeo-logical research. This challenge may be addressed by providing VREs for certain domains or fields of research, and an environment that allows bringing together, integrate and synthesise the results of different investigations, i.e. with a focus on archaeological sites.
- The environments should be developed in view of wider range investigations (i.e. beyond individual sites) based on sharing of the collected data through the ARIADNE e-research infrastructure.

## Recommendations for the Development of ARIADNE VREs

Use of VREs on top the ARIADNE e-infrastructure could bring about significant progress in e-archaeology, in particular through enabling collaboration between and cross-fertilization of knowledge and research agendas of scholars of different domains. With regard to the development of ARIADNE VREs the study recommends:

- Investigate further different concepts of virtual environments for archaeological research, e.g. which research tasks could research groups conduct more effectively online and which requirements need to be fulfilled.
- Promote the development of relevant VREs with functionalities (tools, services) and data resources required by archaeologists to carry out various research tasks online.
- Take account of the particular requirements of archaeological researchers in different domains as well as in cross-domain/disciplinary collaboration.
- Consider cases where researchers use data mediated by ARIADNE and by data infrastructures and services of other disciplines (e.g. geo, environmental, biological data). For the development of cross-domain VREs collaboration between e-infrastructure initiatives of different disciplines may be necessary.
- Support the use of domain-specific vocabulary as well as integrating ontologies such as the CIDOC Conceptual Reference Model (CIDOC CRM) and its recent extensions CRMsci, CRMarchaeo, CRMba, and others.
- Aim to develop VREs that enable collaboration between and cross-fertilization of knowledge and research agendas of scholars of different domains.
- Foster cross-fertilization also between scholars and developers of software tools for research purposes, in which developers learn about the requirements of scholars' projects, and scholars how to apply novel technological solutions.

# 2 Introduction and overview

ARIADNE has implemented an e-infrastructure platform where archaeological data resources can be uniformly described, discovered and accessed. The ARIADNE data registry and portal help to overcome a situation of high fragmentation of archaeological datasets in Europe (and elsewhere). At the same time, the ARIADNE e-infrastructure is a step towards the even more ambitious goal of providing an environment capable to support web-based research aimed to create new knowledge (e-archaeology).

Thus a major next step could be to implement virtual research environments (VREs) that, in addition to data access, provide services and tools which allow archaeological researchers carrying out research tasks online. Such environments may range from loosely coupled services/tools and data resources to tightly integrated workbenches for researchers of different domains of archaeology. The current ARIADNE project has not been charged to develop VREs, but the implemented data infrastructure and portal provide a basis for future archaeological VREs.

## E-archaeology

In this report the term "e-archaeology" generally refers to the use of web-based tools/services and data resources for established and new forms of collaborative digital archaeological research (e-research). In archaeology, e-research is conducted in fieldwork (e.g. capture of data with various digital tools) and post-fieldwork processing, analysis, publication and linking of data. In recent years both areas have experienced an increasing use of digital methods and tools.

### Field surveys and excavations

With regard to fieldwork, ever more data capture technologies have been added to the toolbox of archaeologists. For example, the use of web-based geographic information systems (WebGIS) has become a standard practice in field surveys and excavations. Other developments focus on streamlining data workflows. One example is "paperless archaeology". Mobile applications on iPads or other tablets instead of paper-based recording templates are increasingly employed in field surveys and excavations. This avoids the "double entry" problem, first filling paper templates, then entry of data in a database. The goal clearly is to speed up data collection in the field and bring, where possible, also the data processing and analysis closer to the trench.

Thus the use of digital methods and tools has become an essential element of archaeological fieldwork. But it is not a focus area of the studies presented in this report. ARIADNE does not aim to provide archaeologists with novel tools for capturing and processing data in the field, but focuses on services for online data sharing, discovery and re-use. To go beyond this, future developments in ARIADNE will consider how web-based research tools/services could be provided in addition to data resources, ideally integrated as VREs for different areas of archaeological research.

This said, we recognise of course that fieldwork and post-fieldwork are not fully separated areas of archaeological research. There are information loops, e.g. between excavators and finds experts working remotely, and also tools such as project wikis which allow continued documentation and interpretation during and after the fieldwork.

### Report focus on post-fieldwork e-archaeology

The ARIADNE e-infrastructure allows registration, discovery, access to and use of data across distributed digital archives/repositories. The project does not provide services/tools for capturing data in the field, but aims to support e-research based on already produced data that is shared and accessible online. The support currently focuses on making data resources better discoverable and accessible for researchers, for example, based on enhanced data documentation, sharing, linking and access for re-use. ARIADNE services such as data registration, search and access are generic services, whereas e-research environments provide special tools/services for research tasks of researchers of different domains of archaeology. Some ARIADNE services already signal a development towards e-research capability, for example, the services for publication and exploration of visual media (e.g. interactive 3D models of objects and landscapes).

Because ARIADNE services do not support fieldwork (or laboratory work), the WP17 study group decided to focus on web-based tools/services and data resources that are relevant for new forms of digital archaeological research. The study group recognised that there are many online platforms available where researchers share information, social media sites (e.g. Flickr or YouTube) as well as dedicated professional platforms, i.e. Academia.edu, ResearchGate, and others. Such platforms were not considered as relevant for this study.

## E-research methodologies and case studies

ARIADNE does not prescribe e-research methodologies, but aims to support archaeological research with novel approaches and useful services and tools. Therefore, the objectives of WP17 have been to collect and review innovative e-research frameworks and approaches and assess their current applications. The objectives did not include to discuss fundamental questions of different paradigms, theories, methodologies, etc. that are present in the archaeological research community. Rather the approach should be to look into current practices and relevant available or missing applications for innovative e-archaeology.

Furthermore, a number of case studies have been produced as pilot investigations for the development of e-archaeology scenarios and future experiments in the context of the ARIADNE data infrastructure and portal. These investigations are different from those of the pilot deployment experiments conducted in Work Package 14. The WP14 demonstrators employed the advanced tools and services developed in ARIADNE to demonstrate their innovative capabilities; their results are presented in Deliverable 14.2. Compared to these most WP17 case studies intentionally address a lower technological level to align with systems and tools archaeologists are familiar with. Furthermore, different archaeological subjects have been chosen to cover together a wider spectrum of subjects.

## Brief overview

This deliverable presents the results of the WP17 study as follows:

*Chapter 3 – E-Archaeology Frameworks*: This chapter addresses basic elements of e-archaeology frameworks which include the general research and data lifecycles. In the last decades the cycles have become ever more supported by digital tools and services, so that e-research frameworks have emerged. Where digital means have been developed or specialised for use by particular disciplines or research specialties we can speak of specific e-research frameworks, e.g. e-archaeology frameworks. The chapter also identifies differences e-archaeology and other "digital humanities" which should be taken account of in the development e-research environments for these disciplines as well as for cross-/multi-disciplinary e-research.

*Chapter 4 – Virtual Research Environments (VREs):* This chapter looks into the definition and development of VREs since the 1990s, including taxonomies of different types of VRE and research activities they may support. Furthermore, a section on the current state of development and use of VREs in the field of archaeology is included.

*Chapter 5 – Case Studies:* This chapter presents several case studies corresponding to different e-archaeology settings and approaches, however with existing or emerging e-research environments as a common perspective. The case studies cover a wide range of e-archaeology subject matters, including archaeological methodology, archaeological ontologies, archaeological research infrastructure and VREs at the national level, geo-physical surveying, 3D archaeology, physical anthropology and archaeobotany.

*Chapter 6: Conclusions and recommendations:* Summarises the overall conclusions of this report, taking account of the results concerning e-archaeology frameworks, virtual research environments, and the related thematic or domain-focused case studies. The recommendations given are meant for the ARIADNE network, closely related and other organisations in fields such as e-infrastructure, data repositories and other service providers which are interested in the development of e-research/ science environments, tools/services and data resources.

*Chapter 7: Literature and web-based sources:* The chapter lists the references for chapters 1-4 and 6, as well as includes publications of general interest referenced in the case studies. All references of the individual case studies are given in the respective sections of chapter 5.

Please note that links for websites of important organisations, projects and other sources are not given in footnotes but included in the lists of references.

# 3 E-Archaeology Frameworks

This chapter addresses basic elements of e-archaeology frameworks which include the general research and data lifecycles. In the last decades the cycles have become ever more supported by digital tools and services, so that e-research frameworks have emerged. Where digital means have been developed or specialised for use by particular disciplines or research specialties we can speak of specific e-research frameworks, e.g. e-archaeology frameworks. The chapter also identifies differences e-archaeology and other "digital humanities" which should be taken account of in the development e-research environments for these disciplines as well as for cross-/multi-disciplinary e-research.

## 3.1 E-Archaeology

A core term throughout this report is "e-research", which basically means the use of web-based digital data, tools and services for research purposes. We prefer "e-research" to "e-science", because the latter term carries with it notions mainly of data-centric computational methods with a focus on quantitative/mathematical analysis. E-research is more inclusive of a variety of research approaches and methods. Thus the variant "e-archaeology" stands for the use of web-based digital data, tools and services in archaeological research for any quantitative and/or qualitative research methods.

It can be said that today all archaeologists are "e-archaeologists", because they generate various digital content with software tools, publish information on project websites and professional platforms such as Academia.edu, and communicate with colleagues directly using e-mail, skype and other services. But in this study we are looking for something more integrated, which supports ICT-based collaborative research work, i.e. a Virtual Research Environment (VRE).

E-archaeology may be subsumed under the "digital humanities", although digital archaeology has its own disciplinary challenges and some different characteristics (cf. Huggett 2012a/b). Indeed, there are significant differences between archaeological and other humanities e-research practices. For example, digital humanities scholars mostly work with cultural content from archives, libraries and museums, while archaeologists produce most of their data themselves. This includes field and laboratory work, with methods and tools typically not used in other humanities, e.g. data capture and analysis methods such as terrestrial laser scanning and chemical analyses of micro-remains.

We note, however, that there are also some commonalities or overlaps between historical humanities and archaeology. These can be found where researchers work with historical content (e.g. archival records) *and* analyses of material remains, i.e. in some fields of the Classics, Medieval History/Archaeology, or Historical Archaeology (the term used in the United States for more recent historical periods).

But existing differences are essential when it comes to specific e-research frameworks, data and tools afforded by the research in different scientific disciplines and specialities. For example, environmental archaeologists may need a set of tools which help them aggregate, visualise and analyse data on ancient vegetation and land use, whereas a research environment for classical studies could help researchers to create a digital scholarly edition of ancient texts. Therefore, essential differences between e-archaeology and other digital humanities are discussed further below. The next sections first address common basic elements of e-research.

## 3.2 Basic E-Research Frameworks

Under basic research frameworks we subsume the general research process (or lifecycle) and the related data lifecycle. In the last decades the cycles have become ever more supported by digital tools and services, so that e-research frameworks have emerged. These e-frameworks comprise of digital means (i.e. services/tools) that are generic and used by researchers of all disciplines and elements which may be specific for one or a few disciplines. Where digital means have been developed or specialised for use by particular disciplines or research specialties we can speak of specific e-research frameworks, e.g. e-archaeology frameworks.

### 3.2.1 Research Process/Lifecycle

The research process comprises of the steps from a project idea to the publication of the final results, including the research data lifecycle (see below). Furthermore, there are many related activities, for example reporting of project financials and outcomes to funders, or use of project results in research -based education and training, which are not addressed here.

In the empirical disciplines the research process in general comprises of the following steps, which nowadays are all supported by digital means that are generic or have been adapted or developed for carrying out research tasks more effectively or in novel ways. The latter may range from tools that are being used by researchers of many disciplines (e.g. GIS) to only one project (e.g. a software or algorithm developed for a particular research problem):

- *Identification and formulation of the research problem:* In this step the researchers take account of the state of knowledge in their field/s of research, i.e. the current literature and own previous research, and seek to identify a problem that is worth and possible to tackle. The specific research problem is being formulated, including the objectives, hypothesis etc. which will largely determine the appropriate methodology.
- *Definition of the research methodology and design:* In this step the empirical approach to address the research problem is being defined and designed, including the tools, procedures, data sources, and other means required for carrying out the research.
- *Data acquisition and organisation:* This step concerns the acquisition of the data with particular tools and may also include re-use of data from previous own or other projects. The data is being organised (e.g. in a database) and may need dedicated management if the research process extends over a long period.
- *Data processing, analysis and interpretation:* In this step the data is being processed and analysed with appropriate tools and procedures (e.g. statistical analysis, simulations, etc.). The results are scrutinized and interpreted (i.e. if they confirm hypotheses), including comparison to results of other investigations, and conclusions drawn about what new knowledge they provide about the research problem addressed.
- *Publication of the research results and data:* Finally, the results of the investigation are formally published, including review by other researchers, and become part of the scientific record and state of knowledge in respective field of research. Increasingly this also includes making available the data which underpin the published research results through a publicly accessible repository, allowing for re-use of data for further research.

In different empirical disciplines and specialities, the research approaches differ with regard to the methodologies, tools, data, etc. that are being employed to address research questions. Some disciplines and research specialities also have characteristics which they do not share with many others. For example in archaeology, in particular, excavation projects, the research process can extend over several excavation campaigns hence take many years. More importantly, excavation projects involve research methods and results of different specialties, which need to be combined to arrive at solid conclusions about the past communities, cultures and lifeways whose material remains and traces are preserved in the so called archaeological record of sites.

### 3.2.2 Research Data Lifecycle

The research data lifecycle concerns the "active" phases of data in the research process, those phases in which the data is being generated and/or existing data re-used, processed, interpreted, presented and used for underpinning publications. The lifecycle thus concerns the whole process from data acquisition to products such as tables or charts in publications.

The research data lifecycle largely overlaps with the research process model, and is often presented as identical, but there are some important differences. Firstly, the data lifecycle does not include the research design phase, except where re-use/purposing of available data is considered. Secondly, the research process does not necessarily include data archiving for long-term curation and access for everybody. As available data are an asset, researchers keep it, re-use/purpose it in new projects, also sometimes share data directly with close colleagues. But such "active data" does not require depositing it in a data archive, including preparation and description (metadata), so that it can be preserved and made available by the archive. Furthermore, the research process includes essential activities which do not necessarily involve data, communication between project partners, for instance.

Models of the research data lifecycle presented from an archival perspective, such as the model of the UK Data Archive (Figure 1), introduce and emphasise (their) phases and tasks of long-term preservation of and giving access to deposited research data. This has an "educational" function because digital archives of course do play an important role in an extended research data lifecycle.

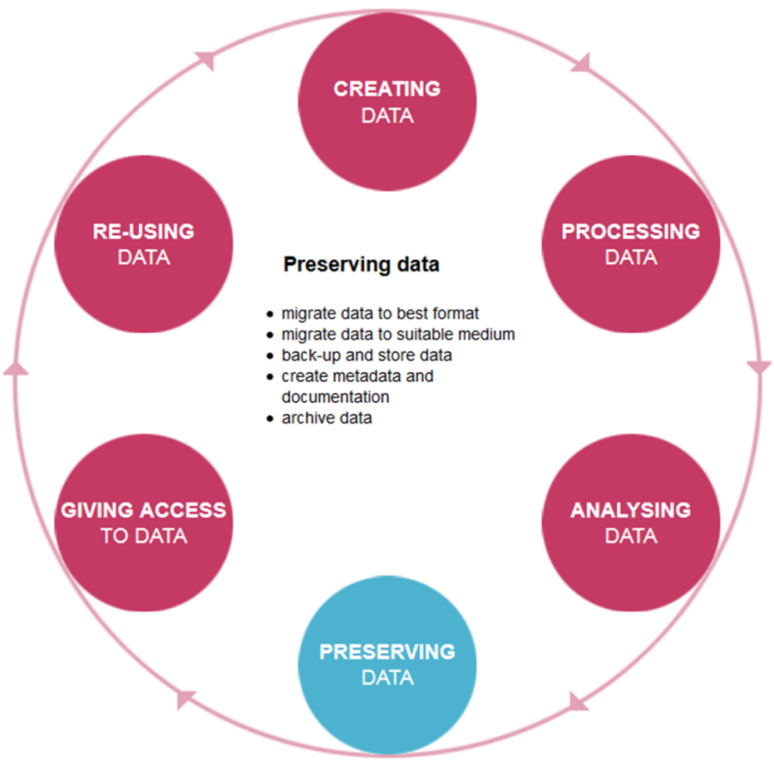


*Figure 1. Research data lifecycle. UK Data Archive (n.y.). http://www.data-archive.ac.uk/create-manage/life-cycle*

Archives set up to ensure long-term curation of data are essential for several reasons. These include, but are not limited to, that archives prevent loss of valuable data and make it available for further use. Preserving and providing access to data is particularly important in archaeology, where excavations destroy the primary evidence. Therefore, archaeologists have a strong responsibility to share collected data with the research community to enable further research, for example, asking new questions from combined datasets.

Through long-term curation digital archives make an extended "active life" of data possible. Some data lifecycle models understand also researchers as curators, for example the model promoted by the Digital Curation Centre UK (Higgins 2008; Ball 2012 compares it to other models). One basic idea of all models is that the data should finally be deposited, well described, in a digital archive. But excavation projects often take many years, if not decades, therefore data curation is essential already during the research process.

Some projects have looked into researchers' data curation practices with the aim to develop approaches and tools that may enhance data practices. For example, the Data Curation Profiles project (2008-2012) studied such practices extensively. The project invited researchers of several disciplines to document how they work with data, different forms and stages of data, tools used, and what they consider as sharable forms of data in their field of study (Cragin *et al*. 2010; Witt *et al*. 2009). Researchers of ARIADNE partner Athena RC (Digital Curation Unit), have proposed an extended digital curation lifecycle model (Constantopoulos *et al*. 2009). Also, they worked with humanities researchers to better understand their digital curation requirements (e.g. Benardou *et al*. 2010). Dallas (2015) considers the curation of archaeological knowledge "in the digital continuum" as a grand challenge of digital archaeology.

## 3.3 Specific E-Archaeology Frameworks

Having established some basic elements of e-research frameworks, we now ask if there are any e-archaeology specific aspects. Archaeology studies past cultures based on their material remains. Therefore, the discipline is generally subsumed under the humanities. However, archaeology is a multi-disciplinary field of research that involves researchers, especially finds experts with different disciplinary backgrounds who identify and analyse physical and biological remains such as ceramics, metals, bones, plants, etc. These experts come from different research specialities (e.g. zooarchaeology in the case of animal bones), each with their own subject knowledge and methodologies.

Moreover, the material remains of past cultures include objects such as cuneiform tablets, papyri, inscriptions, art works and others that are studied by scholars of ancient languages, literatures, religions, philosophies, etc. In turn, these can contribute to the interpretation of archaeological sites. Hence, there is the question of where to draw the line and focus on e-archaeology frameworks and their methods, tools and data, thereby avoiding less relevant fields of research.

In the sections that follow, first we address archaeology as a multi-disciplinary field of research, and then point out important differences (and commonalities) between archaeology and humanities disciplines not or only occasionally involved in archaeological research. The identified differences can help distinguishing between e-research frameworks, and to take them into account in the development of digital research environments for different disciplines.

### 3.3.1 Archaeology as a Multi-Disciplinary Field of Research

The classical "tree of knowledge" model splits the scientific and scholarly knowledge into different branches (i.e. natural sciences, social sciences, arts & humanities), major disciplines within these branches, and the disciplines into sub-disciplines and research specialties. In the development of e-research infrastructures it is very important to take account of differences between disciplines with regard to research practices. Archaeology poses a challenge because it is a multi-disciplinary field of research, in which theoretical concepts, models and methods from different branches of knowledge are being used. Sinclair (2014) provides a visualisation of the multi-disciplinary map of archaeological research.

Archaeology covers several fields of the humanities as well as has close ties with the applied natural sciences and other disciplines. In a volume of papers on "Archaeology 2.0", Eric C. Kansa notes: *"Archaeology is an inherently multidisciplinary enterprise, with one foot in the humanities and interpretive social sciences and another in the natural sciences. As such, case studies in digital archaeology can help illuminate changing patterns in scholarly communications across a wide array of disciplinary contexts"* (Kansa 2011: 2). With regard to the natural science component of archaeology Degryse & Shortland (2013) highlight that "*there are very few sciences that have no relevance to archaeology"*, and see an increasing influx of scientific methods in archaeological research.

Archaeology indeed comprises of different disciplinary fields of research, where some fields present mainly characteristics of the humanities (e.g. history of arts and architecture, classical studies, medieval history), others lean heavily towards the natural sciences and employ methods of archaeometry or biological sciences, others relate to the earth & environmental sciences, while still others use models and methods of the social sciences (e.g. models of social structure and ethnological methods, for instance).

The paradigmatic case of multi-disciplinary archaeological research is excavation projects. These projects are carried out by teams involving the excavating archaeologists and finds experts of different specialities who identify and analyse physical and biological remains such as ceramics, metals, bones, plants, etc. They all contribute to the interpretation of archaeological sites, but their work requires different subject knowledge and methodologies.

Archaeological excavation projects thus are essentially team-based and multi-disciplinary. There has been (and still often is) the classical figure of the lead archaeologist at a site ("his/her site"). Also traditional divisions are still present, for example between field and lab, excavators at the site and specialists working remotely, sending reports to the lead archaeologist.

Killick (2015) describes the traditional model and its erosion in recent years as follows: "*The old model of site excavation resembled a wagon wheel, with the principal archaeologist (site director) at the hub, a ring of specialists around the rim, and the spokes of the wheel representing the separate two-way communication between the site director and each specialist. Today the specialists often need to communicate directly with each other to do their job – for example, the archaeometallurgist needs the geologist to identify ore samples, the botanist to identify charcoals, the lead isotope specialist to distinguish local from exotic metals. Synthesis and interpretation today tends to be made by teams rather than by the site director. Trends in publication reflect this tendency; scientific studies now tend to be published separately rather than included as dry appendices in the site monograph, as used to be the case"* (Killick 2015: 170).

First efforts towards VREs for archaeological excavations (e.g. the VERA project) aimed to make the traditional model more effective. However, as Killick's describes, archaeological has become less centralised (around the principal archaeologist) and there is a need to support the interaction between researchers of different specialities. Moreover, different specialties could benefit from having specialised VREs which support their research specifically. Concerning such VREs it should be noted that researchers who serve as finds experts are also scholars in their specialties. These scholars seek research results, often derived from work at different sites, which are of particular interest to their own specialty, for example, physical anthropology or archaeobotany.

This suggests a need for two types of collaborative e-research solutions: a) a VRE that allows bringing together, integrate and interpret (synthesise) the results of the different investigations on a site, and b) VREs for researchers in specialities that are specialised for their particular data (incl. data standards, terminology) and include services/tools for the identification, description and analysis of their finds (e.g. access to reference collections for the identification of finds). Importantly, both should be developed in view of wider range investigations (i.e. beyond individual sites) based on sharing of the collected data through domain e-research infrastructures (i.e. ARIADNE).

### 3.3.2 E-Archaeology and/vs. Digital Humanities

In a comparison of archaeology and humanities disciplines not or only occasionally involved in archaeological research we identified important differences and significant commonality with regard to digital practices. These can help to distinguish e-archaeology frameworks from others and to conceive environments for e-research of scholars in different disciplines.

#### Contexts of work

With regard to contexts of work, the difference between humanities studies and archaeological research is rather clear. Humanities studies are mainly an activity of academics with few external constraints except getting access to relevant content, which is being held and increasingly digitised by archives and museums. In contrast, work in archaeology is conducted in contexts which include governmental administrations, national heritage agencies, infrastructure development companies, and commercial archaeology services (contract archaeologists). Excavations are subject to regulations, requires permit, entail reporting duties, etc.

While most researchers in the humanities and certainly "digital humanities" would not agree to the image of the "lone scholar", in archaeology research teams are common practice. Importantly, in research on archaeological sites these are interdisciplinary teams involving excavators, finds experts, laboratory-based researchers, data managers, and others.

Jeremy Huggett (2012b) sees few relations between e-archaeology and the "digital humanities": *"From an archaeological perspective, a relationship between Digital Archaeology and Digital Humanities is largely absent and the evidence suggests that each is peripheral with respect to the other"*. He notes that e-archaeology does not need the digital humanities for legitimacy and support because archaeology builds on its own arsenal of research approaches, including many well-established digital methods and tools.

One example Huggett analyses is the use of Geographic Information Systems (GIS) by archaeologists compared to which *"DH [digital humanities] applications of GIS can seem very limited, even simplistic, to archaeological eyes in that they often seem to focus on interactive hypermedia visualisation with little use of GIS analytical tools"*. Even better examples are data capture, processing and visualization tools which are essential for archaeological, but not other humanities research, e.g. terrestrial laser scanning or photogrammetry and software for the creation and visualization of 3D reconstructions of buildings and landscapes.

#### Different Research Paradigms

Most "digital humanities" research is informed by paradigms of textual and visual studies of historical and modern cultural content. Archaeologists instead focus on the material remains of past cultures and their traces in the environment, including remains such as biological material, artefacts, built structures as well as traces in the landscape (e.g. agriculture, routes between places, etc.). Accordingly, the paradigms and tools for "reading" the remains and traces are very different from textual analysis and other humanities studies of cultural content.

Textual information plays a significant role in archaeology only for cultures and periods for which such information exists (e.g. cuneiform tablets, papyri, epigraphy, historical manuscripts). When considering texts, many archaeologists would first think of maybe available reports of fieldwork already conducted at a site, nearby or in the region. As Stuart Dunn elaborates, *"Texts occupy an important place in archaeological research, chiefly in the form of so-called grey literature reports of excavations, which are often the only extant records of those excavations, along with secondary literature and publications. But the bulk of primary archaeological excavation data comes in the form of numeric, graphic, statistical, and formal descriptions of the material record"* (Dunn 2011: 95).

On the other hand, material objects and traces of past cultures as studied by archaeologists usually are *"not among the standard resources of academic research in the humanities and social sciences. Historians are used to dealing with literary sources, and all our sophisticated methodology focuses on the investigation of these. Meanwhile, we observe the march of images into the historian's study, but physical objects are still mostly kept at arm's length"* (H.O. Sibum in Auslander *et al*. 2009: 1384).

But there are some commonalities and overlaps between archaeology and historical humanities, for example in some research fields of the Classics (Babeu 2011), Medieval History (Graham-Campbell & Valor 2007; Carver & Klápště 2011), and Historical Archaeology, i.e. the post-Columbian history of the Americas (Hall & Silliman 2006; Mehler 2013).

The overlaps can be found where humanities scholars work with texts *and* evidence for certain historical developments drawn from material such as sculptures and architecture, or more mundane objects of ancient everyday life. The overlap is particularly clear between archaeological research and classical studies, and also the adoption of information technologies in specialties of the Classics is particularly high. The Digital Classicist wiki documents over 300 projects that employ ICT for ancient and classical research.

Alison Babeu (2011) gives an excellent overview of the field of "digital classics". She characterises it as an interdisciplinary field of research which includes (digital) classical archaeology, philology of ancient Greek and Latin texts, epigraphy, papyrology and manuscript studies, numismatics, classical art and architecture, ancient world geography, and others – each with their own objects of study and research methods. Many of the projects concern the collaborative development of digital resources and scholarly editions of classical content.

## Different Data and Tools

E-research practices of humanities scholars have been investigated in studies on the actual use of digital tools and data in different fields (e.g. Benardou *et al*. 2010; Research Information Network 2011; Rutner & Schonfeld 2012; Svensson 2010). One significant difference between archaeology and other humanities disciplines are the "data" that are being used.

Scholars in the so called digital humanities use mainly cultural content, e.g. literary texts, paintings, photographs, music, films, etc., most of comes from collections of libraries, media archives and museums. Without the massive digitisation of and online access to this cultural heritage content, and novel tools for studying, annotating and interlinking of various content (and pieces thereof), the recent boom of digital humanities scholarship would not have been possible.

In contrast, archaeologists generate most of their data themselves, various data produced in surveys, excavations, laboratory analyses of physical and biological finds, etc. The array of data also includes data from specialised laboratories which serve archaeologists among other clients (e.g. synchrotron facilities or sequencing labs with regard to ancient DNA). Furthermore, data not produced but used by archaeologists (if affordable) are airborne or satellite remote sensing and imaging data. Some field surveys and archaeological excavations amass large volumes of various data, but not "big data" like the volumes of continuously collected data from environmental sensors or generated by high-throughput DNA sequencing technologies.

Archaeologists and other humanities scholars need appropriate solutions for handling, bringing together and studying their data/content. In archaeology this often is a Geographic Information

System (GIS) on top of a database of geo-referenced digital content. In other fields of the humanities scholars may work with a large amount of high-resolution images or audio-visual material. Therefore, the scholars could benefit from using advanced e-infrastructure and tools. Rather than for massive computation, in the first place they would need it to store, manage, remotely retrieve, load and visualise the material (e.g. juxtaposed display of images). Then comparison, transcription, annotation and other work typical for scholarship in the humanities can begin, with specific tools for these tasks. For example, Ainsworth & Meredith (2009) and de la Flor *et al*. (2010) describe prototypes for working with high-resolution images of ancient and medieval manuscripts.

Many "classic" digital humanities products are so-called digital scholarly editions, one or a few richly annotated cultural works (Cayless *et al*. 2009; Porter 2013; O'Donnell *et al*. 2015) or a database of hundreds or thousands of objects, including images, translations, literature references, etc. For example, the Epigraphic Database Heidelberg documents about 74,000 inscriptions. Archaeologists do not create such works, but maybe look up an epigraphic database to compare a newly found inscription and contribute an image to the database. Indeed, the need to identify new finds by comparing them to specimens of reference collections is one essential commonality among researchers in different specialities of archaeology and other humanities.

### Little Usage of Advanced Computation

One commonality of the digital humanities and archaeology is that researchers seldom employ advanced computation for their research. There has been much debate about the question if e-infrastructure for advanced data processing and computation as developed for some natural science and engineering disciplines can be adjusted to the needs of the humanities. In the debate, most representatives from the humanities hold that scholarship in these disciplines affords different solutions than "heavy" e-infrastructure for massive Grid or Cloud based computing. A common view is that innovation in the digital humanities may be better promoted by in comparison small scale but highly research-focused IT applications (e.g. Svensson 2010; Wouters & Beaulieu 2006; van Zundert 2012).

The limited use of advanced computation as offered by Distributed Computing Infrastructures (DCIs) by humanities researchers supports these assumptions. DCIs provide a so called "Science Gateway" to (mostly) Grid-based e-infrastructure and software applications for data processing, storage and transfer. User groups can share data resources and computing applications (i.e. virtual machines) and, thereby, form a virtual research community. The leading promoter of DCIs is the EGI.eu - European Grid Infrastructure.

The DCI providers have sought to expand their user base, not least to legitimate the high investments in Grid and high-performance computing. But the demand for DCI has been limited in many disciplines as yet, especially in the humanities. One exception is research groups that need to process large corpora of texts, and there are some other examples which demonstrate potential for wider usage. For example, in the "Digging into Data Challenge" program several humanities projects are present (http://diggingintodata.org).

Major impediments to using DCI in archaeology arguably are the diverse and complex types of datasets, lack of consistent data structures, and incomplete, isolated and often not openly available data sources (cf. Hedges 2009). However, some progress may be achieved at the level of metadata. For example, one project of the Digging into Data Challenge was DADAISM - Digging into Archaeological Data and Image Search Metadata. The project developed search and retrieval procedures for large volumes of images and grey literature.

In recent years, as a response to market developments and user demand, DCI providers have included Cloud services in their offering (Curtis+Cartwright 2010; EGI-InSPIRE 2011; e-IRG 2012). Indeed, many research institutions and projects may be attracted by (academic) Cloud services for a variety of purposes. Reliable and affordable Cloud services could be a solution to many problems of resource-poor institutions and collaborative projects. The services could allow them minimize the effort needed for local management of technology, repository/collection related tasks, as well as the need for dedicated technical staff, that are often not available. These expectations however may underestimate factors such as still required technical knowhow, mandatory control over own or third-party content, and others. In any case, adoption of Cloud-based services, in particular, content management & curation systems, requires high trust of users in the service provider.

Finally, we briefly address High Performance Computing (HPC). HPC means advanced computing facilities and services based on supercomputers. In Europe the field of HPC is represented by the Partnership for Advanced Computing in Europe (PRACE), which provides access to several HPC systems. A few years ago PRACE issued their report "The Scientific Case for HPC in Europe" (PRACE 2012). The PRACE expert panels for this report covered the same HPC application areas as a white paper of the European HPC in Europe Initiative/Taskforce in 2007. The five areas are: Weather, climatology and solid earth sciences; Astrophysics, high-energy and plasma physics; Materials science, chemistry and nanoscience; Life Sciences and medicine; and Engineering sciences and industrial applications. Thus "the scientific case" in 2007 and 2012 did not include the humanities, social and economic sciences; there is no mention of these disciplines, for example, why they may not need HPC.

In summary, the primary needs of humanities researchers with regard to e-research tools and services clearly concern other activities than processing of large volumes of texts, images or numeric data. Such activities for example are to search & retrieve, handle, decipher, compare, translate, describe, annotate and link together digitised cultural objects. The variety of such scholarly digital practices is described in schemes of so called "scholarly primitives" (see *Section 4.4.3*).

While we see little relevance of massive data processing and computing in the humanities, we note an increasing recognition that the opposition of qualitative vs. quantitative analysis, close reading of individual vs. processing of large corpora of texts, individual stories vs. impersonal statistics graphs is unproductive (cf. Anderson & Blanke 2012).

## 3.4 Summary of E-Archaeology Frameworks

### E-Archaeology

In this study e-archaeology basically means the use of web-based digital data, tools and services for research purposes. E-archaeology may be subsumed under the so called digital humanities, however has its own disciplinary challenges and some different characteristics. The study includes an analysis of significant differences which should be taken account of when developing environments for e-research of humanities scholars or archaeologists.

### Basic E-Research Frameworks

Under basic research frameworks we subsume the general research process (or lifecycle) and the related data lifecycle. In the last decades these cycles have become ever more supported by digital tools and services, so that e-research frameworks have emerged. Where the digital means have been developed or adapted for particular disciplines or research specialties we can speak of specific e-research frameworks, e.g. e-archaeology frameworks.

#### Research Process/Lifecycle

The research process comprises of the steps from the identification of a research idea/problem to the publication of the final results, increasingly also the data that underpins the published research.

In different empirical disciplines and specialities the approaches for addressing research problems differ with regard to the methodologies, tools, data, etc. that are being employed to address research questions.

Archaeology, in particular, excavation based research projects, involves research methods and results of different specialties, which need to be combined to arrive at rich and solid conclusions the site. The development of e-archaeology frameworks and environments needs to take account of this multi-disciplinarity of archaeology.

### Research Data Lifecycle

The research data lifecycle concerns the "active" phases of data in the research process, those phases in which the data is being generated and/or existing data re-used, processed, interpreted, presented and used for underpinning publications. The lifecycle thus concerns the whole process from data acquisition to products such as tables or charts in publications.

The research data lifecycle largely overlaps with the research process model, and is often presented as identical, but there are some important differences. Firstly, the data lifecycle does not include the research design phase, except where re-use/purposing of available data is considered. Secondly, the research process does not necessarily include data archiving for long-term curation and access for everybody. However, this is essential as it can keep extend the "active" life of data through re-use.

Archaeological excavation projects often take many years, if not decades, therefore data curation is essential already during the research process. As excavation destroy the primary evidence archaeologists have a strong responsibility to share collected data with the research community to enable further research, for example, asking new questions from combined datasets.

## E-Archaeology vs/and Other Digital Humanities

A comparison between e-archaeology and other digital humanities shows some significant differences and commonalities:

- Most digital humanities research is informed by paradigms of textual and visual studies of historical and modern cultural content. Archaeologists instead focus on the material remains of past cultures and their traces in the environment, including remains such as biological material, artefacts, built structures as well as traces in the landscape.
- Digital humanities scholars mostly work with digitised cultural content from libraries, archives and museums; (e.g. literary texts, paintings, photographs, music, films, etc.). Archaeologists produce most of their data themselves, carried out in field and laboratory work with methods and tools typically not used by other humanities researchers (e.g. terrestrial laser scanning or chemical analysis of materials).
- Some overlaps between archaeology and other humanities exist where researchers use textual content (e.g. historical manuscripts) *and* analyses of material remains, for example Medieval Archaeology & History, but also earlier periods (except of course prehistory).
- Material remains of past cultures include objects such as cuneiform tablets, inscriptions, art works and others that are studied by scholars of ancient languages, literatures, religions, philosophies, etc. In turn, these can contribute to the interpretation of archaeological sites.
- Both e-archaeologists and digital humanities scholars need appropriate solutions for collecting, handling, bringing together and studying their data/content. But, except generic technologies such as databases, the digital tools and products are different: Typical digital humanities products are scholarly editions (e.g. of literary works), which require tools that support tasks such as transcription, translation, annotation, and interlinking. Typical for e-archaeology is GIS based integration of data of sites or virtual reconstruction of ancient buildings.

- A common need is reference collections that allow comparison and identification of cultural products (e.g. pottery) or natural specimens (e.g. remains of plants).
- Another commonality is the little usage of advanced computation based on Grid-based Distributed Computing Infrastructures (DCIs) and supercomputers of High Performance Computing (HPC) centres.

The identified differences (and commonalities) allow basic distinctions between e-archaeology and other digital humanities and should be taken account of in the development in the development of environments for single discipline (or sub-domain/specialty) as well as cross-/multi-disciplinary e-research.

### Enabling Multi-Disciplinary E-Archaeology

Archaeology is a multi-disciplinary field of research that involves researchers, especially find experts, with different disciplinary backgrounds and research questions. They all contribute to the interpretation of archaeological sites, but their work requires different knowledge, methods and tools, for example, to identify and analyse physical and biological remains such as pottery, metals, bones, plants, etc. Therefore, we see a need of two types of collaborative e-research solutions:

- An environment that allows bringing together, integrate and interpret (synthesise) the results of the different investigations on a site, of the core team of archaeologists/excavators and of the different finds experts who work at the site and/or remotely. Typically, such an environment will build on a relational database and GIS, a data model covering the excavation grid, different features, stratigraphic layers, and types of materials/finds (i.e. sediments, soils, bones, plants, pottery, metals and others).
- Environments for researchers in specialities (e.g. physical anthropology, archaeobotany and others) that are specialised for their particular data (incl. data standards, terminology) and include services/tools for the identification, description and analysis of their finds (e.g. access to reference collections for the identification of finds).

Both environments are essential for collaborative generation of research results, in the context of archaeological excavations and the research of archaeological specialities. The environments should be developed in view of wider range investigations (i.e. beyond individual sites) based on sharing of the collected data through domain e-research infrastructures, i.e. ARIADNE.

# 4 Virtual Research Environments

## 4.1 Introduction

Virtual Research Environments (VREs) are web-based environments that provide research communities with tools, services and data resources which they need to carry out research work online. The ARIADNE data infrastructure allows discovery of and access to data across distributed digital archives. The rationale for a focus on VREs is that archaeological researchers in addition to data search and access need services and tools that allow them carrying out research tasks online.

Therefore, VREs will be one next step in the development of the ARIADNE e-infrastructure. VREs implemented on top of the e-infrastructure would support researchers in archaeology and other heritage sciences with specific services/tools for working with different types of data (e.g. numeric data, images, 3D models). Such VREs may range from loosely coupled services/tools and data resources to tightly integrated workbenches and databases for specific research communities. The current ARIADNE project is not charged to develop VREs, but can prepare the ground and present some prototypic examples in order to promote further development.

The development of e-research environments has been driven by a scientific enterprise that has become ever more collaborative, distributed and data-intensive (cf. Wuchty & Uzzi 2007; Frenken *et al*. 2010; Riding the Wave 2010; Llewellyn-Smith *et al*. 2011). Consequently, there is an increasing need in all disciplines to enable sharing of data resources, tools and services over e-infrastructures, aimed to support online team-based and cross-domain/disciplinary collaboration. For the online environments which allow such collaboration the term Virtual Research Environments (also VR Community or Collaboratory) is being used.

The topic of VREs has been around since several years and addressed by many study reports, research papers and edited volumes. Some noteworthy examples are Allan (2009), Candela *et al*. (2013), Carusi & Reimer (2010), Dutton & Jeffreys (eds., 2010), eResearch2020 (2010), Hine (ed., 2006), Juan *et al*. (eds., 2012), Jankowski (ed., 2009), Olson *et al*. (eds., 2008); Voß & Procter (2009), Wouters *et al*. (eds., 2012).

Indeed, a lot of research has already been carried out to conceive, develop and implement virtual research environments. There is also a larger number of publications on such environments for scholars in the humanities, for example Anderson *et al*. (2010), Babeu (2011), Blanke *et al*. (2010), Borgman (2009), Deegan & McCarty (eds., 2012), Dunn & Blanke (2009), Kansa *et al*. (2011), Svensson (2010).

With regard to the essential collaborative dimension of e-research environments Jirotka *et al*. (2013) point out that the development has often not taken account of the knowledge available in the field of Computer Supported Cooperative Work – CSCW (see also the three special issues on VREs in the CSCW journal: Jirotka *et al*. 2006; Lee *et al*. 2010; Spencer *et al*. 2011).

The following sections look into the definition and development of VREs since the 1990s, including taxonomies of different types of VRE and research activities they may support. Furthermore, a section on the current state of development and use of VREs in the field of archaeology is included.

## 4.2 VRE Definitions

In the United States the Computer Science and Telecommunications Board of the National Research Council promoted scientific "collaboratories" using information technology as early as 1993 (NRC-CSTB 1993). The aim was to establish national research & IT centres as hubs for the collaboration of natural scientists and their computer science counterparts. One example of an established hub is the National Center for Biotechnology Information (NCBI) which provides access to biomedical and genomic information.

Around 2000, as an effect of the rapid spread of the Internet, the concept of IT-enabled research collaboratories had become much broader. Finholt summarised it as, *"Using distributed, media-rich network connections to link people to each other, to facilities, and to information"* (Finholt 2002: 80; cf. Finholt & Olson 2000). In Europe the term collaboratories has been adopted in some countries (e.g. the Netherlands), while in others VRE became popular. In the UK, the dedicated VRE programme of the Joint Information Systems Committee (JISC) started funding projects in 2004.

The often referenced definition of a VRE by the JISC Programme is, *"A VRE comprises a set of online tools and other network resources and technologies interoperating with each other to facilitate or enhance the processes of research practitioners within and across institutional boundaries. A key characteristic of a VRE is that it facilitates collaboration amongst researchers and research teams providing them with more effective means of collaboratively collecting, manipulating and managing data, as well as collaborative knowledge creation"* (JISC 2012). The JISC definition clearly emphasises the collaborative dimension of a VRE.

In recent years, the interest in VREs has become ever more centred on research environments based on e-infrastructures, most strongly in the framework of the EU Research Infrastructures Programme. The latest H2020 call for "e-Infrastructures for virtual research environments (VRE)" (H2020-EINFRA-9-2015) characterises VREs as supporting groups of researchers of a specific scientific community, typically widely dispersed, who are working together in a virtual environment based on e-infrastructure. The e-infrastructure/s would provide ubiquitous, trusted and easy access to services for networking, data access and computing. The development of the VREs should be community-led and employ user-oriented services. Overall the VREs should allow easier discovery, access and re-use of shared and integrated research resources (data from multiple sources, software tools, computing) enabling more effective collaboration and higher productivity of researchers. Also emphasised is that VREs should foster and support cross-/interdisciplinary research.

Eight new projects for VREs of different research domains resulted from the H2020-EINFRA-9-2015 call, including two with a focus on cultural heritage (see *Section 4.3.2*). Each of the funded projects characterises the intended e-infrastructure and VRE/s in similar terms and according to their specific case. Particularly noteworthy is how BlueBRIDGE, a marine science focused project, summarises the key features of a VRE:

- *"i. It is a web-based working environment*
- *ii. It is tailored to serve the needs of a Community of Practice*
- *iii. It is expected to provide a Community of Practice with the whole array of commodities needed to accomplish the community's goal(s)*
- *iv. It is open and flexible with respect to the overall service offering and lifetime*
- *v. It promotes fine-grained controlled sharing of both intermediate and final research results by guaranteeing ownership, provenance, and attribution"* (BlueBRIDGE 2016a/b).

BlueBRIDGE employs the D4Science infrastructure which has been developed specifically for setting up and managing research environments in a "VRE as a service" approach (Candela *et al*. 2014). At present the infrastructure supports mainly projects in fields of biodiversity, fisheries and marine research.

### Summary of Definitions

As a summary of the various attributes of a VRE mentioned in different definitions:

- A VRE is as a web-based collaboration environment that provides an integrated set of services and tools according to the needs of a community of researchers; the set comprises of data, communication and other collaboration support services and tools.
- In general, a VRE is not a stand-alone solution for one project or institution, but based on common e-infrastructure.
- There are some contradictory or at least difficult to fulfil expectations from a VRE, i.e. open vs. controlled, flexible vs. tailored, and domain vs. cross-domain. For example, a VRE for cross-domain research will tend to provide generic services/tools or require much tailoring to support collaborative work on particular, interdisciplinary research questions.

## 4.3 VRE Development

Online environments for collaborative development, sharing and use for research purposes have been created since the 1990s. This section presents results of an analysis of the compilation of information about such projects by the Science of Collaboratories study, and of projects carried out in the frameworks of VRE programmes in Europe, at the national level (Germany, Netherlands, UK) and at the European level.

### 4.3.1 Research Collaboratories

The US-based Science of Collaboratories project (SoC, 2001-2004) collected information about research collaboratories since the early 1990s. Their list contains about 700 projects, including over 50 entries added after 2004, up to 2010. Listed are projects across all disciplines and of various types; the taxonomy SoC used for the different types is described in *Section 4.4.1*. The compilation of collaboratories has a focus on Anglo-American countries, but includes also examples from others (e.g. Germany and the Netherlands), and of course international projects.

About 50 of the collaboratories can be subsumed under digital humanities. They range from the Project Runeberg (started in 1992 and still active), where volunteers create digital editions of classic Nordic literature, to the humanities e-infrastructures DARIAH (various arts and humanities) and CLARIN (language resources and tools), which have been built since 2006.

Many of the projects created digital libraries/collections of historical literature and/or explored the use of text annotation, search and mining tools, including the “e-science” approach of Grid-based data processing. Other projects used various prototypic systems to describe, annotate, link etc. inscriptions, papyri, medieval manuscripts, historical maps, scholarly correspondence or historical newspapers (e.g. some of the VRE projects developed in Germany, the Netherlands and UK).

Other humanities entries on the SoC list are research centres, studios and labs, projects which collected requirements of humanities scholars to use digital resources and tools, projects devoted to individual thinkers, writers and artists, and large online databases, for example, ArchNet (Islamic architecture) and Europeana. Also projects for digital archiving solutions have been put on the list.

Concerning archaeology, only four projects are present. The projects are ArchaeoTools (UK), the archaeology node of the Arts and Humanities Data Service (UK), Transatlantic Archaeology Gateway (UK and USA), and Virtual Environment for Research in Archaeology - VERA (UK). ArchaeoTools, 2007-2009 funded by a UK e-Science Research Grant, was a pioneer in the use of Natural Language Processing and Semantic Web standards and techniques for archaeological information (Jeffrey *et al.*

2008 and 2009). But the project outcome certainly was not an online collaboratory or VRE. The Arts and Humanities Data Service – Archaeology and the Transatlantic Archaeology Gateway are collaboratories aimed to build and share data resources, while the VERA project is the best known example of an archaeological VRE (see *Sections 4.5.5* and *4.5.6*).

### 4.3.2 VRE Funding Programmes and Projects in Europe

In recent years, a major driver of VRE research & development has been dedicated funding programmes in some European countries. In the UK, the JISC VRE Programme started in 2004 and ran until 2011. In the Netherlands, the SURFshare programme (2007-2011) of the SURF Foundation had a Colllaboratories component, but other funders played an equally important role. Among the funding programmes of the German Research Foundation from 2009 to 2015 there was one strand for "Virtuelle Forschungsumgebungen" (VREs). We briefly address the general patterns of these programmes and some exemplary projects.

#### JISC VRE Programme, UK, 2004-2011

In the UK, the VRE Programme of the Joint Information Systems Committee (JISC, 2004-2011) in three phases funded 29 projects (Brown 2012; JISC 2012). The projects produced requirements studies, experimental and prototypic applications and, in the final phase, aimed to broaden the use and embed solutions in actual research practice.

Six projects had a humanities focus, including the VERA - Virtual Environment for Research in Archaeology, which is described in *Section 4.5.6*. The other projects concerned mainly VREs for textual studies. For example, at Oxford University the user requirements definition project Building a VRE for the Humanities (BVREH) was followed by the demonstrator project Virtual Research Environment for the Study of Documents and Manuscripts (VRE-SDM, 2007-2009). The TextVRE project at Kings' College London (2009-2011) aimed to develop a collaborative environment supporting the complete research lifecycle of textual scholarship. The project built on the e-infrastructure of the German TextGrid project (2006-2015). The "rapid innovation" project gMan at Kings' College London (2010) set up and tested a prototypical VRE for Classical studies (papyri and inscriptions) on the e-infrastructure of the EU-funded D4Science project.

As these examples show there has been (and still is) quite some collaboration in VRE research and development across Europe. The JISC VRE Programme ended in 2011, but thereafter two humanities VRE-related projects were funded under the Research Tools part of the JISC Digital Infrastructure Research programme (2011-2013). Increasing Interoperability between Corpus Tools was a highly technical project, while the Histore project aimed to raise the take-up of online research tools amongst historians.

#### DFG VRE Funding, Germany, 2009-2015

Among the funding programmes of German Research Foundation (DFG), the "Virtuelle Forschungsumgebungen" (VREs) strand started in 2009 and ran until end of 2015. In 2016 it became the e-Research Technologies programme. The title of the programme may be misleading, because the focus is not technological research but consolidation and better application and organisation of existing systems, and fostering their wider use in the relevant domain/s. The first call invited proposals concerning the sustainability of research software.

Unfortunately, the GEPRIS database of projects funded by the DFG does not allow spotting all VRE projects funded in the years 2009 to 2015. But it appears that DFG supported more VRE projects than JISC in the UK (29). Already in the first two rounds in 2009 and 2010 DFG funded 22 projects (Schirmbacher 2011); 10 were humanities VRE projects. These concerned art history, literature and cultural studies, history of education, study of religions, early, medieval and recent history, and human geography / cultural landscapes.

No project aimed to build a VRE for archaeological research specifically. Two projects of the closest neighbour, Medieval history, focused on the content annotation aspect. For example, “Virtuelles deutsches Urkundennetzwerk” (2010-2013) built a networking environment for manuscripts archives, including content digitisation, organisation and annotation workflows; the project employed the platform of the EU-funded project Monasterium. In art history, the Meta-Image project (2009-2014) developed the collaborative annotation tools for the Prometheus portal, which connects 88 databases of humanities research centres and museums. One project in the field of human geography, “VKLandLab” (2010-2014), developed a VRE for spatio-temporal research on cultural landscapes, including interfaces for connecting databases and digital libraries, WebGIS, data-tagging, wikis/weblogs, project management, and other components.

The most interesting VRE project with a cultural heritage aspect is the WissKI - Scientific Communication Infrastructure (DFG-funded 2009-12 and 2014-16). The modular VRE is based on Drupal and supports semantic annotation (manual and semi-automatic), integration, and querying of content. It employs the CIDOC CRM as semantic backbone which can be extended with other domain vocabularies (i.e. LIDO for museum objects). The WissKi environment has been applied to cultural heritage collections, digital humanities and biodiversity research use cases. The project provides all of the WissKi components as free and open source software code on GitHub.

It appears that no archaeological research environment has been funded in the VRE programme. DFG’s GEPRIS database allows searching of all projects for infrastructure and systems aimed to support scholarly communication, research data and e-research. In this wide array of ICT applications only two archaeological projects have been funded, in the category “Information-infrastructures for Research Data”: The projects are OpenInfRA, a web-based information system for the documentation and publication of archaeological research projects (Brandenburg University of Technology - Cottbus-Senftenberg, 2011-2016); and the IANUS - Research Data Centre for Archaeology and Classical Studies (funded since 2011). The IANUS project is being coordinated by the German Archaeological Institute (DAI), a member of the ARIADNE consortium.

### SURFshare Programme, Netherlands, 2007-2011

In the Netherlands, the SURFshare programme (2007-2011) of the SURF Foundation had a rather broad focus, including Collaboratories, e-infrastructures, open access publications and data, and others (van der Vaart 2010). Humanities collaboratories were funded in the first funding rounds, 2007-2009.

Virtual Knowledge Studio Collaboratory (1 and 2) was a collaboration on digital scholarship between the Virtual Knowledge Studios in Amsterdam, Maastricht and Rotterdam. The VKS for Humanities and Social Sciences in Amsterdam served as the main hub of the studios until 2010. VKS Amsterdam also hosted the AlfaLab, a joint project of five institutes of the Royal Netherlands Academy of Arts and Sciences (KNAW), which developed digital humanities resources and tools. In 2011 the VKS Amsterdam became the KNAW E-Humanities Group (until 2016), from which emerged the Netherlands Network for Humanities, Social Sciences and Technology (eHumanities.nl).

Hublab (1 and 2) developed a research environment for social and economic historians. This environment was implemented in the second project phase by the Virtual Knowledge Studio Rotterdam employing the Liferay collaboration platform. The Tales of the Revolt Collaboratory at Leiden University developed digital resources and tools for studying the role of memories of the Dutch Revolt for personal and public identities in the seventeenth century Low Countries. The project was continued until 2013 with funding by the Netherlands Organisation for Scientific Research (NWO) and Leiden University.

An archaeology focus had the SURFshare project Enriched Publications in Dutch Archaeology, which explored novel forms of publishing archaeological research results. Project partners were the Journal of Archaeology in the Low Countries (open access e-journal), University of Amsterdam (Digital Production Centre), and the E-Depot for Dutch Archaeology (Adema 2011a/b). The Digital Collaboratory for Cultural Dendrochronology (DCCD) project of DANS and Utrecht University, hosted by the Cultural Heritage Agency, was funded 2008-2011 by the Humanities section of NWO. Since 2010 other European partners joined, and since 2013 some work on the DCCD environment has been carried out within ARIADNE.

### EU Framework Programmes (FP7, H2020)

In the recent EU Framework Programmes the VRE theme has been present in the E-Infrastructures strand of the Research Infrastructures programmes, as "Virtual Research Communities" and "e-Science Environments" in FP7 and "e-Infrastructures for Virtual Research" in H2020. The latter topic corresponds to the increasing interest to develop e-infrastructure based VREs with advanced services and tools for research in and across different disciplines.

From a Research Infrastructures call in 2010 (INFRA-2010-1.2.3), ten Virtual Research Communities projects resulted, but none concerned cultural heritage or archaeology. One example is ViBRANT, the Virtual Biodiversity Research and Access Network for Taxonomy (12/2010-11/2013). ViBRANT developed further the Scratchpads environment which supports distributed groups of biodiversity researchers. Scratchpads could serve as VRE platform for archaeobotanical researchers (see Case Study, *Section 5.7.3*).

In 2011, seven e-Science Environments projects resulted from the call INFRA-2011-1.2.1, also with no project focused on cultural heritage or archaeology. An example of a funded project is BioVeL, the Biodiversity Virtual e-Laboratory (9/2011-12/2014). The project developed data workflows and analysis tools for use cases such as phylogeny, population and niche modelling for species, and eco-systems analysis. BioVel deployed and customised the Taverna/myExperiment and BioCatalogue family of software.

The latest H2020 call for "e-Infrastructures for Virtual Research Environments (VRE)" (H2020-EINFRA-9-2015) led to eight funded projects. Two projects have a cultural heritage aspect: READ - Recognition and Enrichment of Archival Documents aims to make historical manuscripts better accessible and usable for researchers. READ is a follow-up to the tranScriptorium project (FP7, ICT, 1/2013-12/2015). The future READ tools and services will be made available on their Transkribus platform. The second project, VI-SEEM, has use cases of virtual communities in climate, life sciences and digital cultural heritage research, with a focus on researchers in Southeast Europe and Eastern Mediterranean regions.

Considering only VRE projects funded under the Research Infrastructures programmes does not give a full picture of EU funded development of research platforms and tools. Like transScriptorium, the precursor of READ, also other VRE developments have been supported by the FP7 ICT Programme. To give but one example of a successful development, the open source Pundit environment of Net Seven (Italy) originated from the FP7-SME project Semantic Tools for Digital Libraries - SEMLIB (1/2011-12/2012). Pundit allows studying, annotating and linking together humanities research content such as historical documents (Grassi *et al*. 2013). The environment has been adopted by other projects, for example, Digital Manuscripts to Europeana - DM2E (2012-2015) and European Correspondence to Jacob Burckhardt - EUROCORR (2010-2015).

## 4.4 Taxonomies of VREs and Research Activities

To provide some systematics we briefly present two different taxonomies developed for online collaboratories and VREs. Furthermore, taxonomies of so called "scholarly primitives", which are activities common to scholarly work across disciplines, are addressed.

### 4.4.1 A Taxonomy of Research "Collaboratories"

The Science of Collaboratories (SoC) project employed a taxonomy to distinguish between nine categories of projects on their list of research collaboratories (see above). Two categories proved to be not useful, expert consultation and product development. Bos *et al*. (2007) present the other seven categories and discuss related technical and organisational issues.

Table 1 shows their dimensional classification of the categories based on the type of resource to be shared (tools, information, knowledge) and the type of activity to be performed across distance (aggregate, co-create). The latter takes account of the observation that aggregation and organisation of some resources can be done in a loosely-coupled setup, while others require tightly-coupled work. For example, the distinction between a Community Data System and an Open Community Contribution System considers that in the former mainly data is being shared while in the latter efforts toward a common research problem.

| | ***Tools (instruments)*** | ***Information (data)*** | ***Knowledge (new findings)*** |
|---|---|---|---|
| ***Aggregating across distance*** (loose coupling, often asynchronously) | Shared Instrument | Community Data System | Virtual Learning Community, Virtual Community of Practice |
| ***Co-creating across distance*** (requires tighter coupling, often synchronously) | Infrastructure | Open Community Contribution System | Distributed Research Center |

*Table 1: Collaboratory types by resource and activity, Bos et al. 2007.*

The authors hold that, in general, it is more difficult to share knowledge than data or tools, and easier to aggregate than co-create. Furthermore, that each category of collaboration requires different technologies, practices and organisational structures.

### 4.4.2 A Taxonomy of "Virtual Laboratories"

David & Spence suggest a taxonomy of "virtual laboratories" that is meant as useful for distinguishing e-science VREs (David & Spence 2003: 62-65). Around the time when the taxonomy was conceived e-science was understood in the narrow sense of using advanced computing in the natural sciences and engineering disciplines. However, David & Spence considered a wider range of VREs, distinguished by their primary function and activities they enable: community-centric, data-centric, computation-centric, and interaction-centric. Furthermore, they divided each of them up into two sub-categories, using category-specific characteristics.

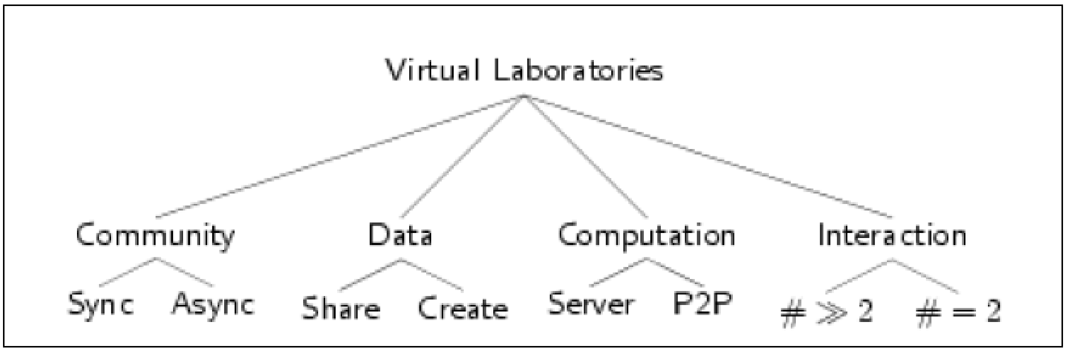


*Figure 2. Taxonomy of on-line collaborative activities, David & Spence 2003: 63.*

The "species" of virtual laboratories can be briefly described as follows.

- *Community-centric:* The primary function is bringing researchers together for collaboration. The two sub-categories are distinguished considering the communication tools the community uses. The category synchronous (real-time), for example, uses chat rooms or a video conferencing tool, the asynchronous category mailing-lists or bulletin boards. An important other characteristic that should be considered is if community membership is open or restricted to a certain group of researchers.
- *Data-centric:* This category concerns data-focused tasks such as generation, management and sharing of data. The sub-categories Share and Create distinguish between "laboratories" which mainly make existing data accessible to researchers (share), or generate new data, including modification, annotation, etc. of existing data (create). Taxonomies of "scholarly primitives" distinguish between many more data/content related tasks (see *Section 4.4.3*).
- *Computation-centric:* The primary function is computer-based processing of data, which in e-science would include high-performance computing. The sub-categories concern the technical question if the computing power is provided to clients centrally (e.g. by a super-computer) via a Server or mobilised from many distributed computers based on a peer-to-peer (P2P) setup.
- *Interaction-centric:* This category overlaps with the synchronous variant of community-centric virtual laboratories, i.e. requires real-time interaction. In addition to communication it involves decision-making or interaction with specific applications (e.g. control of instruments). The sub-categories concern the question how many participants are involved (≥ 2).

David & Spence (2003) applied the taxonomy to 24 pilot projects of the UK E-Science Programme which ran from 2001-2009. Interestingly not the computation-centric but the data-centric category was by far the most populated. In the community-centric category there was only one project, myGrid, which is still alive and their tools (Taverna, myExperiment) are being used by many researchers in the life sciences.

### 4.4.3 Taxonomies of "Scholarly Primitives"

The taxonomies presented above do not address in detail the wide range of activities which may be supported by VREs. This is supplied by taxonomies of so called "scholarly primitives". The term was coined by Unsworth (2000) and means activities common to scholarly work across disciplines, independent of theoretical orientation, e.g. searching, collecting, comparing, etc. (cf. Jessop 2004; Blanke & Hedges 2013). Unsworth referred to humanities scholars' use of digital content/data and tools and the term is being used widely especially in this context. Different taxonomies of "scholarly primitives" are available, e.g. Palmer *et al*. (2009), the Taxonomy of Digital Research Activities in the

Humanities (TaDiRAH), and the NeDiMAH Methods Ontology (NEMO). Below we briefly describe the latter two taxonomies.

### TaDiRAH - Taxonomy of Digital Research Activities in the Humanities

TaDiRAH has been developed 2013-2014 by researchers of the German branch of DARIAH (Digital Research Infrastructure for the Arts and Humanities) and the DiRT - Digital Research Tools directory (Dombrowski & Perkins 2014; Borek *et al*. 2016). The pragmatic purpose of the taxonomy was to improve the discovery of relevant tools in the large DiRT registry, but the work was carried out also in view of potential adoption of the taxonomy by other directory-like websites. The developers took account of available classifications, i.e. the existing DiRT categories of tool functions, the methods part of the extensive taxonomy of research projects of the UK arts-humanities.net (which ceased operation), and the tag-set of DARIAH-DE's "Doing Digital Humanities" bibliography assembled on the Zotero platform. Initial drafts of TaDiRAH were discussed and received suggestions by many community members.

TaDiRAH breaks down the research process (lifecycle) into high-level "goals", each with a set of "methods". The eight top-level categories represent broad goals: Capture, Creation, Enrichment, Analysis, Interpretation, Storage, and Dissemination; in addition there is a "meta" category that includes activities which transcend the others (e.g. "Community Building"). Each top-level category includes three to seven methods, in total 40. In addition to these closed sets of concepts, there are two open lists: one list covers specific research techniques (34), e.g. debugging of software or topic modelling, the other list digital research objects (36), e.g. metadata or manuscript. As an example, the goal Analysis includes the methods Content Analysis, Network Analysis, Relational Analysis, Spatial Analysis, Structural Analysis, Stylistic Analysis, and Visualization. A particular tool, for example the QGIS desktop GIS application could be tagged with the terms Analysis (goal), Spatial Analysis (method), Georeferencing (technique) and Maps (object).

To make available TaDiRAH in a standards-based, machine-readable format, the developers produced a W3C SKOS (Simple Knowledge Organization System) based version, employing an instance of the TemaTres Vocabulary Server. SKOS is being used widely for thesauri and classification systems to support Linked Data. The SKOS version of TaDiRAH is available on GitHub under the Creative Commons Attribution license. It can be browsed online (http://tadirah.dariah.eu/vocab/), and developers may access it through an available TemaTres SPARQL endpoint.

Borek *et al*. (2016) mention some examples of "early adoption" of TaDiRAH. The largest example of actual use is the DiRT directory. Other projects plan to adopt it for structuring their content. Here the largest project is the DHCommons directory of digital humanities projects, which intends to use TaDiRAH in a new project profile schema. Currently this directory documents 779 projects. About 10% are tagged with the keyword "archaeology", 35 only with this keyword while others mainly include "Classics and Ancient History" and "History".

### NeMO - NeDiMAH Methods Ontology

The NeDiMAH Methods Ontology (NeMO) has been developed by the Network for Digital Methods in the Arts and Humanities project (5/2011-4/2015), funded under the Research Networking programme of the European Science Foundation. Experts of ARIADNE partner Athena Research Centre (Digital Curation Unit) had a major role in the development of NeMO. The ontology models research actors and their goals, processes (activities and methods), and resources (content/data, concepts, tools) manifest in scholarly digital practices. The development of NeMO took account of existing taxonomies of scholarly methods and tools, e.g. TaDiRAH and Oxford taxonomies of ICT methods, but had higher ambitions. NeMO is an ontology with defined classes (27) and properties

(42), which means that the semantic relations between the (abstract) entities involved in the modelled scholarly digital practices are formally defined/typed.

NeMO comprises of 27 classes, for example, Actor, Activity/ActivityType, InformationResource/ InformationResourceType, MediaType, Method, Model, Object, Place, Project, Service, Time, Tool, Topic). Furthermore, there are 42 properties, according to the different classes. For example, the class Method has eight properties, e.g. isUsedFor (ActivityType) or isReferencedIn (Information Resource); the class InformationResource has seven properties, e.g. isProductOf (Activity), hasTopic (Topic), hasFormat (MediaType). Concepts of taxonomies are being used at the level of class types, particularly ActivityType (161 concepts), InformationResourceType (106), and Media Types (1531). While inspired by TaDiRAH, the class types are structured in different ways and the taxonomies are more extensive, for example, many concepts of the Oxford taxonomies of ICT methods are being used for Media Types.

NeMO has been implemented based on the W3C RDF Schema (RDFS) specification, with the type taxonomies in W3C SKOS (as TaDiRAH). Furthermore, the ontology is generally compliant with the CIDOC Conceptual Reference Model (CIDOC-CRM). NeMO can be browsed on the website of Athena-DCU (http://nemo.dcu.gr), but there is no information where the machine-readable ontology could be downloaded or accessed via a SPARQL endpoint. A recent paper abstract mentions that SPARQL queries have been run against the ontology, but not if any content has actually been annotated with the ontology (Constantopoulos *et al*. 2016). One use case of the NeMO developers concerns documentation of scholarly research conducted in the course of a synthetic study of the socio-economic history of Classical Corinthia (Benardou 2007; Benardou *et al*. 2015).

### 4.4.4 VREs and Research Workflows

The taxonomies addressed in the previous section can be used to distinguish between different research activities that may be supported by VREs. For example, TaDiRAH breaks down the research process into steps such as data creation, enrichment, analysis, interpretation and dissemination, methods and techniques that are being used in these steps, and various research objects that are being used in or result from the activities. However, the main purpose of this taxonomy is to structure and annotate tools, content and other research items in order to make them better discoverable.

NeMO goes a step further by introducing semantic relations between activities, methods and resources (content/data, concepts, tools) of scholarly digital practices. A further step would be that an ontology such as NeMO can be used to effectively support research workflows. This means that the ontology would underpin ICT applications which suggest, link together, and help carrying out research tasks as a sequence of activities. The NeMO developers do not state this as a goal of the ontology, and such workflow engineering may also be perceived as inappropriate for humanities research, which very much relies on interpretative acts along the research process.

In other quarters of research since about 10 years the application of workflow management systems has enabled much progress in the systematic, IT-supported conduct of research (Curcin & Ghanem 2008; Deelman *et al*. 2009; Talia 2013; Mork *et al*. 2015). Most systems support research processes of the physical and biological sciences, but some are being used also in other domains of research (e.g. Kepler and Pegasus). However, we could not find a use case in archaeological research.

All archaeological research activities in the field and laboratory of course consist of successive activities (workflows), are guided by certain methodologies, and supported by some tools, templates etc. In recent years the use of “paperless”, usually mobile recording applications has become more widespread in field surveys as well as excavations. Users in general report improvements in data collection, processing and availability to team members, but a re-organisation of workflows and (re-

)training of staff is required (cf. Averett *et al*. 2014: 53-55; Caraher 2013; Goodale *et al*. 2013; Motz & Carrier 2012; Wallrodt 2013).

One system that could be characterised as a workflow system for archaeological fieldwork is FAIMS - Field Acquired Information Management Systems (Ross *et al*. 2013 and 2015). FAIMS provides a suite of tools for all stages of the digital data collection and management lifecycle. Clear candidates for applying workflow management systems are also archaeometry laboratories, where such systems could support workflow automation, control of instruments, and capture, storage and management of information obtained in the course of the laboratory work.

One line of research conducted in ARIADNE's Work Package 17 specifically studied work processes which archaeologists carry out when they "do archaeology", the things they create or use, the temporal organisation of the work, different functions/roles involved, etc. Methodological practices of archaeological research partners have been analysed based on their documentation of work. References to methods followed, distinct units and stages of work, producers and things involved, etc. have been extracted and modelled in a situational method engineering approach. The formalized descriptions of methodological practices can be shared and used for different purposes. One scenario is a methodology composer that allows archaeologists to select the methods components they need for a project and assembles them in a VRE which supports their different tasks and workflows.

### Example VRE: A Methodology Composer for Archaeology (CSIC)

It is often said that a good product can only come from a good process. The way in which we do things affects what we produce, be it a document, an idea, or a physical artefact. For this reason, taking care to employ a rigorous and well-known methodology when carrying out research work is paramount. Without a good-quality methodology, the results that we obtain will probably be difficult to validate, reproduce and reuse. Archaeological practice has traditionally worried about this, and the literature contains many examples of what a sound archaeological methodology should look like. However, observation tells us that no comprehensive effort has been attempted so far to reuse methodological knowledge in archaeology in a systematic manner.

#### Reusing Methodological Knowledge

Reusing methodological knowledge has an obvious benefit: it allows us to proceed along lines that have been shown to work well in situations like ours, and discard approaches that have been shown to waste time, be ineffective, or ill-adapted to our needs. In any case, reuse must always occur in a situated context; that is, not every approach is applicable to every situation. On the contrary, each kind of project, theoretical approach, or research line needs its particular methodology. This may seem to mean that archaeologists are condemned to creating custom-made methodologies for each new project they tackle, missing the benefits of reusing well-established knowledge. However, this does not need to be the case.

As described in the case study by CSIC on archaeological methodology (see *Section 5.2*), the discipline of Situational Method Engineering (SME) has long proven that methodological knowledge can be systematically reused and enhanced over time by decomposing good practices into small, self-contained blocks called "method components". A method component may describe what a particular task consists of, what a specific interim product should look like, or what responsibilities a particular role or team is expected to have. A methodology, then, is conceived as an organised collection of inter-connected method components that are selected and assembled for a specific situation such as an archaeological project.

#### A VRE Based on Methodology Composition

A virtual research environment (VRE) based on methodology composition is thus suggested, taking the Situational Method Engineering case study of CSIC as a basis. This VRE would allow an archaeologist to describe the project to be tackled in terms of some variables related to the project itself (e.g. how much time is available), the products to be generated as a result (e.g. what degree of quality assurance they need), and the organisation tackling it (e.g. what skills are present or absent in the team). Once this is done, the VRE would suggest an overall methodological approach, ranging from very simple "waterfall"-style sequence of tasks to a very complex, distributed, parallel project lifecycle. Then, the archaeologist would be able to browse a large catalogue (or "repository") of method components, organised by type (tasks, techniques, documents, models, artefacts, ideas, teams, roles, tools, phases, milestones, etc.), source, reliability or other parameters, and select the components that best fit the project needs and the adopted methodological approach.

Since method components are inter-linked in the repository, the VRE may suggest additional components every time the archaeologist incorporates one to the methodology. For example, the archaeologist may select a particular precision aerial survey technique from the repository. The VRE, knowing that this technique needs qualified specialists to fly the craft, would suggest incorporating them to the team. Similarly, the VRE, knowing that vegetation should be removed from the areas to be surveyed before the flights, would suggest that an additional land clearance task is carried out, accompanied by the necessary timing and personnel requirements. Of course, the archaeologist would always have the last word on what is adopted as part of the methodology and what is not.

Once all the dependencies between method components have been resolved and the archaeologist is happy with the result, the VRE would put the methodology in document format, or in the form of a searchable web site, or distribute it to interested parties in any suitable manner.

During the project, the VRE would continue supporting the project through "just in time" enactment of the methodology. This means that the methodology retains a high flexibility. It is only "enacted" (i.e. actually carried out) gradually and component by component as the necessary conditions are met. At any given time, any team member could view a list of what work is pending and to be tackled. Since the VRE knows the methodology being carried out, and the status of each interim product is kept up to date with it, it would be able to evaluate the relevant dependencies and spot bottlenecks, new needs, and even future issues with the enactment. For example, the VRE would be able to suggest delaying lab work for a collection of samples by two weeks if the necessary excavation and preparation works are not progressing at the expected pace.

Finally, designated team members would be able to provide feedback into the VRE about how well each selected method component is working, and suggest ways to improve it. For example, a task that was not well described, or which was missing an important aspect, can be suggested to be reformulated. In this manner, future projects that adopt that task would benefit from the accumulated previous experience of other archaeologists.

### Major Issues and Requirements

A toolset not too different from the VRE here described was proposed and specified by Gonzalez-Perez and Henderson-Sellers (2008). The major barriers for adoption, which are also expected to play a part in the current archaeological proposal, were the following:

- A sizeable method component repository is needed before this approach can be useful. Developing a comprehensive repository is expensive and time-consuming; please see CSIC's case study in the next chapter for details.
- Specialised software tools must be constructed in three areas: repository construction and maintenance, methodology composition, and methodology enactment. Without tools, applying Situational Method Engineering is very tedious and error-prone.
- Some kinds of organisations and disciplines have traditionally rejected automated or assisted approaches to planning and managing specialised work. This is probably based on the

assumption that these approaches are too rigid, and are thus seen as a straightjacket that hinders progress and limits creative work. However, current SME techniques are far from this. Some education work is needed to make potential users aware of realistic benefits and costs before an SME-based VRE is attempted.

In conclusion, if a VRE is to be developed for archaeological methodology composition, then these issues are to be tackled. All of them entail research as well as non-trivial design and development work, so the appropriate funding schemes to support them should be sought.

## 4.5 Current State of VREs in Archaeology

In the previous chapters we learned that Virtual Research Environment (VRE) is an umbrella term for different types of digital/ICT-based environments which support collaborative research of VR Communities or Collaboratories. Among the common features of VREs are that they are intended to help connecting researchers to each other, to content/data resources, and to research tools and services. Some VREs may centre more on scholarly communication and networking, on building and sharing data resources, or providing research tools and services.

An international online survey on VREs developed until 2009/2010 asked about which functions they are being used for. According to the 86 respondents most often this was: share data with others (72), support communication in a team (64), and provide access to tools, services or an infrastructure (55). Somewhat less present were support of project management (44), collaboratively annotate data (41), and analyse and process data (32). Most of the 86 respondents were located in Europe, North America and Australia; notably the arts & humanities and social sciences were strongly present in this survey (Carusi & Reimer 2010: 9-10 and 19).

In this chapter we look into the current state of VREs in archaeology. Taking the general features of VREs as a starting point, we define an archaeological VRE simply as a web-based environment that combines digital tools/services and content/data resources with features that allow collaboration on some tasks of archaeological research. The latter features are crucial because no environment would be considered as a VRE which does not have a collaborative component, i.e. support project-focused communication/ interaction between researchers. On the other hand, communication/interaction tools alone do not represent a VRE.

### 4.5.1 Web 2.0 / Social Media Platforms

In the discussion about e-science infrastructures so called Web 2.0 or social media tools and platforms are often mentioned as an alternative solution to enabling collaboration between researchers. Such tools and platforms include collaborative weblogs, content sharing platforms such as Flickr and YouTube, and professional platforms such as Academia.edu. They are presented as bottom-up, flexible and arguably more readily accessible solutions for researchers and practitioners than VREs developed in the context of e-science infrastructure. However, Web 2.0 or social media platforms mainly serve the need of professional networking and information exchange (Colley 2013; Dunn 2011; Kansa 2011), whereas the building and usage of data collections and processing software require other systems.

Eric Kansa notes: *"While Web 2.0's impact is far reaching, it does seem to have limits. Web 2.0 platforms and services mainly facilitate informal communications among archaeologists. Web 2.0 systems are simple to use, fast, and geared to content that requires relatively minimal investment to create. Archaeologists tend not to use Web 2.0 platforms as the primary dissemination channel for forms of content that take a great deal of effort and expertise to create. In this light, data sets and* *sophisticated scholarly manuscripts see less circulation in Web 2.0 channels."* (Kansa 2011: 5; cf. Dunn 2011).

Results of substantial surveys on the use of such tools by academics confirm that they are mainly perceived as an informal supplement to academic communication channels. Furthermore, they are actively used only by a small segment of researchers and, surprisingly maybe, young scholars are not among the avid users (cf. Procter *et al*. 2010a/b; Research Information Network 2010; UCL & Emerald 2010). In short, Web 2.0 or social media platforms support professional communication, networking and content sharing but can hardly serve as VREs. On the other hand, these functionalities should also be provided by VREs.

### 4.5.2 Wiki-based Collaboration

Wikis are sometimes subsumed under Web 2.0 or social media applications, but they are a distinct category of online collaboration with much potential for e-research applications. For example, in the biological research community many Wiki-based environments have been developed for sharing models and descriptions of biological entities and processes (Waldrop 2008). Some proposed solutions did not make it into actual use (i.e. WikiGenes, WikiProteins) while others proved to be useful, e.g. EcoliWiki (McIntosh *et al*. 2011), WikiPathways (Kutmon *et al*. 2015) and Proteopedia, the "3D-encyclopedia" of proteins & other molecules (Prilusky & Sussman 2016).

A typical example of Wiki use in the humanities may be the Digital Classicist, which is a website that links together several information resources and allows researchers to catalogue projects, tools, publications, etc. (Mahony 2011). For research purposes a semantic Wiki can provide a useful collaborative environment. According to the WikiApiary the Semantic MediaWiki is being used worldwide by over 1700 projects, including many digital humanities projects, e.g. CARE - Corpus architecturae religiosae europeae, IV-X saec. (Leclercq & Savonnet 2010 and 2011; Chevalier *et al*. 2013), and Semantic MediaWiki for Collaborative Corpora Analysis - SMW-CorA (Schindler *et al*. 2011; Ell *et al*. 2013).

A group of archaeologists at the University of Siena, Department of Historical Sciences and Cultural Heritage since 2006 uses a MediaWiki, called GQBWiki, as the digital documentation and interpretation platform for their investigations in the Byzantine Quarter near the Pythion shrine in Gortyn, Crete (Costa & Carabia 2016). 10-15 team members used GQBWiki during and after excavation campaigns. They produced over 2000 wiki pages, with over 28,000 modifications, and about 16,000 internal links. The wiki pages include journal entries, documentation of stratigraphic units, context plans, find records, 3200 images, bibliographic and other references, often with extensive notes on research results on other sites.

The GQBWiki presents a case of wiki-based Linked Data, with a unique URI for each journal entry, stratigraphic unit, significant find, etc. It uses the Semantic MediaWiki extension with a lightweight ontology of typed internal links, for example, between pages describing stratigraphic units, finds and units, etc. The excavation has been prepared for a traditional narrative and synthetic publication, but with accompanying wiki-based data. The GQBWiki has been made open access under the CC BY-SA license in 2015, already before the print edition. The release of the collaborative work aims to allow attribution of all contributors in a transparent way.

Huvila (2012) addresses challenges faced in the development of an archaeological e-research environment based on the Semantic MediaWiki. Some of the issues may have to do with the intended user group of contract archaeologists who typically work on short-term projects and have particular reporting requirements defined by their clients.

### 4.5.3 GIS-based Environments

It may be argued that a web-based Geographic Information Systems (GIS) is the main e-research environment of many if not most archaeologists. A GIS allows them bringing together data of individual excavations as well as regional analyses of many sites (e.g. settlement patterns). Consequently, archaeologists have acquired great mastery in the use of GIS, much more so than other humanities scholars who's usage of GIS *"can seem very limited, even simplistic, to archaeological eyes"* (Huggett 2012b). However, there are of course also advanced uses of GIS by other humanities, for example among the over 150 examples collected by the GeoHumanities SIG of the Alliance of Digital Humanities Organizations.

Although the application of GIS in archaeological projects is well established (Conolly & Lake 2006; Campana & Remondino 2014), the proceedings of the Computer Applications & Quantitative Methods in Archaeology (CAA) conferences still regularly contain many papers on advances in archaeological GIS. Among the more recent developments is the integration of GIS and 3D technologies for web-based presentation and exploration of archaeological sites and landscapes. Some examples are the 3D-GIS environment of the Swedish Pompeii Project for the Pompeian city block, Insula V 1, developed since 2011 based on the ESRI ArcGIS 10 suite (Landeschi *et al*. 2014); the 3D-GIS component of the Mapping the Via Appia project, which is led by the Spatial Information Laboratory (SPINlab) of the VU University (de Kleijn *et al*. 2015); and the MayaArch3D web-based environment for archaeological research (von Schwerin *et al*. 2016).

MayaArch3D is presented as *"a virtual research environment for the documentation and analysis of complex archaeological sites – specifically, it is a web-based, 3D-GIS that can integrate 3D models of cities, landscapes, and objects with associated, geo-referenced archaeological data"*. The MayaArch3D project started in 2009 in work on the UNESCO World Heritage site of Copan in Honduras and became an international project. It is being led by the German Archaeological Institute and the GIScience Research Group at University of Heidelberg (funded by the German Federal Ministry of Education and Research). MayaArch3D offers tools for analysing 3D models and associated spatio-temporal data online. The system is intended to support collaborative research, but it does not support live communication among researchers. Also the other GIS-based environments lack this important component of collaborative VREs.

### 4.5.4 3D Virtual Reality Environments

Beside the widespread use of GIS, virtual representation of archaeological monuments, sites and landscapes based on various 3D recording and visualization technologies is a major field of archaeological IT. The case study on 3D Archaeology gives an overview of several methods and techniques that are being employed in this field of research (see *Section 5.4*).

3D technologies have been applied by ever more projects since the early 1990s, were already rather well established 10 years ago (Frischer 2008), with numerous projects reported since then in CAA and other conference sessions devoted to advances in 3D applications for archaeological purposes. As some examples in the field of classical archaeology Babeu (2011) mentions Digital Karnak, Pompey Project and projects focused on ancient Rome, Digital Roman Forum, Plan de Rome, Rome Reborn and Stanford Digital Forma Urbis Romae. Projects such as 3D-ICONS (EU, ICT-PSP, 2/2012-1/2015), which provided 3D content to Europeana, exemplify that the use of 3D technologies for single objects and monuments has already reached a high degree of maturation. Indeed, in recent years the emphasis is on 3D virtual reconstruction and visualization of complex architectures (cf. the 3D-ARCH [ISPRS & CIPA] workshops, http://www.3d-arch.org).

As with other environments our key point with regards to archaeological 3D virtual reality environments is that they usually do not support research collaboration, hence do not qualify as VREs. This includes on-site CAVEs (e.g. Gauge *et al*. 2014; Knabb *et al*. 2014; Smith *et al*. 2013) as well as many online 3D environments. Exceptions are some online virtual reality environments which experimented with tele-immersive approaches involving avatars or other means of co-presence of and communication between researchers (Forte & Pietroni 2009; Kurillo *et al*. 2010; Kurillo & Forte 2012). Bennett *et al*. (2014) conducted experiments with archaeologists to evaluate their preference of and actual capability to identify archaeologically relevant features with a GIS desktop, a 3D web application, and a CAVE-type immersive system. They found that the archaeologists tended to prefer the CAVE system but performed better with the 3D Web application; only one preferred using a GIS desktop application.

### 4.5.5 Data Archives as Collaboratories

In the literature data archiving and publication services are sometimes presented as collaboratories or potential VREs. For example, among the four examples of archaeological collaboratories identified by the Science of Collaboratories project (see *Section 4.3.1*) is the former UK Arts and Humanities Data Service (AHDS) and the Transatlantic Archaeology Gateway (TAG) project. Among the five digital archives of the AHDS was one for archaeological data. When the AHDS ceased operation in 2008 (after cut of JISC funding) only this archive survived and became the Archaeological Data Service (ADS). The Transatlantic Archaeology Gateway investigated cross-searching of and semantic interoperability between digital records of the Archaeology Data Service (UK) and The Digital Archaeological Record (tDAR) archive of the Digital Antiquity consortium (USA). TAG also implemented a prototypic search portal. The project was carried out 2009-2011, jointly funded by the JISC (UK) and the National Endowment for the Humanities (USA).

Alison Babeu provides an extensive overview e-research environments developed for Digital Classics (Babeu 2011). In the chapter on classical archaeology she mentions the Archaeology Data Service, The Digital Archaeological Record (tDAR), and the archaeological data publication platform Open Context (Alexandria Archive Institute). Similarly, articles in a volume on Archaeology 2.0 (Kansa *et al*. 2011) address the Archaeology Data Service and Open Context as innovative services for data sharing and access (Richards *et al*. 2011; Kansa & Whitcher-Kansa 2011). Data archives can indeed be understood as collaboratories for data mobilization, sharing and access however we do not subsume them under VREs. Their activities allow the "collaborative" building of digital resources, but there is no direct interaction between the data sharers and users, hence, no online research collaboration.

However, we see some potential for data archives to become VREs, if they incorporate added value services for research tasks. For example, the Archaeology Data Service has implemented a 3DHOP-based 3D viewer for accessing and exploring 3D models deposited in their digital archive. The viewer extends the web-based browsing functionality of the ADS project archives by enabling users to browse 3D geometry directly. The greater ambition is to provide an interactive 3D web-based working environment for the management, visualisation and analysis of archaeological data. This would include different layers of archaeological stratigraphy, e.g. 3D metric reproductions of the excavation process, and the interpretations made by different scholars of the same context (Galeazzi 2015; Galeazzi *et al*. 2016).

### 4.5.6 VERA and Various Other Examples

#### VERA - Virtual Environment for Research in Archaeology

In the literature the most often described example of an archaeological VRE is VERA, the Virtual Environment for Research in Archaeology, which has been developed in the context of the large-scale excavations of the Silchester Town Life Project (UK). VERA was funded in the first and second phase of the JISC VRE Programme and ran from December 2004 to March 2009. The project was carried out by the University Reading (Department of Archaeology and School of Systems Engineering) in partnership with the York Archaeological Trust and the University College London (School of Library, Archive and Information Studies). The UCL researchers conducted the user testing and analysis in the second phase of the project.

VERA built on the functionality of the Integrated Archaeological Database (IADB) and added features which improved the online collaboration of the excavators and finds specialists, particularly those geographically remote from the project base or involved with the project on a part-time basis (Rains 2011 and 2015). Furthermore, the VERA project trialled data entry with digital pens and mobile devices. Three papers at the CAA 2009 in Williamsburg describe various aspects of the VERA project, including the technical infrastructure (Mills & Baker 2009) and issues in the integration of new tools such as hand-held devices in established archaeological practice (Clarke & O'Riordan 2009; Fisher *et al*. 2009; see also Warwick *et al*. 2009).

#### Various Other Examples

Here we briefly describe four examples that do not fit in the categories such as GIS or 3D environments addressed above but present some interesting aspects.

##### BoneCommons

BoneCommons is an open access system aimed to advance communication and sharing of information within the zooarchaeological community. It is sponsored by the International Council for Archaeozoology (ICAZ) and managed by the Alexandria Archive Institute (Whitcher-Kansa & Deblauwe 2011; Whitcher-Kansa & Kansa 2011). The BoneCommons website is based on the Omeka open source content management software. It hosts information of the ICAZ Neotropical Zooarchaeology Working Group (meetings, newsletter, bibliography) and offers forums/collections to which researchers can post announcements, publications and data (mainly images of bone specimens). The website also experimented with displaying a filtered subset of zooarchaeology related content from the Open Context data publishing platform. All information comes with clear licensing information and citation and is archived properly. Particularly interesting is the data sharing functionality which most often is being used for seeking help of colleagues with the identification of bone specimens.

##### ETANA

Babeu (2011) in a chapter on digital classical archaeology mentions the ETANA - Electronic Tools and Ancient Near Eastern Archives. ETANA is an advanced digital library, built since 2000 in a multi-institutional collaborative effort. It allows searching of various resources, but research tools are missing. For example, the eTACT resource (translations of Akkadian materials), could benefit from supporting tools. Currently eTACT contains only 29 translations, although it has been promoted by the International Association for Assyriology.

##### FAIMS

The FAIMS - Field Acquired Information Management Systems (formerly Federated Archaeological Information Management Systems) initiative developed e-infrastructure, tools and services for the archaeology sector in Australia (Ross *et al*. 2013 and 2015). The project has been funded by the

National eResearch Collaboration Tools and Resources (NeCTAR) program of the Australian Government. FAIMS provides a suite of digital tools and services, including advanced mobile recording applications, an online database system, and federated data services (i.e. The Digital Archaeological Record - tDAR archive), which replace FAIMS' own data repository. FAIMS is not a VRE but can be employed to build one. As the FAIMS suite of integrated tools/services supports several stages of the data lifecycle it may serve as a workflow system for archaeological surveys.

#### OCHRE

The OCHRE - Online Cultural Heritage Research Environment is another digital classical archaeology example addressed by Babeu (2011). OCHRE is an advanced online database management solution which has a VRE flavour. The developers of OCHRE claim that it is particularly well-suited for scholarly collaborative projects. They emphasise the OCHRE data model which, among other features, allows attribution of specific content to the contributing scholar and distinct interpretations of single items by different scholars. Furthermore, various options to share and access data as well as interfaces for different users/audiences are provided. Five projects are present with an openly accessible OCHRE instance, including digital classics (e.g. Ras Shamra Tablet Inventory) and archaeological projects (e.g. The Leon Levy Expedition to Ashkelon). It is also worth to mention that the Open Context platform uses a subset of the OCHRE data model to support diverse cultural heritage content.

## 4.6 Summary of VREs

### Definitions

As a summary of the various attributes of a VRE mentioned in different definitions:

- A VRE is as a web-based collaboration environment that provides an integrated set of services and tools according to the needs of a community of researchers; the set comprises of data, communication and other collaboration support services and tools.
- In general, a VRE is not a stand-alone solution for one project or institution, but based on common e-infrastructure.
- There are some contradictory or at least difficult to fulfil expectations from a VRE, i.e. open vs. controlled, flexible vs. tailored, and domain vs. cross-domain. For example, a VRE for cross-domain research will tend to provide generic services/tools or require much tailoring to support collaborative work on particular, interdisciplinary research questions.

### VRE Development

Some general aspects of the development of VREs are:

- There have been a large number of projects aimed to develop a VRE. These included many VREs for humanities scholars and the main focus here was studies of textual content (e.g. inscriptions, papyri, manuscripts).
- Only few VRE projects had an archaeological focus. The main example is the Virtual Environment for Research in Archaeology – VERA, developed in the UK, with funding from the JISC VRE Programme.
- Other projects which concerned archaeological data, but do not qualify as VREs, for example are Arts and Humanities Data Service – Archaeology, Transatlantic Archaeology Gateway (UK/USA), Digital Collaboratory for Cultural Dendrochronology (Netherlands) and the IANUS - Research Data Centre for Archaeology and Classical Studies (Germany). These are collaboratories aimed to build shared data resources.

- The funding of VRE projects contributed to the development of humanities e-research centres, for example the centres at Oxford University and King's College London and the Virtual Knowledge Studios in the Netherlands.
- As typical for research & technological development there were projects funded more than once, ideally to proceed from a prototype to a productive solution. This, however, happened only in a few cases, for example Pundit and Scratchpads. These are solutions for building VREs: Pundit for digital humanities research with a focus on textual content, Scratchpads for taxonomy and other biodiversity research.
- The current development trend is to build VREs on top of research data infrastructures. This is evident in the Research Infrastructures strand of the EU Horizon 2020 as well as in national funding programmes.

### Taxonomies of VREs and Research Activities

Some projects have developed systematics of online collaboratories, virtual laboratories or VREs, and taxonomies of activities scholars could carry out with resources (services, tools, content/data) provided by such environments:

- The Science of Collaboratories (SoC) project categorised a large number online collaboratories based on the type of *resource* to be shared and the type of *activity* to be performed. The resource could be tools, information or knowledge, and the type of activity to be performed online either aggregation or co-creation. New knowledge would be brought together by a *Virtual Community of Practice* while co-creation of knowledge by a *(virtual) Distributed Research Center*.
- In the context of the UK E-Science Programme a taxonomy of *Virtual Laboratories* has been proposed and applied to a number pilot projects. The taxonomy distinguishes such laboratories based on their primary function and activities in four categories: *community*-centric, *data*-centric, *computation*-centric, and *interaction*-centric. Furthermore, specific characteristics allow distinguishing different exemplars within these categories. For example, if a data-centric collaboration focuses more on creating or sharing of data.
- Taxonomies of so called "scholarly primitives" distinguish different activities and sub-tasks of scholarly work in all or a larger number of research domains. While the previous two classification schemes focus on types of VREs, these taxonomies detail the activities that a VRE could support. We looked into two taxonomies TaDiRAH and NeDiMAH which recently have been developed for digital humanities.
- The Taxonomy of Digital Research Activities in the Humanities (TaDiRAH) has been mainly developed for registries of research resources, i.e. the DiRT directory of tools. It breaks down the research process (lifecycle) into eight high-level "goals" (e.g. Creation, Analysis or Dissemination), each with a set of "methods" (e.g. Spatial Analysis). Furthermore, research tool based activities can be distinguished with regard specific techniques (e.g. Georeferencing) and research objects (e.g. maps). A machine-readable version of TaDiRAH is available in W3C SKOS (Simple Knowledge Organization System) format. Beside the DiRT directory adoption of the taxonomy is reportedly intended by the DHCommons directory of digital humanities projects.
- The NeDiMAH Methods Ontology (NEMO) provides a model of research actors and their goals, processes (activities and methods), and resources (content/data, concepts, tools) manifest in scholarly digital practices. As an ontology it has defined classes (27) and properties (42), which means that the semantic relations between the (abstract) entities involved in the modelled practices are formally defined/typed. At the level of class types concepts of available taxonomies can be used (e.g. 161 concepts for ActivityType). NeMO has been implemented in machine-readable W3C RDF Schema, with the type taxonomies in W3C SKOS (as TaDiRAH). Reportedly it is

also generally compliant with the CIDOC Conceptual Reference Model (CIDOC-CRM). One use case has been reported recently.

- One motivation to look into TaDiRAH and NEMO has been that such knowledge organisation systems might be used for processes supported VREs. A taxonomy like TaDiRAH could be used to structure and annotate available content, tools and other research resources to make them better discoverable. NeMO might be developed further to support research workflows. An application using such an ontology could help tie together sequences of VRE based activities, including tools, content/data and other resources.
- Workflow management systems are quite common in the physical and biological sciences, but not yet in the humanities. In archaeology "paperless", usually mobile data recording in field surveys and excavations is one of the recent developments to make workflows more seamless and effective. A suite of tools and services that supports several steps of the archaeological workflow is the FAIMS system.
- We expect that in near future support for the research workflow (or lifecycle), i.e. the whole research data lifecycle, will become an important topic. A save bet here is that it will require much attention to standards, including data, metadata and vocabularies.
- At the higher level of methodologies, one case study of this report addresses the potential of formalised descriptions of methodological practices. One scenario is a methodology composer that allows archaeologists to select the methods components they need for a project and assembles them in a VRE which supports their different tasks and workflows.

## VREs in Current Archaeology

The topic of virtual research environments or collaboratories has been around since many years and a lot of research has already been carried out to conceive, develop and implement solutions, specifically also for researchers in the humanities. However, few had an archaeological focus and the main example of a VRE is the VERA Virtual Environment for Research in Archaeology.

Looked at from a wider perspective, there are various environments that archaeologists use for carrying out and presenting results of their research. These include GIS-based environments, 3D and Virtual Reality environments, project wikis, and domain databases and archives, among others.

In our review we applied as main criterion for a VRE that it should allow web-based collaborative research. An environment that lacks such a collaborative component, i.e. research-focused interaction between researchers, would not be considered as a VRE. On the other hand, a platform mainly for research communication is also not a VRE.

The main result of our survey is that most identified environments lack a component for collaborative research in an interactive mode:

- *Data archiving and publication services:* In the literature these are sometimes presented as research collaboratories. Their activities allow the building of content/data resources, but typically there is no direct interaction between the data sharers and users involved. VREs could include such services for such interaction.
- *Web GIS-based environments:* Are among the most widely employed environments archaeo-logists are using. A Web GIS allows the visualization and exploration of geo-referenced data stored in the database underlying the online frontend. Project members collaborate through building a common resource by adding and annotating content in the database.
- *Web 3D environments:* These are mainly employed to present and allow exploration of products such 3D models of objects, buildings, sites and landscapes, including virtual reconstructions. A more recent trend is increasing use of 3D Web GIS in archaeology.

- *Online Virtual Reality environments:* Can allow users to explore the represented environment and objects within it. Avatars or other means of co-presence can allow user to communicate with each other. There have been experiments with tele-immersive approaches for collaborative research, but it seems unlikely that are adopted by practicing archaeologists.
- *Wiki-based collaboration:* Many projects use wikis to describe and communicate ongoing work. There are also examples where a wiki is being used by archaeologists for the collaborative documentation and interpretation of the research content.
- *Social media platforms:* This category includes content sharing and information dissemination platforms such as Flickr, SlideShare, YouTube, Facebook, Twitter (and others) which clearly are not VREs. Also dedicated platforms such as Academia.edu or ResearchGate are not VREs as these mainly serve professional networking and information sharing purposes.

Some general characteristics of the digital environment of archaeology (seen as a whole) are

- It comprises of a mix of various, mostly project-centred environments,
- These environments are often isolated, not or only loosely connected to others,
- Today the main variant of an archaeological e-research environment arguably is the Web GIS of an excavation project.

# 5 Case Studies

## 5.1 Introduction and Overview

This chapter presents several case studies corresponding to different digital archaeology settings and approaches. The objectives of the WP17 case studies have been to collect and review cases of e-research systems and tools that are currently being used by the archaeological community and, based on this review, consider what is required for advances in e-archaeology.

The case studies have been produced as pilot investigations for the development of e-archaeology scenarios and future experiments in the context of the ARIADNE data infrastructure and portal. A common perspective of the studies is the potential development of virtual research environments on top of or connected to the data infrastructure.

The WP17 investigations are different from those of the pilot deployment experiments conducted in Work Package 14. The WP14 demonstrators employed the advanced tools and services developed in ARIADNE to demonstrate their innovative capabilities; their results are presented in Deliverable 14.2. Compared to these, most WP17 case studies intentionally address a lower technological level to align with systems and tools archaeologists are familiar with.

The case studies cover a wide range of e-archaeology topics and subject matters,

- *Archaeological methodology*
- *Archaeological ontologies*
- *E-infrastructure VRE at the national level*
- *3D archaeology*
- *Geo-physical surveying*
- *Physical anthropology*
- *Archaeobotany*

The studies describe exemplary current practices in the respective area, recent advances and/or existing shortcomings, and outline how the area could be developed further. The conclusions and recommendations can concern adoption of novel approaches, standards, methods, tools or other means, depending on the topics and subject areas addressed.

## 5.2 Archaeological Methodology (CSIC)

### 5.2.1 Introduction and Overview

Archaeologists not only document the physical evidences that they find or the interpretations and conclusions that they draw. They also need to document the research process itself; in other words, what they do and how they do it. This is often done in a descriptive manner, so that a record is generated of the work that was done, the products that were generated, and the teams and tools involved, usually with the goal to provide context for whatever research question was being addressed. However, it can also be done in a prescriptive manner, to guide future projects regarding what work is to be done, what kinds of artefacts should be generated, and who should tackle what. Whatever way it is done, the rigorous description of archaeological methodologies is a crucial aspect of archaeological research, and comprises the focus of this case study.

Through this case study, different archaeological practices have been studied and analysed with the aim to create semi-formal models of them by using the Situational Method Engineering (SME) approach. SME acknowledges that “no size fits all”, that is, no single methodology is applicable to every situation, and therefore methodologies must be situated in a context. Also, it uses an approach by which methodologies are not considered to be monolithic, but made of individual method components that get assembled together into a meaningful whole. These components are usually taken from an existing repository and improved during use, thus achieving a virtuous feedback loop that systematically reuses ever improving methodological knowledge.

A method component repository was created as part of the work, and populated with method components derived from several of the analysed archaeological practices. This constitutes a first step towards a potential virtual research environment for "method composing", as described in a previous chapter.

### 5.2.2 Current Digital Practices

#### Situational Method Engineering

The comprehensive study and analysis of methodologies, regardless of their field of application, has been tackled for the last couple of decades by the field of *situational method engineering* (SME). Although SME was born as a discipline inside software engineering (Kumar and Welke 1992; Rolland and Prakash 1996), it has since been applied to a variety of fields, such as business process modelling (Gonzalez-Perez and Henderson-Sellers 2010), archaeology (Gonzalez-Perez and Hug 2013) and other areas of the humanities (Hug et al. 2011). The fact that it is the word “method” (rather than “methodology”) which appears in “situational method engineering” obeys to historical reasons, and the literature has repeatedly remarked that “method” and “methodology” should be understood as synonyms within this context (ISO/IEC 2014, section 3.2).

SME acknowledges that each methodology needs to be specifically *situated*, or adjusted to the project or endeavour to which it is going to be applied. At the same time, it tries to avoid circumstances that involve reinventing the wheel every time, by providing a solid knowledge reuse framework, so that methodologies are never created from scratch. In particular, and from the perspective of SME, a methodology is not a monolithic entity, but an assembly of *method components* that are carefully connected together after being selected from a pre-existing repository. Once a methodology has been created by assembling selected components, it can be enacted on an endeavour (i.e. applied to a project or other activity). During enactment, the performance of each component can be assessed, and the result of this evaluation fed back into the repository in the form of improvements to the components stored there. This way, methodologies that are assembled in the future from the improved components will take advantage from the accumulated enhancements that occur over time, thanks to the ongoing feedback loop. Figure 3 shows an overview of the processes involved.

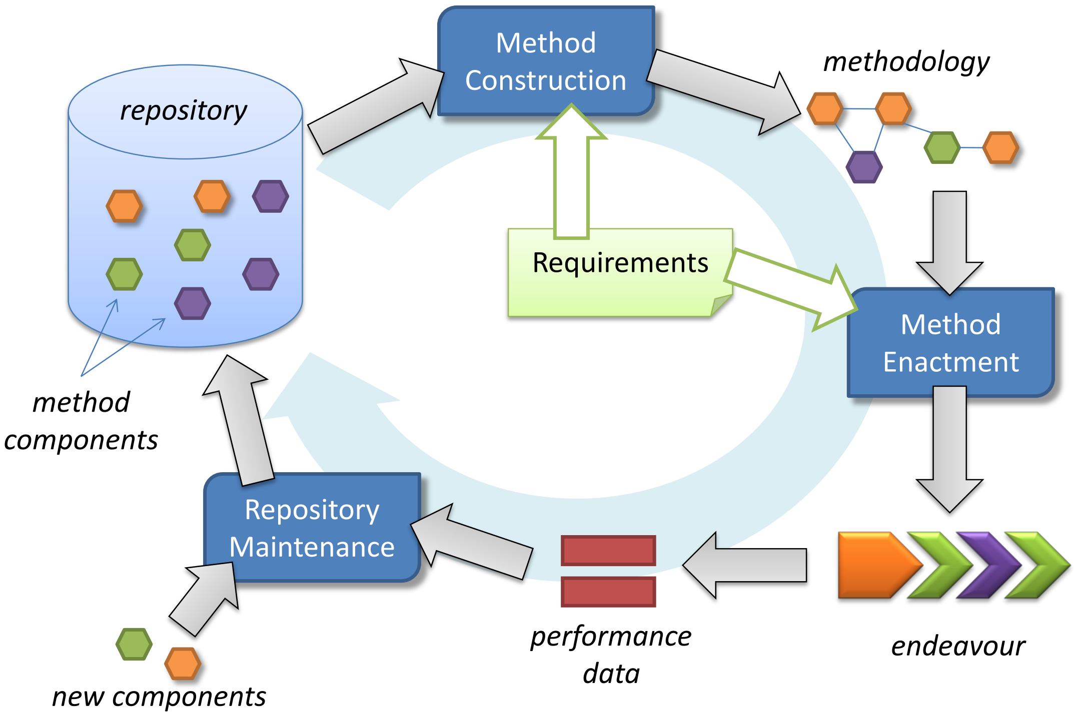


*Figure 3. Overview of the dynamics of Situational Method Engineering (SME). The three major processes involved are depicted as dark blue boxes. Method components are depicted as small hexagons. The continuous improvement loop is depicted as a light blue circular arrow in the background.*

There are a few aspects that need to be clarified. First of all, and as described in (Gonzalez-Perez and Hug 2013; Gonzalez-Perez and Henderson-Sellers 2008), method components are reusable, atomic, self-contained packages of methodological knowledge, i.e. knowledge that is related to how things should be done, what artefacts are involved in doing them, who should do them, or similar methodological aspects. Different colours in Figure 3 are meant to depict different "kinds" of method components (but see below in this section for further discussion on this point).

Secondly, and although it is often assumed that the collection of method components in the repository changes little over time, the specific ways in which method components are combined in order to make up methodologies are highly diverse, as are the ways in which said methodologies can be later enacted on specific endeavours. Method construction and method enactment, therefore, rely heavily on methodological requirements, shown in green in Figure 3. These requirements are often described in terms of what outcomes (such as documents, theoretical models or physical objects) the endeavour is aiming to achieve, the conditions of the environment where the endeavour will take place (such as any time or resource constraints that there may exist), and the sociotechnical characteristics of the organisational environment (such as team management style or even personal preferences).

Third and last, what types of method component are considered, and the ways in which method components can be assembled and enacted are often regulated by a formalism called a *metamodel*. This metamodel acts as a "grammar" that dictates what kinds of combinations are permissible, avoiding meaningless arrangements. The metamodel is not depicted in Figure 3, but it can be thought of as a set of operating rules that permeate everything that one does in SME, like the grammar rules that underpin the English language when we use it to talk or write. Thus, having a solid and expressive metamodel is crucial for a successful application of SME. This case study selected the ISO/IEC 24744 standard metamodel for this purpose.

### Previous Works

The application of situational method engineering to the humanities in general, and archaeology in particular, has been very scarce so far. However, some initial works strongly suggest that SME can provide significant benefits to the archaeological practice.

In (Gonzalez-Perez and Hug 2013), the authors propose the hypothesis that SME "can be applied to the construction, documentation and improvement of methodologies in archaeology and, possibly, the humanities and social sciences in general, as a response to a long-standing and increasing demand for attention to process-related issues within these communities". Also, they identify several benefits of doing so, including the fact that methodologies tailored to specific projects could be quickly assembled from well-known components; they would be easier to communicate and institutionalise, because the components they are made of would be already documented; and they would be easier to improve over time.

In (Hug et al. 2011), the authors show that the process models that are often used in the humanities (and in archaeology in particular) are barely suitable, and that finding an adequate modelling language to describe methodologies is very important.

In (Gonzalez-Perez and Martín-Rodilla 2013), the authors describe the initial analysis of textual sources of methodological knowledge in archaeology in order to construct a method component repository. Benefits reported include obtaining a high-quality record of what was done, when, how and by whom; the possibility to verify that every artefact produced in a project has a well-known goal and is used for something; and the fact that dynamic replanning becomes much easier. Despite these benefits, the authors identify some open issues, especially related to the fact that most of the sampled archaeological organisations rely heavily in tacit previous experience and develop very scarce encoding of their knowledge.

In (Gonzalez-Perez, Martín-Rodilla, and Epure 2016), the authors report on a more advance stage of the same work as above, and introduce an explicit connection to natural language processing (NLP) techniques in order to assist the analysis of the textual sources. The need for specific tools that help archaeologists exploit method component repositories is highlighted.

In summary, the scarce literature on the topic seems to suggest that:

- There is a need to develop and/or adopt suitable modelling languages to express and communicate methodologies in archaeology.
- Tacit knowledge "in the head" must be extracted and put "in the system", if we want to benefit from the methodology improvement feedback loop.
- Specific tools to manipulate and exploit method components repositories are needed; without them, SME is difficult to apply.

### ISO/IEC 24744

ISO/IEC 24744 Metamodel for Development Methodologies (ISO/IEC 2014) is an international standard that defines a “grammar” for situational method engineering. It contains a formal language, a recommended graphical notation, and a collection of usage and extension guidelines. ISO/IEC 24744 is highly extensible, so that shortcomings with regard to its application to WP17 can be easily resolved by custom-made extensions. The ISO/IEC 24744 extension mechanism is highly formal and well documented as part of the standard specification, so very little ambiguity is introduced at this point.

The most basic aspect that is regulated by a metamodel for SME is what types of method components may exist, and how they can be combined with one another. According to ISO/IEC 24744, the essential method component types are as follows:

- **Work units**. A work unit is a job that is carried out, or intended to be carried out, within an endeavour. These include large-grained jobs that describe an area of expertise (called **processes**), small-grained jobs that focus on what is to be done (called **tasks**), and small-grained jobs that focus on how to do it (called **techniques**).
- **Work products**. A work product is a thing of interest to the endeavour, either because it is created by it or because it is used by it, or both. Pre-defined subtypes of work products include **documents** and **models**. Additional archaeology-oriented subtypes were defined as through extension, as described in the next section.
- **Producers**. A producer is an agent that has the responsibility to carry out work units. Types of producers include the individuals involved in the endeavour (appropriately called **persons**), the abstract sets of responsibilities that are defined and named (called **roles**), any organised set of producers that collectively focus on common work units (called **teams**), and even instruments that help other producers to better carry out their responsibilities in an automated fashion (called **tools**).
- **Stages**. A stage is a managed time frame within the endeavour. Work units (see above) describe what is supposed to be done, but they do not say when. Stages, on the contrary, establish a time frame for work units to occur. The major types of stages are those during which the endeavour changes levels of abstraction (called **phases**), and those that represent a point in time that mark a significant event within the endeavour (called **milestones**).

ISO/IEC 24744 also defines other relevant types of method components and additional concepts, such as **actions**, **outcomes**, **guidelines**, **languages** and **notations**. Additionally, it defines attributes (i.e. properties) of each of these concepts; for example, it defines that every work product (regardless of its subtype) has a *Title*, a *CreationTime*, and a *Status*, which can be *Initial*, *Complete*, *Accepted* or *Approved*. Similarly, ISO/IEC 24744 defines what relationships exist between concepts (thus determining how method components of each type may be assembled together); for example, it defines that each task may cause effects on work products, and that these effects may be of several types (*Create*, *Modify*, *ReadOnly* or *Delete*). A comprehensive description of ISO/IEC 24744 is beyond the scope of this report; the relevant aspects that are needed to understand each section will be briefly described on demand. In addition, and for further details about the standard, please see (Gonzalez-Perez and Hug 2013) for a specific application to archaeological methodologies, (Gonzalez-Perez and Henderson-Sellers 2006) for an ontology-oriented description, or (ISO/IEC 2014) for the complete specification.

### 5.2.3 Case Study

As shown in Figure 3, situational method engineering (SME) is based on the existence of a method component repository, i.e. a database of suitable method components. In the case of WP17, this means that a good collection of archaeological method components must be gathered in the first place. Without this, the feedback loop, and thus the added value of SME, will not work. Much of the work done so far in WP17 fits into the “Repository Maintenance” box in Figure 3; in other words, it aims at the production of solid, reusable method components that can be later used by archaeologists as part of their methodologies.

The SME literature shows that the best way to populate a repository with method components is to “mine” them out of existing methodologies (Gonzalez-Perez et al. 2004; Henderson-Sellers, Debenham, and Tran 2004), which are often expressed in natural language. Project partners were asked to document their usual practices with a five-month deadline, and were given the following guidelines:

> *Documentation should be concise and informal. Use plain English, diagrams, tables or whatever other means you find necessary to describe the work that your organisation and/or your partners carry out. Please focus on the following aspects:*
>
> - *The **process** that you follow, i.e. what tasks, activities or techniques you perform.*
> - *The **products** that you engage, i.e. what documents, models, artefacts and other relevant things you use and/or create during said process.*
> - *The **people** in charge of the former, i.e. what teams, roles or even tools are employed.*
> - *The **stages** that you use to organise all of the above over time, i.e. what major phases or milestones are important in your work.*

A wide array of archaeological practices was documented in this manner, covering the following areas:

- 2D and 3D documentation of features and landscapes
- Site location analysis
- Recording during surveying
- Recording during excavation
- Recording of rock art
- Recording and analysis of stratigraphy
- Management and treatment of finds
- Analysis of stone, ceramic, wood, charcoal, phytolith, carpological, human anthropological, and archaeozoological finds
- Strontium and oxygen isotope analysis
- Archaeological impact management
- Publication of archaeological results

All input was collected and analysed centrally. The documents provided were in plain English and made heavy use of graphics and other non-discursive material. Most of the documents were highly structured around the four suggested axes (process, products, people and stages). The level of detail varied significantly between documents and between sources, and even within the same document, ranging from very abstract descriptions of processes to highly detailed accounts of protocols and data structures. There was some thematic overlap between documents, which was very welcome so that multiple approaches to solving the same problems could be obtained.

Analysis consisted of the identification of discourse elements in the provided documents that made clear reference to individual work units, work products, producers, or stages; the characterisation of the corresponding method component; and its cross-referencing to other method components extracted from related discourse elements. Figure 4 illustrates this process.

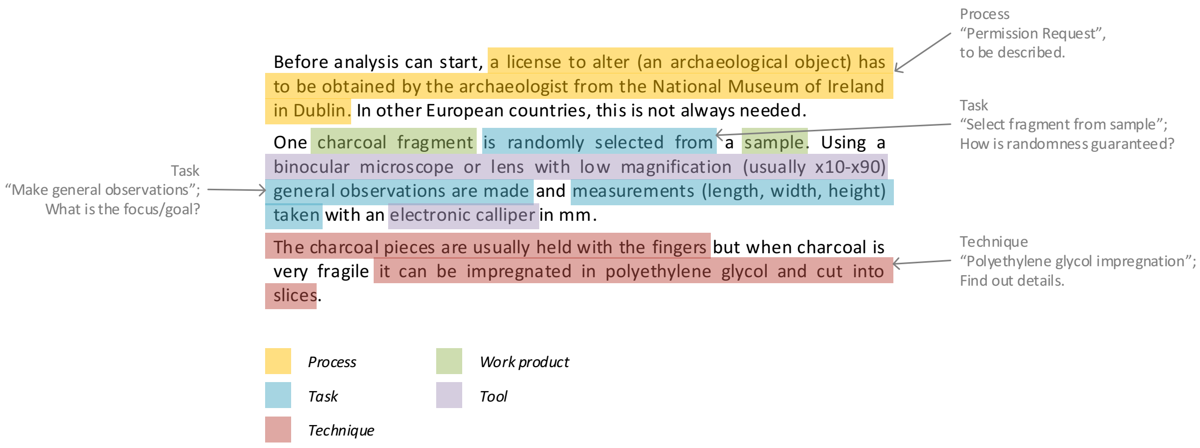


*Figure 4. Excerpt of the Charcoal Analysis document provided by one of the partners. Colours are used to highlight different elements of the discourse that have been identified as making reference to specific method components. The text annotations around the coloured excerpt are a sample of the analyst's notes.*

Analysis was conducted mostly by hand and by SME specialists with a significant experience in archaeology. Also, Natural Language Processing (NLP) techniques were employed as an aid to find process-product relationships in the texts (Gonzalez-Perez, Martín-Rodilla and Epure, 2016). As Figure 4 shows, the analysis process not only identified method components from the provided documents; it also raised interesting questions and highlighted further areas to explore. In addition, the analysis process on the provided documentation suggested that ISO/IEC 24744 should be extended in order to cope with a number of new demands. The next section describes these technological adaptations.

## Implemented Extensions to ISO/IEC 24744

When applying ISO/IEC 24744 to a domain other than software engineering, it is to be expected that an extension is necessary, in order to add the required concepts. WP17 of ARIADNE entailed the analysis of a small corpus of texts describing different portions of archaeological methodologies, and the construction of a database to store and manage this methodological knowledge. During these works, the conceptual needs for an ISO/IEC 24744 extension became apparent. These needs can be summarised as follows.

1. The subtypes of WorkProduct that are included in ISO/IEC 24744 were insufficient for archaeological work. In particular, two kinds of work products were found missing: purely cognitive artefacts that exist only in the mind of a producer, such as a plan or a hypothesis; and physical objects that are relevant to the archaeological record, such as a rock, a construction or a coal fragment.
2. The standard does not distinguish between work products that are created by the endeavour team from those that are provided by external parties or are readily available to within the organisation. These two situations turned up to be very common in archaeological works.
3. Sometimes, a work product such as a document or a model goes through different states as the endeavour progresses. The work product is still the same, but its state changes. For example, a 3D model of an archaeological feature may start its life as a *draft*, then move to *revised*, and end up as *final* as more details are added and checks performed. The standard doesn't cater for work product states, so this feature needs to be added.
4. Work in WP17 showed that, in some cases, the methodology being applied to an archaeological project is often a work product as well. This entails a non-trivial degree of recursiveness. For example, some decisions that an excavation director may make on what technique to use to continue digging depend on the outcomes of previous digging work; this means that the enactment of the methodology (what technique to use) is affected by

information generated during the enactment itself (outcomes of previous digging work). The standard cannot capture this information in its base form.

Needs 2 and 3 are not particularly specific to archaeology, and can certainly be relevant to any domain. For this reason, we have noted them down as potential improvements for a future revision of ISO/IEC 24744. Need 1, on the other hand, is specifically archaeological. Need 4, in turn, may be applicable to other domains as well, although some research is needed to ascertain the degree to which different disciplines employ the recursive nature of enactment as described above.

This section contains the semi-formal specification of the ISO/IEC 2474 extension for archaeology, expressed through UML class diagrams and natural language, and following a similar structure as in the standard itself. It also contains matching notational extensions. The notational graphical families used by the standard have been maintained so that the new symbols integrate well with the standard ones.

## Work Product Subtypes

Four classes in two powertype patterns have been introduced, as shown in Figure 5 and Figure 6. This satisfies need number 1 above.

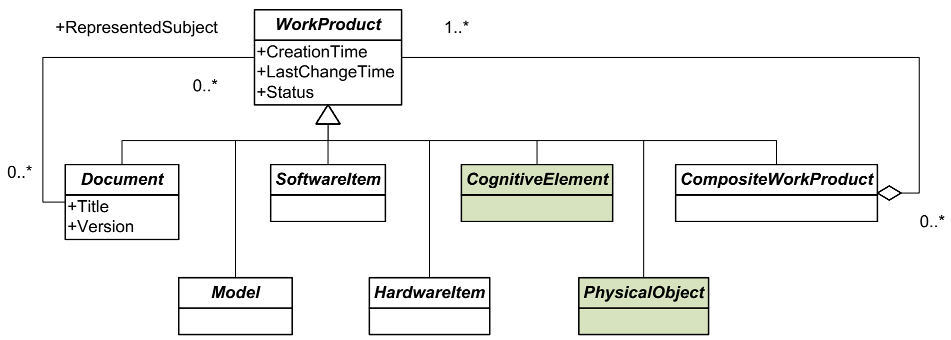


*Figure 5. New work product endeavour-level classes, highlighted in green.*

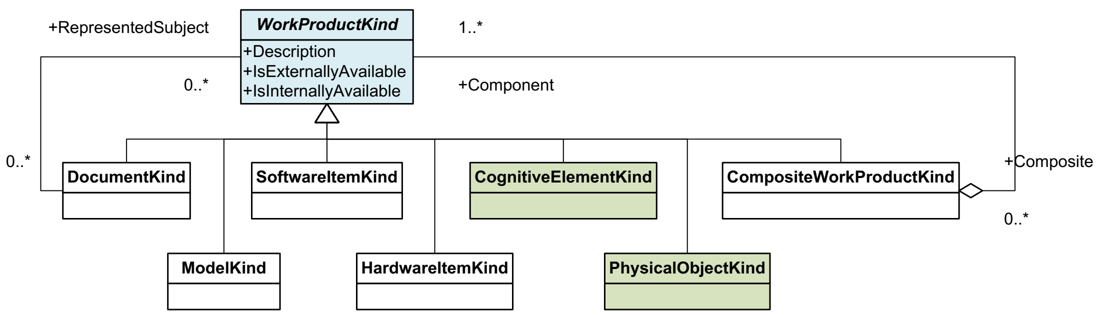


*Figure 6. New work product method-level classes, highlighted in green. Modified classes are highlighted in blue.*

The powertype patterns are composed by name-matching classes, following the same naming convention as in the standard: CognitiveElement/*Kind and PhysicalObject/*Kind.

A **cognitive element** is *a purely cognitive work product, in the mind of a producer*. Examples include a hypothesis or a plan.

A **physical object kind** is *a specific kind of physical object, characterised by its type according to any relevant classification scheme*.

Figure 7 shows the symbols used for the new classes PhysicalObjectKind and CognitiveElementKind.

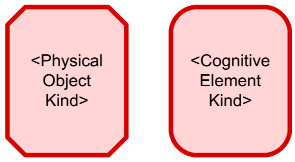


*Figure 7. Symbols used for PhysicalObjectKind and CognitiveElementKind.*

## Work Product Availability

Two attributes have been added to WorkProductKind in order to satisfy need number 2 above, as shown in Figure 6.

**IsExternallyAvailable** (Boolean) specifies whether work products of this kind are readily available from external sources during enactment.

**IsInternallyAvailable** (Boolean) specifies whether work products of this kind are internally available in the organisation during enactment.

Figure 8 shows the notation employed to mark work product kinds that are externally and internally available, respectively. This notation is based on that of action kinds.

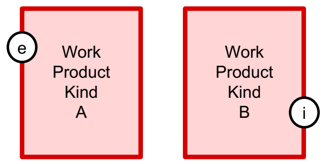


*Figure 8. Symbols used for externally and internally available work product kinds, respectively. The "e" inside the circle stands for "external", whereas the "i" stands for "internal".*

## Work Product States

Two classes in one powertype pattern, as well as a number of associations, have been introduced to cater for need number 3 above. This is shown in Figure 9 and Figure 10.

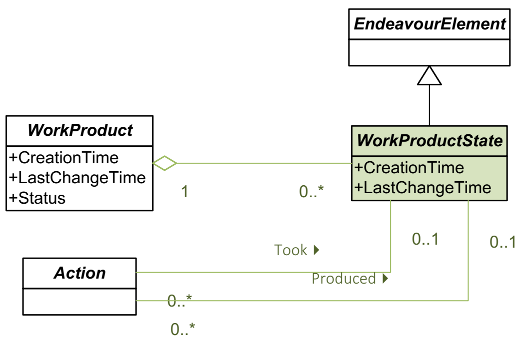


*Figure 9. New endeavour-level class and associations for work product states, highlighted in green.*

A **work product state** is *an endeavour element representing a specific state of a particular work product*. For example, if a particular document goes from draft to approved within a project, both *draft* and *approved* are work product states.

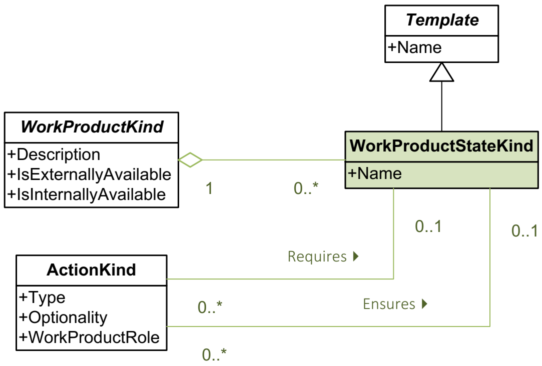


*Figure 10. New method-level class and associations for work product states, highlighted in green.*

The powertype pattern is composed by name-matching classes, following the same naming convention as in the standard: WorkProductState/*Kind.

A **work product state kind** is *a specific kind of work product state, characterised by its semantics in relation to the lifecycle of the associated work product kind*.

Note that actions work as the mechanism that entail state transitions for work products within an endeavour. In this regard, each action may take a particular initial state and produce a particular final state upon completion. Similarly, action kinds can be used to model what work product kind states are required upon start and which are ensured upon successful completion.

The different states that a work product kind may be in a particular methodological situation are depicted as labels in square brackets next to the related action kind circle, as shown in Figure 11.

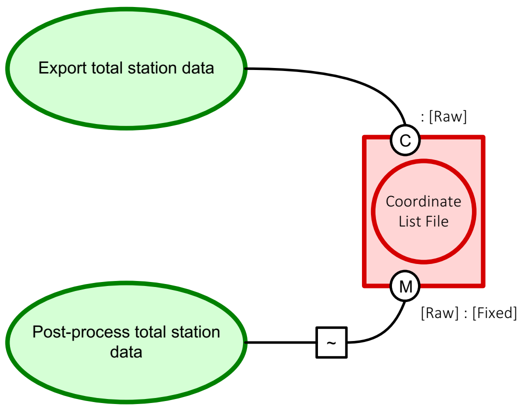


*Figure 11. Notation example for work product states. See the main text for a detailed description.*

The "[Raw]" label next to the "C" action kind indicates that the "Export total station data" task kind ensures that the coordinate list file produced is left in a raw state. The "[Raw] : [Fixed]" label next to the "M" action kind indicates that the "Post-process total station data" task kind requires that the coordinate list file to be modified is in a raw state, and ensures that it is left in a fixed state upon successful completion. The text before the colon indicates a required or taken state, whereas the text after the colon indicates an ensured or produced state.

### Recursiveness of Enactment

Need number 4 above is implemented by the addition of an association, as shown in Figure 12.

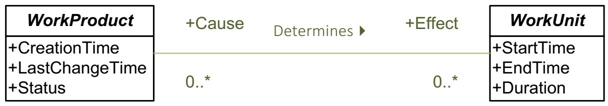


*Figure 12. New association to support enactment recursiveness, highlighted in green.*

By using this association, situations can be modelled where a particular work product (such as a redesigned work plan or altered hypothesis) occurring during an enactment determines, fully or partially, a number of associated work units (such as a new task to gather extra information or dig in a different place).

The fact that work products of a particular kind may determine one or more kinds of work units can be depicted by using a labelled generic link between the relevant symbols, as shown in Figure 13.

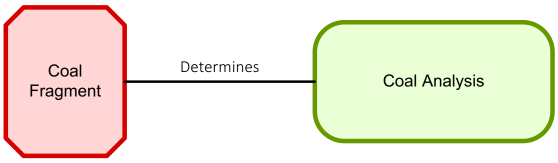


*Figure 13. Notation example for enactment recursiveness. The work product kind is the one which determines the work unit kind. In this example, the occurrence of coal fragments determines the need to carry out a coal analysis process.*

## Method Component Repository

Once the necessary extensions to ISO/IEC 24744 were clear, a method component repository was constructed. This was implemented as a Microsoft Jet relational database, which implemented a structure following the ISO/IEC 24744 plus the added extensions. The database contents were delivered in XML form, using a schema chosen for maximum interoperability.

### Repository Structure

The XML repository that is attached to this document has the following structure. 19 XML files are provided in a ZIP package, corresponding to the following:

- 14 files correspond to ISO/IEC 24744 (or extension) classes. These are named after the matching class, such as “ProcessKinds.xml” (for the “Process” class).
- 4 files correspond to ISO/IEC 24744 (or extension) associations. These are named after the matching owner class and association or role, such as “TeamKinds_Members.xml” (for the “TeamKind” class and its “Members” role).
- 1 file corresponds to ISO/IEC 24744 (or extension) enumerated types and items. This file is named “_Enums.xml”.

Each XML file contains an embedded XSD schema plus data. Cross-references are managed through repository-unique codes.

### Content Sample

A small selection of the method components in the repository is shown below. These have been obtained as a result of analysing the input provided by partners using the methodology described in previous sections.

According to the documents provided by one of the partners, the “Total Station and GPS Georeferencing” process comprises a series of tasks, such as “Create total station surveying network", "Set up total station equipment", etc. Roles such as "Total Station Operator" and tools such as "Total Station" are identified. Figure 14 shows a diagram depicting this.

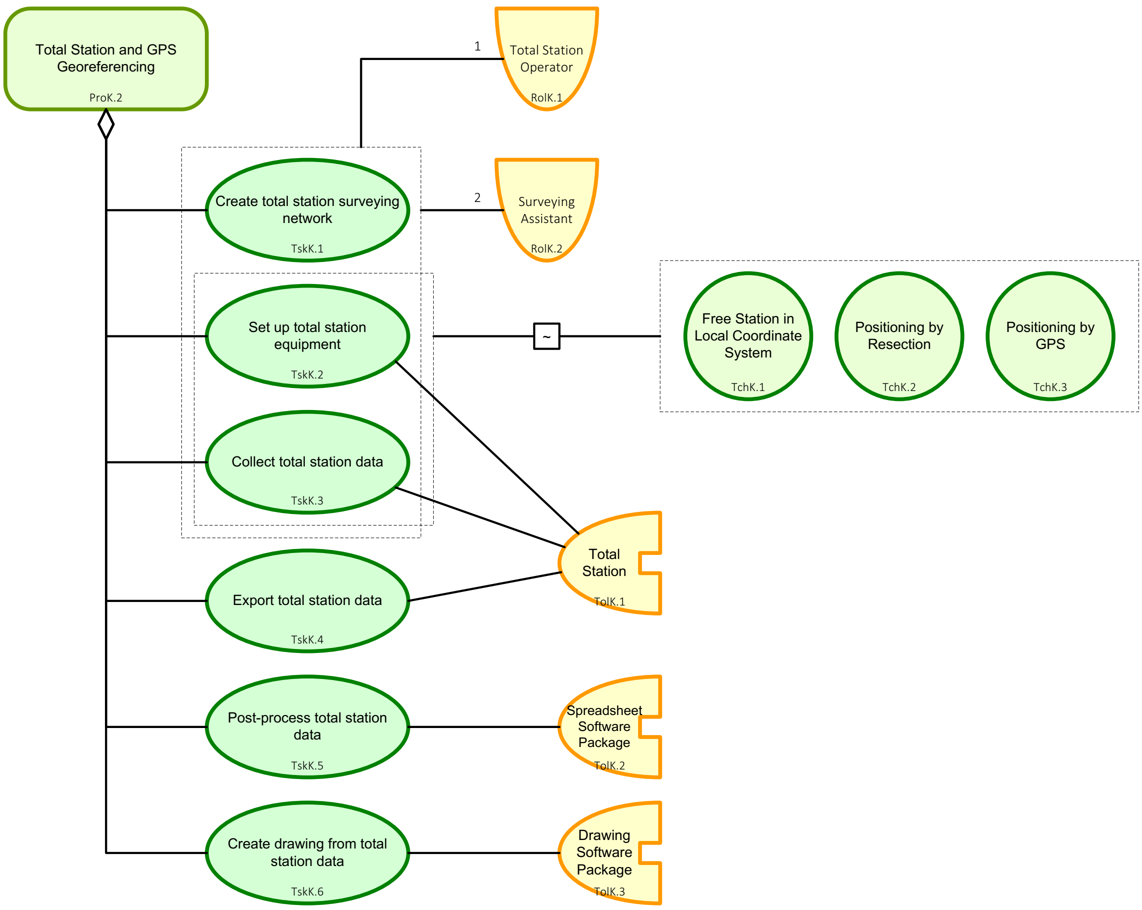


*Figure 14. Process diagram for the "Total Station and GPS Georeferencing" process kind of one of the partners. The ISO/IEC 24744 graphical notation is used. Please see the text for a description of this figure.*

For some tasks, a number of optional techniques are provided; in Figure 14, three alternative techniques are shown for tasks "Set up total station equipment" and "Collect total station data". For example, one could choose to carry out these tasks by "Free Station in Local Coordinate System", "Positioning by Resection", or "Positioning by GPS".

The tasks in the process, in turn, operate on a series of work products and, in doing so, these work products get created, changed and used. Figure 15 shows a diagram illustrating this.

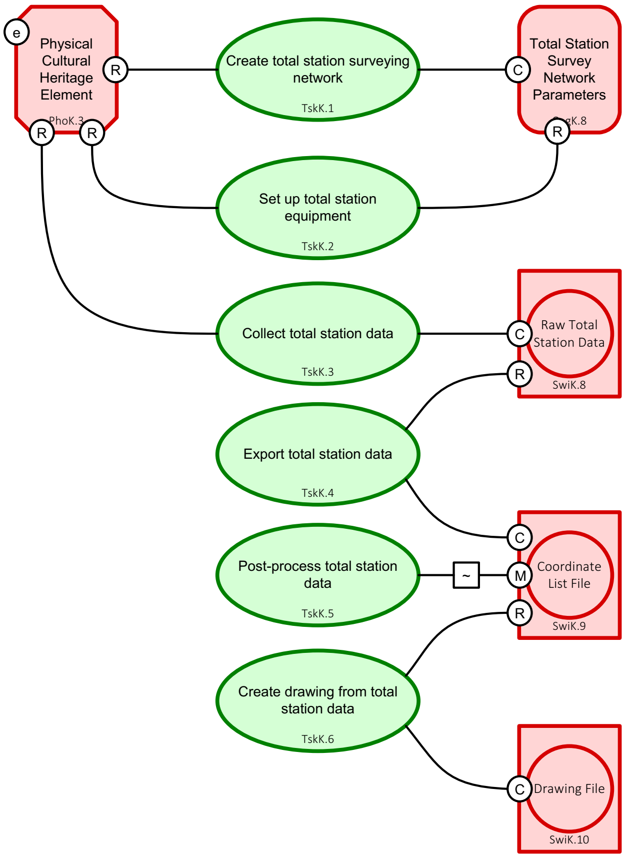


*Figure 15. Action diagram for "Total Station and GPS Georeferencing". The ISO/IEC 24744 graphical notation is used. Please see the text for a description of this figure.*

In Figure 15, the "Create total station surveying network" task is depicted as acting upon two different work products: it "reads" (i.e. uses but without modifying) the "Physical Cultural Heritage Element" being documented (which, by the way, is externally available, as marked by an "e"); and it creates a new "Total Station Survey Network Parameters". Other tasks operate on other work products of different types all the way down to "Drawing File".

These two examples illustrate two different levels in the abstraction scale: from a very abstract view of the process diagram in Figure 14 to the high level of detail of the action diagram in Figure 15. It is not always possible or necessary to describe methodologies in as such a detailed manner as that shown in Figure 15, but we have included it here for the sake of illustration.

## Using the Method Component Repository

The method component repository was circulated to collaborating partners, and several attempts were made to use it in real-world settings to assist with the documentation of archaeological methodologies. In most cases, significant barriers were found for adoption by final users (i.e. archaeologists), although consulting with an SME specialist alleviated the learning curve remarkably. Also, it was found that most methodological carried out by the involved archaeologists was of a descriptive, rather than prescriptive, nature. Although the SME approach and the method component repository can be applied in this kind of setting, the benefits of the continuous improvement loop are maximised in prescriptive situations. The lack of specialized software tools that can help users to explore the repository and compose methods from the stored components was an additional issue.

### 5.2.4 Conclusions and Recommendations

The major conclusions of this work are three:

- "Mining" textual descriptions of archaeological practices by hand is extremely tedious and error-prone. Although natural language processing techniques can help, a better method is needed for assisted knowledge extraction.
- SME works well in a humanities setting, despite the fact that it was ideated for engineering purposes. Through small extensions, ISO/IEC 24744 has proven capable of describing complex archaeological practices as described by the actual practitioners.
- Adoption of a method component repository by archaeologists is difficult if not accompanied by an SME specialist who can coach them through. This is very likely a consequence of SME being a foreign domain to archaeology, as well as the lack of specialised software tools.

Based on these, we can recommend the development of a comprehensive toolset for SME in archaeology. This would entail tools for repository creation and population, possibly from textual sources, as well as tools for repository usage and exploitation. Also, we suggest that the ISO/IEC 24744 standard is augmented to adopt some of the extensions that were implemented in this case study as part of the standard. This is especially the case of internally/externally available work products, work product state machines, and methodological self-referencing.

#### Specific Application Scenarios

Our experience with applying SME to archaeological practice suggests that the following scenarios are good candidates for SME adoption and application, and can be used as a guide for adoption.

##### Simple Project

Let us imagine a simple archaeological project where a small team led by an individual is expected to carry out some work. This could be a small excavation, a survey, or a lab analysis, for example. In situations like this, major methodological issues usually involve agreeing on who does what, making sure that the relevant deadlines are observed, and ensuring that the final outcome of the project (an archaeological report, a set of lab results, etc.) is delivered with acceptable quality. Small projects are usually extremely sensitive to irregularities in the productivity of individuals; for example, one team member falling ill usually has a big impact in the overall project. For this reason, a clear distribution of tasks and responsibilities is crucial in small projects.

In this context, the project leader would first determine what the final project outcomes are in terms of work products, and then back track from them in order to define the necessary process and interim products. First, the project leader would ask themselves "what specific task do we need to carry out in order to obtain these products?" The answer to this would probably involve one or more interim work products. For each of them, they would ask again "what do we need to do in order to obtain this?", and so on and so forth, until the necessary inputs are all available from internal or external sources. For example, let us imagine that the desired final outcome is an excavation report. When asking ourselves "what do we need in order to obtain this?", we determine that we can only write up the report if we have excavation find data, a Harris matrix of the site, and lab results. These are intermediate products. Now we focus, for example, on the Harris matrix, and ask again what we need to obtain it. We answer this by saying that we need an excavated site. Again, this is an interim product. Eventually we would reach a point in which every new product that we need is either available from within the team (such as maps of the site or a database to record information) or from external sources (such as the physical site itself).

At this point we would have constructed a network of products linked by dependency relationships. Now we would explore what tasks are necessary to fulfil each dependency. For example, going from excavation find data, the Harris matrix of the site plus the lab results to the final report would need writing the report. This is a task. Similarly, going from the excavated site to the Harris matrix would involve digging the site. By repeating this logic over the whole network, we will have determined the process to carry out in terms of specific tasks.

Finally, we would allocate each task to one or more team members according to their profiles or expertise.

This process can easily be done on paper for a small project. The first time we do this, we would probably need to define most products and tasks from scratch, by drawing on our experience as archaeologists and perhaps previous projects of a similar nature. The value of SME is realised when we start writing down the tasks and products that we identified for a project in order to re-using them next time. To create a method component repository, we can write down a name and description for each work product, as well as a name and purpose for each task. We can do this on a small database, a spreadsheet, or even on index cards.

During the project, we would observe how well each task and product works. We would look at issues such as how well the products cover the expressive needs in the project, whether the planned tasks are sufficient to convert "input" products into "outputs", and how well the tasks are adjusted to the skills of the team members. We would be able to correct defects and update the names or descriptions of the components in the repository with new information as we see fit.

Next time we need to plan for a project, we would use this repository as a starting point. We would probably find that some of the work products that we need for the new project have already been defined in the repository, so that we can take them as they are to get an immediate overview of what the associated tasks are and what other interim products are needed. In this regard, the more projects we approach by using this method, the fewer tasks and products we will need to define from scratch, because we will be finding more and more pre-defined and pre-tested method components in the repository.

### Co-Ordinated Project

Let us imagine a complex archaeological project where different teams carry out different sub-projects or activities, and a co-ordinating team or individual supervises everything. This could be a large excavation, a comparative study of geographical-distributed sites, or a multidisciplinary project involving archaeologists, anthropologists and sociologists, for example. In projects like these, the major concerns are co-ordination and dependency management, so that no one is stalled because a necessary interim product is not available when it should. Additional concerns involve the clear and unambiguous dissemination of what is expected from each project participant, and managing the delegation mechanisms between and within sub-teams.

In this context, the project leaders would create an overall plan like in the previous case, but focussing on products and avoiding the specification of tasks as much as possible. If a method component repository exists from previous projects, they should use it to find already defined products. Once the overall plan is ready, they would allocate specific products to specific sub-teams. At this stage, it is crucial that all the sub-teams have a clear idea of what their allocated products are, and what dependencies they have to other products, both upstream (what other products and therefore sub-teams they depend on) and downstream (what and who depend on them).

Then, each sub-team would create a specific plan for their work, by taking their allocated interim products as if they were the final products in a project, and determining what tasks, and perhaps additional interim products, are needed. Also, tasks would be allocated to individuals as in the previous case. The backtracking process will finish once every new product that is needed is either available from within the sub-team, the environment, or upstream sub-teams. Again, this planning process is best carried out if a method component repository is available. If this was the case for the leading team, then they should make the repository available to all sub-teams to facilitate methodological integration.

Sometimes, parallel collaboration on specific products is necessary. This means that two or more sub-teams work at the same time on the same product. In situations like this, one of the sub-teams must be designated as the "owner" of the product, and the changes or interactions of other sub-teams must be clearly specified, in order to avoid clashes and instances of the "tragedy of the commons".

During the project, and like in the previous case, sub-team members would update the repository with the necessary adjustments as the project progresses.

### Organisational Methodological Guidelines

Let us imagine a large organisation, such as a sizeable company or a government agency, who wants to institutionalise a particular approach to working in archaeology. This could involve, for example, a government agency establishing the minimum requirements for any approved excavation, or an intervention company establishing the standards to be met for any of their projects. In situations like these, the focus is not carrying out a particular project, but setting up an infrastructure that, hopefully, will serve multiple projects in the future by providing common bases while, at the same time, allowing them to diverge in approach and scope as much as necessary.

In this context, a small team would be in charge of setting up the methodological guidelines for the organisation. The guidelines themselves would probably take the form or a method component repository, perhaps together with some textual description of what is expected. Populating the method component repository would be carried out by "mining" previous projects that are considered successful or exemplary in any way for method components. This will often involve the analysis of reports or field diaries in order to determine what tasks were carried out, what products were generated and used, and what connection existed between both. The objective should not be to cover everything that every successful project did in the past, but to construct a solid backbone on which future projects can develop. In this regard, the team should better focus on high-level process-oriented constructs such as phases or processes rather than specific tasks. For example, the team could define what standard phases a project goes through, and what processes are usually carried out at each phase. The team could also describe the major typical products, especially in terms of what final outcomes are expected, and with which kinds of contents and quality.

Once the methodological guidelines are in place, any project that happened and to which the guidelines were applicable would need access to the associated method component repository, so that they would be able to incorporate the applicable phases, processes and products in their plans, and complete them with customized tasks and additional products.

Feedback to the repository would be probably controlled by the team in charge, instead of being freely available to anyone. This means that any project member wishing to contribute a change to a method component in the corporate repository would probably need to go through a process supervised by the team in charge, in order to maintain the consistency of the changes and make sure that every proposed change is potentially useful to all the parties involved.

### Government Recommendation

Let us imagine a government agency that wants to establish a recommendation for archaeological work that will affect third parties outside the agency. This is the case, for example, when specific requirements on standards, contents and formats of archaeological information are established by a government agency so that researchers and companies working on the archaeological record must comply with it.

This situation is very similar to the previous one, but incorporates the complication that the method component repository must be made publicly available so that anyone can draw components from it, and suggest changes to the existing components or even the incorporation of new components. This often involves web-based tools and software-assisted planning and method design approaches. For example, the government agency may make their repository available through a collection of web services, and distribute a desktop app that archaeologists can use in order to plan their project, record their data, and upload it when finished. Alternatively, this can be done fully on the web.

### 5.2.5 Summary

In this case study we have briefly introduced situational method engineering (SME) as an infrastructural solution for methodology management in archaeology. In particular, we have looked at how the adoption of a particular modelling language to express and communicate methodologies in archaeology can help, and we have recommended ISO/IEC 24744. We have also described how tacit knowledge “in the head” can be partially extracted and put “in the system” in the form of a method component repository constructed from textual accounts of archaeological practices from several partners. The repository was structured along the lines of the ISO/IEC 24744 standard metamodel plus some custom extensions to cater for the archaeological domain. Although adoption of the repository for actual methodological work was difficult in the absence of an SME specialist, a number of application scenarios have been identified. The need for software tools was emphasised throughout the phases of the SME application.

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## 5.3 Archaeological Ontology (PIN)

### 5.3.1 Introduction and Overview

PIN, together with other ARIADNE partners, has been involved in the definition of CRMarchaeo, an extension of CIDOC CRM created to support the archaeological excavation process and all the various entities and activities related to it. The model was created starting from standards and models already in use by national and international cultural heritage institutions, and has evolved through deep analysis of existing metadata from real archaeological documentation. It has been enriched by continuous collaboration with various communities of archaeologists from different countries and schools. Furthermore, it takes advantage of the concepts provided by CRMsci, from which it inherits most of the geological and stratigraphic principles that govern archaeological stratigraphy, extending these principles.

CRMarchaeo is the result of collaboration between archaeological institutions and CRM experts of other research centres involved in ARIADNE. The first need that the model attempts to meet is to create a common ground for the integration of archaeological records on every level, from raw excavation data to official documentation produced according to national and institutional standards. This document describes a community model, which has been approved by the CRM SIG to be formally and methodologically compatible with CIDOC CRM. However, in a broader sense, it is always open to any possible integration and addition that may become necessary as a result of its practical use on real archaeological problems on a large scale. The model is intended to be maintained and promoted as an international standard.

### 5.3.2 Current Digital Practices

The CIDOC CRM is already in wide use by leading institutions of the cultural heritage sector. Adoption in archaeology has been hampered by the lack of an extension that takes account of the specific requirements of archaeological research, particularly the documentation of excavations.

#### CRMarchaeo

CRMarchaeo is intended to provide all necessary tools to manage and integrate existing documentation in order to formalise knowledge extracted from observations made by archaeologists, recorded in various ways and adopting different standards. In this sense, its purpose is to facilitate the semantic encoding, exchange, interoperability, and access of existing archaeological documentation. The model takes inspiration from the basic idea on which archaeology is based according to (Harris 1989), that the features of an archaeological site are to be found in the stratified context, which is investigated by an archaeological excavation. It takes into consideration the physical arrangement of archaeological stratification and the events that led to the formation of a particular stratigraphic situation. The model comprises entities and properties for describing stratigraphic genesis and modifications and the natural phenomena or human intervention that led to their creation, the nature and shape of existing stratifications and surfaces, and the analysis of the human remains or artefacts found within the strata. This will enable archaeologists to determine the relative chronological order in which stratification was formed. The interpretation of the chronological sequences, also based on the space-time analysis of a specific site, provides all the elements needed for the reconstruction of the identity, life, beliefs, behaviour, and activities of a given group of people in the past in that specific place.

Furthermore, the model documents, in a transparent way, the various aspects of archaeological excavation process, including the technical details concerning different methods of excavation, the reasons for their application and the observations made by archaeologists during their activities in the field. This approach allows the creation of an objective documentation that can guarantee the scientific validity of the results, making them revisable following further investigations and reusable in different research contexts, in order to answer further (and potentially different) research questions.

One of the most important goals of the model is to overcome the differences resulting from the application of different excavation techniques and procedures, e.g. from different traditions and schools of archaeology, revealing the common ways of thinking that characterise the stratigraphic excavation. This will serve to provide a unified view that can express the common concepts without imposing any specific recording or investigation technique, on stratigraphic activity, and will also provide a sound basis for the integration of various methods.

### The Conceptual Model

CRMarchaeo, from a technical point of view, provides conceptual descriptions of classes and properties in an encoding-agnostic formalism, inherited from CIDOC CRM, allowing implementation of its concepts and relationships using various languages and formal encodings (such as RDF and OWL), thereby providing maximum flexibility for operations of mapping and conversion and giving IT experts the freedom to implement it in the way they prefer.

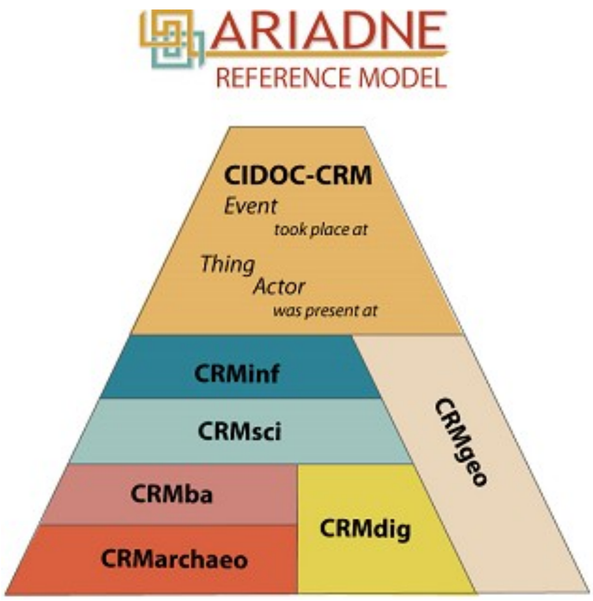


*Figure 16. The ARIADNE Reference Model.*

The interpretation of the chronological sequences, based on the analysis of time and space of a specific site, offers all the elements to reconstruct the identity of a group in a specific place and a time-span. One of the fundamental elements of CRMarchaeo model is, in fact, to offer the ability to record information relating to the physical layout of the archaeological stratification and the events that led to its formation, in order to allow the documentation and subsequently the interpretation of the archaeological stratification. CRMarchaeo provides a tool for archaeologists to support the determination of a relative chronology of the layers. The CRMarchaeo has been developed from the definition of the main entities involved during the archaeological excavation, the Stratigraphic Units (SU) and the Stratigraphic Interface (SI).

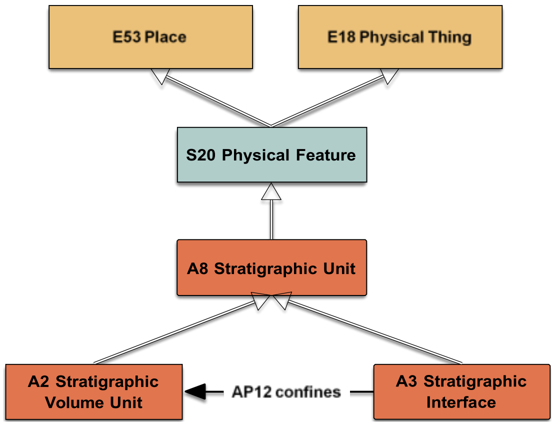


*Figure 17. The Stratigraphic Unit representation in CRMarchaeo.*

Stratigraphic units, which comprise the minimum unit of information, are characterized by their space-time nature, being placed in a certain place for a certain period and linked with other stratigraphic units. In CRMarchaeo, Stratigraphic Unit has been represented by the *A8 Stratigraphic Unit* class, subclass of *S20 Physical Feature*. This entity has been developed within another extension of the CIDOC CRM, CRMsci, originally defined to describe the geological stratigraphy entities. *S20* is a subclass of *E18 Physical Thing* and *E53 Place*, both classes of the CIDOC CRM model; therefore, *A8 Stratigraphic Unit* inherits the physical and spatial characteristics of them. The *A8 Stratigraphic Unit class* is composed of a volumetric part defined with the *A2 Volume stratigraphic unit* class, and from the stratigraphic interface, represented by the *A3 Stratigraphic Interface* class. The activities and processes related to the creation of stratigraphic units have been represented in CRMarchaeo with the *A4 Stratigraphic Genesis* class, while the processes, which have subsequently modified the shape and position, are encoded through the *A5 Stratigraphic Modification* class. The objects found in the SU are encoded by CIDOC CRM *E18 Physical Thing* class. Their condition to be "content" within a stratigraphic unit is encoded by this conceptual triple: *E18 Physical Thing (physical object) -> AP18 is embedded (is included) -> A7 Embedding* (Container).

Stratigraphic relationships between different SU are expressed through the *AP11 has physical relations* property, which, through the *AP11.1 has type* property describes the relations between US by referring to a common archaeological dictionary to document the relationship between SU. The terms used by CRMarchaeo are *fills/is filled by*, *cut /is cut by*, *is bonded with*, *butted*, *jointed*, *above*, *below.* Stratigraphic relationships between SU are encoded with the *AP13 has stratigraphic relation* property, represented by these types of reports: *before/after/same as*.

### 5.3.3 Case Study

Within ARIADNE, PIN and the Italian Central Institute for Catalogue and Documentation (ICCD) collaborated in order to facilitate the process of standardization of national archaeological data. ICCD creates a series of resources and recommendations, which includes a set of schemas to collect information in a structured way, thesauri and terminological tools to ensure language homogeneity. Amongst this set of schemas, the RA schema, used to record movable objects, is one of the most used for Italian archaeology because of the huge and ever increasing amount of artefacts found during excavations. Related to this schema, ICCD provided a detailed thesaurus to produce a correct encoding.

The RA Schema contains a large number of descriptive information and “cross-sections” allowing cross references with other ICCD resources. The RA Schema, together with the RA Thesaurus, features one of the best tools of this kind in the international panorama of cataloguing systems.

Over the past years of research, a deep analysis of RA schema and thesaurus was conducted, for mapping to CIDOC CRM and other international standards.

The previous mapping work was carried out on CIDOC CRM and took advantage of version 5 of the model, released in 2013. Version 6 and the CRMarchaeo and CRMsci extensions, much more suitable for the description of archaeological phenomena, have strongly enhanced the representation and mapping of excavation entities. Given this, it has been decided to update the previous mapping in order to provide a stronger archaeology-oriented logic to the various concepts and relationships that the RA Schema presents.

One of the most difficult problems to solve in the previous mapping was the representation of the "finding" event, intended as the excavation activity during which objects are found. This event is of paramount importance in archaeology because it is fundamental to trace the object's provenance and to reconstruct its history. Following the CIDOC-CRM model, archaeological objects have been represented by using the E22 Man-Made Object class. However, to describe their relationships with the two important activities of "survey" (corresponding to the "RE" field of the RA Schema) and "excavation" (specified in the "DSC" field), CIDOC CRM core only provided a "change of ownership" relationship that hardly fits here but we decided to use it anyway. Our previous mapping appeared as shown in Figure 18.


*Figure 18. ICCD-RA/CIDOC-CRM mapping.*

Thanks to the release of the new extensions and a deep analysis of the cross-section relating the RA Schema, the new mapping shows a more accurate rendering of these concepts. To express the "object found during an excavation" relationship, *CRMarchaeo* provides the *O19i was object found by* property, through which it is possible to link the artefact with the new S19 *Encounter Event* class, expressly designed to render the concept of "finding" as an event which occurred (*P7 took place at)* at a given Site (*E7)* identified by a given appellation (*P57 is identified by – > E44 Place Appellation),* as shown in Figure 19. This constitutes a more accurate representation of these concepts.

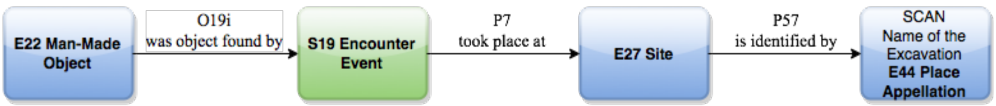


*Figure 19. ICCD-RA/CIDOC-CRM-CRMarchaeo mapping.*

## Using the Mapping Memory Manager Tool

The mapping process was assisted by the X3ML mapping framework developed by FORTH, and it was achieved by the close cooperation of the CIDOC CRM experts. The X3ML mapping framework includes the X3ML mapping definition language, the 3M Mapping Memory Manager, the 3M Editor and the X3ML engine The X3ML framework takes a completely different approach to other data mapping tools. Designed to separate out many of the technical aspects of creating Linked Data, it allows data experts to play a larger role in Linked Data generation creating better end results relevant for larger and wider audiences.

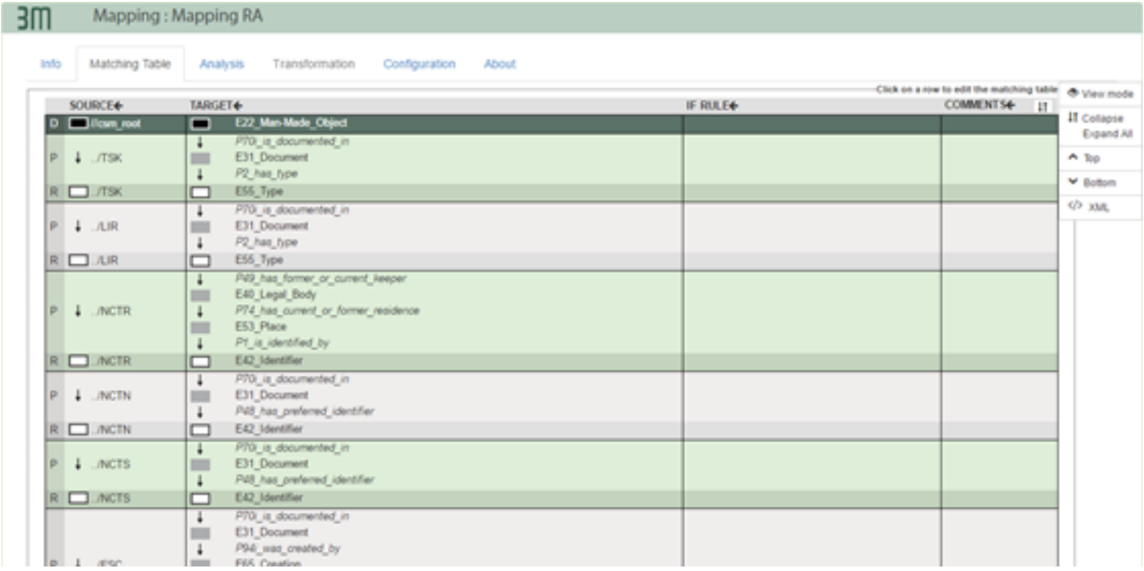


*Figure 20. Using 3M for ICCD-RA mapping.*

The 3M Editor is specifically designed to support mapping to richer ontologies and the CIDOC Conceptual Reference Model. The 3M Editor provides a simple user interface where the main mapping screen concentrates simply on mapping each element of a source schema to an appropriate sequence (path) of CIDOC CRM relationships and entities. The specification of the URI (addresses) generation is a completely separate process, which augments the X3ML mapping definition file with instance generation functions. X3ML provides a clear, human readable format for defining schema mappings.

### 5.3.4 Conclusions and Recommendations

Data standardization is a milestone to promote the long-term preservation of archaeological data. CRMarchaeo has been realized within the framework of the ARIADNE project, in which CIDOC CRM encoding of archaeological datasets has played the role of the “Electronic Esperanto”, ensuring a deeper standardization, looking towards the perspective of sustainability. CRMarchaeo has been created to support the archaeological excavation process and to provide an instrument to manage and integrate existing archaeological documentation. The main goal is the formalization of the heterogeneous knowledge produced by archaeologists, often recorded in different standards. The mapping of a complex schema, such as ICCD-RA, has already demonstrated, at least from the logical point of view, the coherence with CIDOC CRM / CRMarchaeo and a wide compatibility with its schema. From a methodological point of view, the work carried out has highlighted both conceptual and procedural challenges that arise when attempts are made to handle a complex structure in a standard tool. The results achieved are considered satisfactory. ARIADNE assisted ICCD in building and evaluating this process in every phase, from logical mapping to physical conversion of archaeological data. ARIADNE carried out similar activities with other European archaeological institutions (partners of the project) to achieve its main goal: the implementation of interoperability among archaeological data at a European level.

#### Recommendations

The CIDOC CRM extension CRMarchaeo allows addressing better the complexity of archaeological documentation in efforts aimed to integrate such documentation. Therefore, use of CRMarchaeo (as well as CRMsci and other CRM extensions) can be recommended to archaeological research centres and projects for data integration. This is recommended for integration at the local/project level as well as across different projects and institutions, for example in the framework of ARIADNE.

Institutions and projects intending to apply the CRM, CRMarchaeo and other extensions are recommended to look into already available application cases and use the proven Mapping Memory Manager (3M) for database mappings.

### 5.3.5 Summary

Over the last years of research, the CIDOC CRM project expanded its vision, becoming a modular model. The CRM collection of models (extensions) includes CRMarchaeo which has been developed in the context of ARIADNE specifically for advanced integration of archaeological documentation. ARIADNE recommends utilizing it at the local/project level as well as across different projects and institutions, and provides a framework for integration of CRM compliant datasets at the European level.

### 5.3.6 References

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## 5.4 3D Archaeology (CyI-STARC)

### State-of-the-Art and Future Directions

3D Archaeology is the creation and use of 3D models for representing, discussing and advancing archaeological knowledge. The field of 3D Archaeology presents a highly advanced state-of-the-art with regard to the technical capabilities to capture data, model and present 3D models of archaeological artefacts. Much less advanced is the use of 3D models for collaborative research that advances archaeological knowledge about past cultures. This case study first outlines the necessary components for detailed, comprehensive and accurate studies of artefactual remains. Second, the various current practices of representing archaeological artefacts are presented. We note that these representations, as such, lack the capability for collaborative research allowing discussion and collaborative advancement of archaeological knowledge in an e-research mode. E-research here means online representation, critical discussion and knowledge creation involving the researchers who propose a knowledge representation and others who scrutinize it, annotate it with additional information, suggest taking a different research perspective, and so forth. We suggest investigating e-research environments that provide such capability and place the collaborative research process in the centre of 3D Archaeology.

### 5.4.1 Archaeology in a Nutshell

Archaeology is the study of material culture from the past. Its primary objective is to reconstruct social, cultural, economic or spiritual aspects of past societies through research on material remains, products of these societies, within their anthropogenic and natural recovery context. The main assumption of archaeology is that matter, shape and decoration of artefacts reflect deliberate choices made by the artisans producing them, within given social, cultural and economic constraints. Therefore, a detailed, comprehensive and accurate study of such remains may reveal these constraints and thus enable a better understanding of past societies.

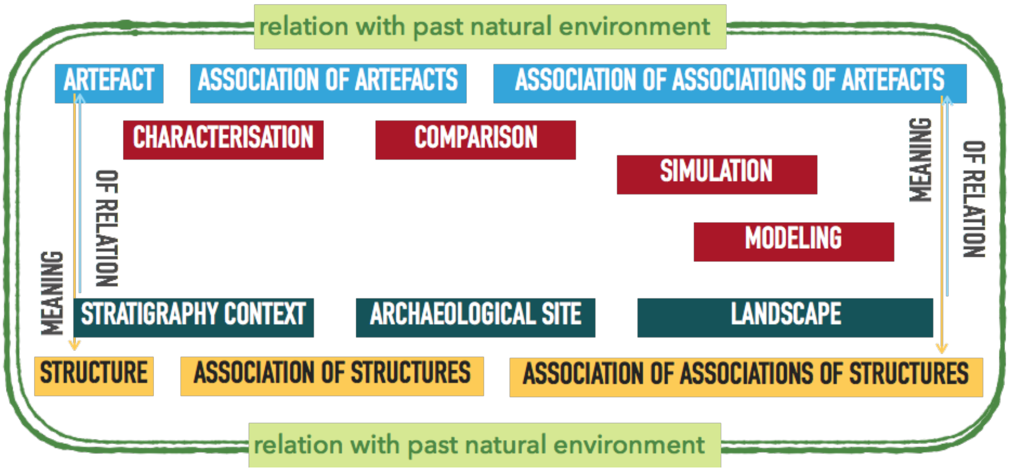


*Figure 21. Archaeological research, by components and investigation approaches.*

Basic research starts at archaeological sites – physical places where a deliberate human activity in the past yielded material culture remains and is investigated in the present. The focus of study is thus on artefacts, built features and structure, their physical location and their relationships with other material culture assets. Research integrates results from analytical investigations, such as chemical and physical properties, with geometrical measurements and shape comparisons and art history approaches (e.g. style). Figure 21 describes the basic framework of an archaeological investigation and its main methodological approaches.

### 5.4.2 Important components

#### Artefacts

The most frequent testimony of a past human activity, and consequently the most common subject of archaeological investigation is the artefact – an intentionally modified object from the past. It can be studied alone, or, as often occurs, in relation with other objects (association of artefacts). These are collections, or assemblages, where a causal relation between objects must be formally expressed and validated. Such relations often derive from a conjuncture of their discovery context (closely located to each other, repetitiveness of such associations in several archaeological sites, etc.). While the subject of study of such objects may be an understanding of their manufacture process, their possible use in the past or the social role they may have played, the study of association of artefacts is a key component for establishing cultural affinity of archaeological sites and their chronological positioning. Further comparisons between assemblages are performed to assess large-scale cultural developments or changes through time / geographic space or further insights into social, economic or cultural organisations of past societies.

A conceptual tool (chaine opératoire) has been proposed as a main framework for the study of artefacts. It focuses research on describing each crucial step in its lifespan and on the relationships between steps:

| | |
|---|---|
| *Stage 0* **Acquisition** | Which raw materials were used, their provenance and strategy of procurement. |
| *Stage 1* **Production** | How and where objects were made – technical production and influencing social / cultural / economic factors. |
| *Stage 4* **Utilization** | How and where objects were utilized and in which manner. |
| *Stage 5* **Discard** | How, where and why objects were discarded and what happened to them until their recovery in modern times. |

*Table 1. Main stages of the "chaine opératoire" conceptual tool*

An "operative schema" for the analysis of material culture remains can be therefore reconstructed. Its descriptive criteria are:

- Complexity of conceptual scheme, i.e. the mental construction that guides execution.
- Degree of chaîne opératoire preconception – precision of forward planning.
- Discrepancy between a project and its achievement – indicative of ability for problem-solving.
- Quality of production – the result of the compromise between technical skills and the planned work.
- Utilitarian productivity – the capability to adjust production to needs.

#### Structures and Features

Further to the investigation of artefacts themselves, archaeology is concerned with the context of artefacts' discovery, within archaeological excavation sites or when collected from the earth surface during reconnaissance surveys. Such a context can be an ancient natural landscape or habitat (e.g. a cave, rock shelter, palaeo-surface), a modified natural landscape (e.g. a rock-cut tomb, an underground dwelling, etc.) or, as in most cases, the context consists of built remains of a human settlement (buildings of various sizes and functions, industrial installations, defence constructions, water systems, etc.). Such remains may often overlap, testifying for several episodes of habitation at the same site, along a given period of time. Therefore, a major task of archaeologists is to clearly identify and separate between occupation layers, each corresponding to a distinct episode of human activity at the site, within a limited segment of time. Consequently, another effort in archaeological investigation is directed towards understanding the nature of relations between structures and artefacts found within a delineated space and to assess their socio-cultural meaning (Figure 22). Structures, association of structures, where a causal relation between structures has been identified (e.g. a village), or comparative studies between groups of structures are common research topics as well.

### Past Environment

Archaeological research often investigates natural past ecological systems and how they have influenced choices made by humans who produced the material culture under investigation. This may be related to, among others, choices made by humans in the past on settlement locations, strategies for exploiting natural resources, paths taken, sacred areas or defence systems. A common reference term is "cultural landscapes", where manifestations of past human activities are analysed within their natural environment. Research in this domain focuses on reconstructing paleo-environments, using several approaches, such as the study of pollen, phytoliths, faunal / floral remains from archaeological sites, palaeo-climate studies, etc. Once environmental conditions for the interested period / geographic area are set, the relationship humans / environment can be explored, mainly through various approaches of simulation or modelling. Typical subjects of such research is performing a site-catchment analysis, i.e. estimating the capacity of a given environment (in terms of water sources and energy sources (food) to support a given population, by calculating the energy a population needs to invest in order to gain sufficient energy from the environment to be self-sustained.

### The Time / Space Conundrum

Archaeologists often attempt at delineating material culture along a time/space axis, trying to isolate unique characteristics of material culture within a limited time / space border (Figure 22) in order to compare them with other characteristics of other time/space segments. These may be arbitrarily decided, may be related to a historic / natural event or may derive from direct chronological / geographic observations. Figure 22 presents various scenarios of analysis of material culture: in a given point in time/space (the human settlement in Rome in the first quarter of the 5$^{th}$ century BC, within a restricted geographic space, delimited by meaningful factors and over a given timespan (e.g. the temples dedicated to Jupiter in Rome between the 5$^{th}$ – 1$^{st}$ centuries B.C.), over a chosen geographic extension and within a limited timespan (the distribution of pottery kilns in Etruria of the 6$^{th}$ century BC).


*Figure 22. Archaeological investigation along the time/space axis.*

From the above it is clear that dealing with time and space, and time/space as well can be a tricky thing. Neither time nor space borders can be easily and meaningfully defined and thus require a special attention. A most recent proposal on how to solve the ambiguity of time/space can be found in Niccolucci and Hermon (2015).

## Agents in Archaeology

Alongside research on artefacts and structures within their context and environment, archaeological research identifies, isolates, and characterizes all factors (sometimes referred to as "agents") that contributed, in the past and in the present, to their current state of existence. A considerable effort is thus invested in estimating the impact of such agents on the analysed material culture:

- **Agents active during the lifespan of the analysed artefact**, directly related to the socio-cultural context, i.e. the society and the individual who produced it. These are analysed within two main frameworks:
    - <u>Technical production</u> - the knowledge and know-how at the concept level methods and techniques, i.e. technical behaviour, expressed in terms of:
        - Conceptual knowledge (*connaissance*) acquired through memorization of concepts – "mental representation of ideal forms and the materials involved.
        - Memorization of operation modes and procedure knowledge (*savoir faire*):
            - Ideational, arising from intelligence and memory, or
            - Physical movement, presupposing bodily skilled.
    - <u>Techno-sociological axis</u> - cultural, spatial and economic implications on which this production depends.
- **Post-depositional factors**, i.e. the processes that influenced the state and the condition of an artefact while buried in the ground, such as:
    - <u>Natural agents</u>
        - soil moisture
        - rain
        - wind
        - earthquake
    - <u>Anthropogenic actions</u>
        - agricultural activities
        - demolitions
        - re-use

Archaeologists analysing artefacts within the framework of such agents face several challenges: correctly identifying them, evaluating their influence on the analysed artefacts and understanding how they relate and influence each other. Research in this domain focuses on relating particular shapes, features or characteristics of the analysed artefacts to a particular agent or to a combination of them. Such studies often rely on experimentation (attempts at creating the same types of objects, under the same (estimated) constraints as in the past and monitoring such a production. Physicochemical studies are particularly relevant here as well, helping in identifying production sequences, materials used or techniques applied.

Understanding the influence of post-depositional agents (taphonomical studies) requires direct observations at the archaeological sites, which may include geo-morphological studies, geo-chemical measurements, environmental studies, etc. As above, understanding how one agent influences and interacts with others is crucial in correctly assessing their overall influence on the nature of the analysed artefacts and their archaeological sites. Simulation of natural events and their modelling may help assessing their impact on the studied artefacts.

## Archaeology and Social Science

Archaeology relates to the study of past societies. As such, it derives much of its theoretical framework from social sciences and anthropology. Ethnographic studies are often consulted and their conclusions are compared with the archaeological evidences. Models of social and cultural structures, based on sociological and / or anthropological studies, may be constructed and evaluated against the archaeological evidences; the opposite process occurs as well – based on the analysis of material remains, socio-cultural structures are constructed and corroborated with existing theories in cultural anthropology or sociology. Here again, such research relies on the ability to construct effective modelling of such structures and simulation of their behaviour.

### Archaeology and Humanities

Archaeologists who study historical periods (i.e. from when written sources are available) often corroborate their conclusions with historical research and thus an exchange of knowledge occurs between archaeologists, historians, epigraphists, philologists and so forth. Such research may also look at historic events from an archaeological perspective, or evaluate the written evidence against the material remains, as found in archaeological excavations.

Art history and architectural history are popular branches of humanities that often interact with archaeological research. Similarly, archaeologists analyse material culture from an art historical perspective, or rely on methods of architectural history to interpret standing monuments and structures unearthed during excavations or urban contexts. Recurrent concepts are, among others, analysis of decorative styles, methods of construction / production or social / cultural meaning of objects.

### Summary

In summary, archaeology as an integrative discipline, that relies on and integrates results from a wide spectrum of disciplines.

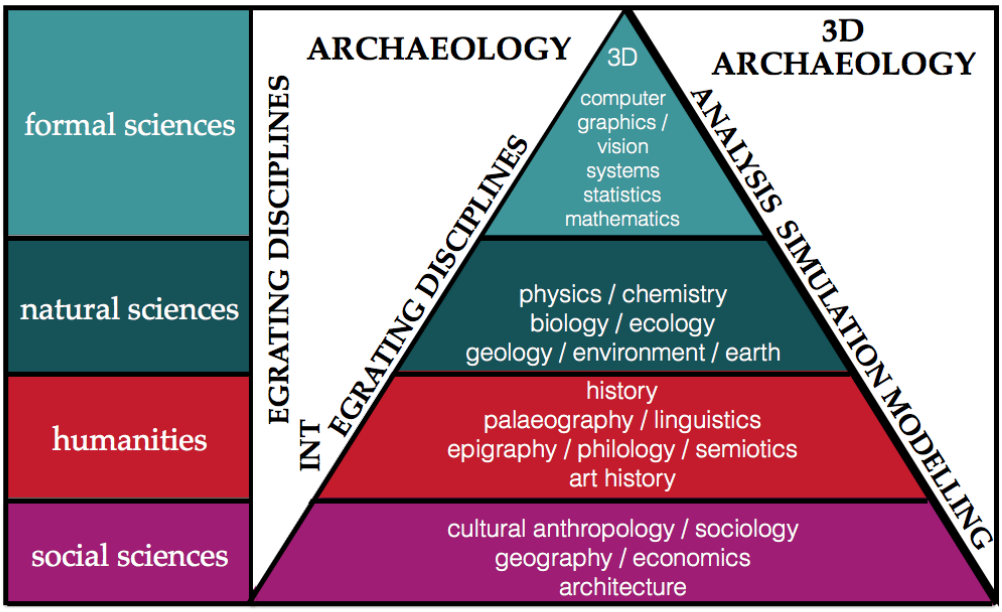


*Figure 23. Archaeology as an integrative discipline.*

The figure illustrates how 3D Archaeology can support the synthesis of results of different disciplines based on its capability to integrate results in the 3D modelling of artefacts, buildings and landscapes, simulate the integration and enable the analysis of the outcome. This is of course an iterative process in which new results are incorporated in the knowledge base, allowing improvements of 3D representations as well as substantial revisions.

### 5.4.3 3D methods and techniques

#### 3D Reality Based Modelling in Archaeology

It is common today that archaeologists still rely on traditional field documentation methods, based on hand made sketches and tape measurements, for recording most information about an excavation. The traditional outputs are often considered two-dimensional line drawings which however are not an objective record of reality.

Nowadays, thanks to the developments in other field of studies and to the multidisciplinary approach in the humanities domain, deal of archaeological data is 'born digital' in the field or lab. This means databases, pictures and 3D models of finds and excavation contexts. Together with the photo realistic qualities, these data provide a unique source for morphological, geometrical and stratigraphic features of an archaeological site.

Different techniques are today available for the documentation of an archaeological area, according with the needs requested by the project. The two main domains are represented by image based modelling techniques exploiting passive sensors (digital cameras) and range based techniques exploiting active sensors (3D scanner). Both of them can indifferently operate on terrestrial or aerial platforms.

##### Image Based Modelling: An Overview

Structure from Motion technology (SfM) functions by sifting through a series of overlapping photos taken from a variety of consistent angles (Figure 24), and finding points between them that match (Keypoints). After turning the matched points into a point cloud (Dense Stereo Matching), the software interpolates the geometry between the points and builds a model (mesh). Since the model is generated from 2D photographs, the software combines them into a single photorealistic texture which is wrapped over the geometry, resulting in an objective depiction of reality. For further accuracy and additional uses, control points in the scene are measured using a total station or GPS and used to geo-reference the model. The latter, is hence placed in a real-world location, allowing an easy integration with GIS software to produce overall site-plans and conduct a variety of spatial analyses.

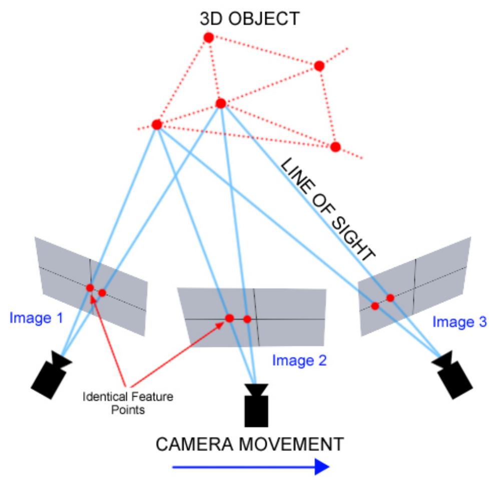


*Figure 24. Photogrammetric Geometric Principle.*

The benefits introduced by the image based modelling techniques not mentioned above are represented especially by the low cost and the portability of the equipment required. Today digital photogrammetry can be a feasible and flexible solution and a quasi-standard procedure may be found to suggest general best practices for systematic 3D surveys.

For the documentation of archaeological sites, which could in details range from the layer to layer 3D recording, to complex area digitization, different user friendly software are today available and widely used by professionals without a specific IT background (Agisoft Photoscan, Pix4D, Capture Reality, etc.).

### Range Based Modelling: An Overview

Range based modelling techniques rely on the use of 3D scanners which are able to acquire a large amount of three dimensional data and therefore are able to describe the site and its main metrical features, freezing its morphological memory at the time of the survey.

3D scanners fall under the acronym of LiDAR which stand for Light Detecting and Ranging and are mainly divided in devices which exploit laser light or visible light. Each technology comes with its own limitations, advantages and costs. Many limitations in the kind of objects that can be digitized are still present, for example, optical technologies encounter many difficulties with shiny, mirroring or transparent objects.

The scanners mainly used on archaeological sites are represented by Terrestrial Laser Scanners (TLS), based respectively on Time of Flight (ToF) (Figure 25) and Phase Shift (PS) principles due to their range of acquisition. A time-of-flight device is a range imaging system that resolves distance based on the known speed of light, measuring the time-of-flight of a light signal between the camera and the subject for each point of the image. A phase-shift scanner compares the intensity of phase of the laser source when the radiation is emitted and when it is received back again to the scanner after its reflection on object's surface-

A high definition 3D Scanner survey creates a model (point cloud) where the object's shapes and dimensions are described by millions of points. From the point cloud data is possible then to extract geometric information, with the main aim to produce:

- traditional 2D CAD drawings (plan; vertical and longitudinal sections);

- polygonal mesh to create interactive photorealistic 3D models for communication purposes;

- images from different point of views.

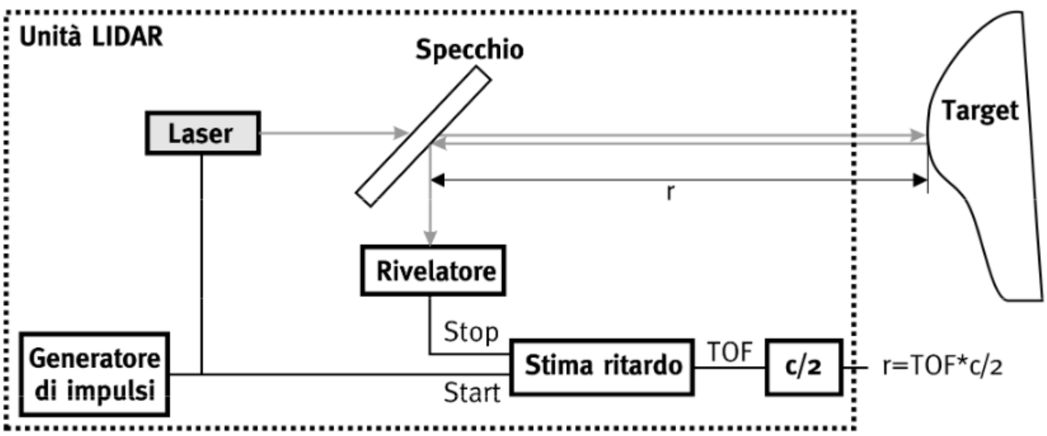


*Figure 25. TOF Working System (source: Guidi et al. 2010).*

In order to digitize objects from medium to small size different kind of scanner can be used, namely Structured Light Scanner or Triangulated Laser Scanners.

Structured light 3D scanners project a pattern of light on the subject and detect the deformation of the pattern on the subject. The pattern may be one dimensional or two dimensional. An example of a one-dimensional pattern is a line. The line is projected onto the subject using either an LCD projector or a sweeping laser. A camera, offset slightly from the pattern projector, records the shape of the line (Figure 26).


*Figure 26. Structured light system.*

A Triangulation Laser Scanner consists of a transmitting device, sending a laser beam at a defined angle from one end of a mechanical base onto the object, and a CCD camera at the other end of this base which detects the laser spot (or line) on the object. The 3D position of the reflecting surface element can be derived from the resulting triangle (Figure 27). Triangulated LS is usually used when an high resolution (micron) is required and the dimension of the object to digitize is less than few meters (archaeological artefacts, statues, etc.).

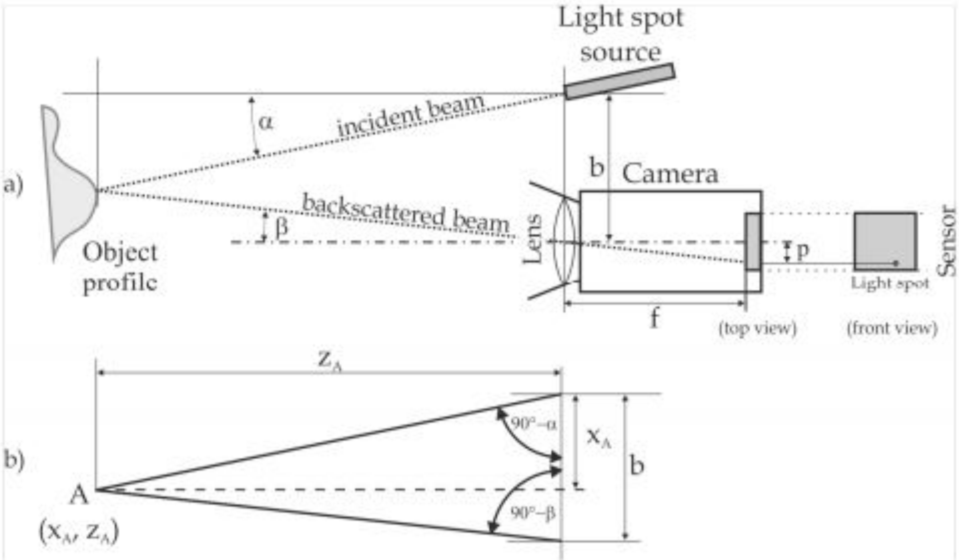


*Figure 27. Triangulation LS Working System (source: Guidi et al. 2010).*

## Use for Documentation

Comprehensive guidelines for the use of three-dimensional modelling techniques for documentation of cultural heritage have been developed by the Getty Conservation Institute (Letellier 2007) in Los Angeles (USA) and by the English Heritage (Barber & Mills 2011) in the UK for the so-called range-based techniques.

During the archaeological research there is often the need to record, detect and preserve sites and objects, as the documentation is an indispensable prerequisite for the analysis, the study and interpretation of artefacts and archaeological areas.

Nowadays our cultural heritage is under constant threat and danger. Architectonical structures and archaeological sites are threatened by pollution (Figure 28 A), mass tourism (Figure 28 B), wars (Figure 28 C) as well as environmental disasters like earthquakes or floods or climatic changes (Figure 28 D).

A 

B 

C 

D 

*Figure 28. Threatened heritage.*

The available technologies and methodologies for digital recording of archaeological sites and objects are really promising and the whole heritage community is trying to adapt these approaches for fastest, detailed and easy 3D documentations. Indeed 3D modelling could be extremely powerful to improve identification, monitoring, conservation and restoration.

It has become evident that the development of non-destructive investigation has led, together with the corresponding increasing of archaeologist's computer skills, to the creation of datasets of extremely complex structures. The activity of three-dimensional documentation is radically changing the documentation process in archaeology, as well as in architecture. We are moving from 2D documentation as basic data for the knowledge of an object to the 3D documentation from which it is possible to extract an unlimited amount of information in a very short time.

At the landscape scales, digital 3D modelling and data analysis allow archaeologists to integrate, without breaks, different archaeological features and physical context and better document the area. At the monuments/sites scale, 3D can give accurate measurements and objective documentation as well as a new view under a different point of view. At the artefact scale, 3D modelling allows to reproduce accurate digital/physical replica of every artefact that can be studied, measured, showed.

## Environments for Data Analysis

Nowadays different software and platform environments are available to analyse archaeological digital born data, even though some of them were not specifically designed for heritage oriented tasks. Four different areas of software can be distinguished:

- 3D acquisition
- 3D post processing
- Data analysis
- Online visualization

This section briefly presents each of these areas.

### Software for 3D Acquisition

Most of the products available for the acquisition and processing of digital three dimensional data are today commercial oriented.

Few efforts have been done in the open source community. However, often the trade-off is represented by the difficult process for installation and setup and by the absence of a GUI which force the user to run commands through traditional command lines input.

In the range based modelling domain the acquisition software is always bound to the hardware (Figure 29). The major scanner vendors indeed provide software packages which allow data acquisition and traditional post-processing tasks in the 3D modelling pipeline (alignment, noise removal, filtering etc.).

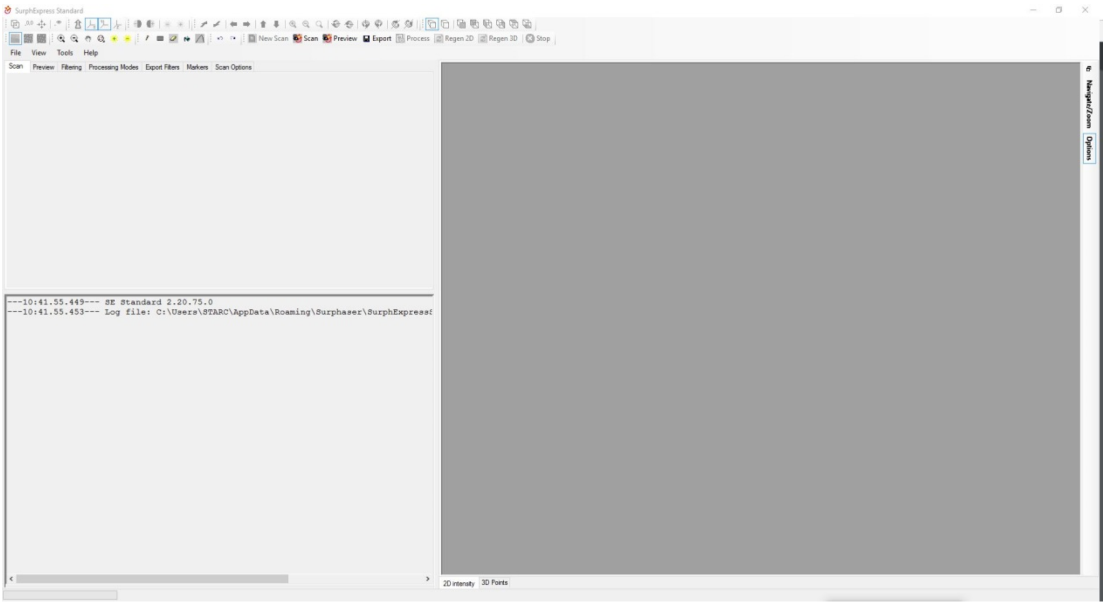

*Figure 29. SurphExpress acquisition software user interface for Surphaser PS scanner.*

For what concern structure from motion technique, today a wide panorama of solutions are available both open source (Visual Structure from Motion, MicMac, Open Multi View Geometry, Pyton Photogrammetry Toolbox, 123DCatch) and commercial (Photomodeler, Agisoft Photoscan, Pix4D, Reality Capture) (Figure 30).

*Figure 30. Agisoft Photoscan UI.*

However most of the products do not offer any tool, or a very limited number of options, for advanced data analysis and interpretation.

## Software for 3D Post-Processing

Post processing packages (i.e. Geomagic, Polyworks, JRC Reconstructor) are available as standalone products by third-part software houses (Figure 31). Although not specifically design to address issues related to CH, these SW suites are widely used by institution working in archaeology due to their potentiality to extracts geometrical information such as sections, plans, elevation maps and performed detailed morphological analysis.

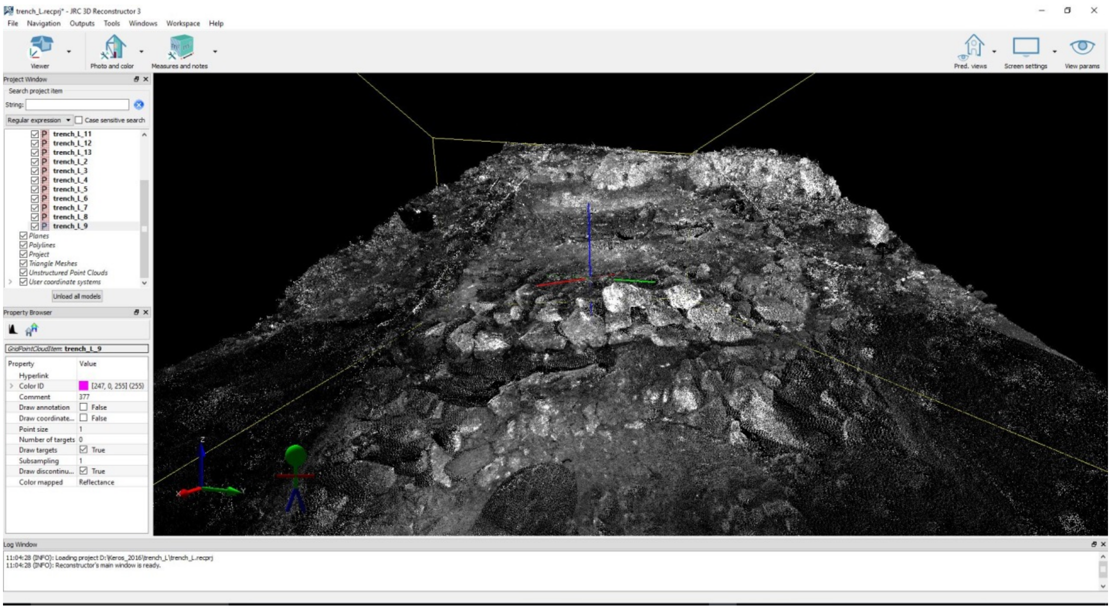

*Figure 31. JRC Reconstructor software.*

## Software for Data Analysis

Beside traditional operations described above, for scientific data analysis other software packages may be used to interpret and extrapolate information from digital archaeological dataset.

A useful resource for data analysis in the archaeological domain is provided by the BAJR Archaeology Software - British Archaeological Jobs Resource[1]. Despite of being an integrated platform, it lists a wide number of software useful for data interpretation and analysis, including GIS software, visualization packages and geometrical extracting features tools.

A product widely used today by the 3D heritage community is the open source software **CloudCompare**[2]. CloudCompare is a 3D point cloud (and triangular mesh) processing software. It has been originally designed to perform comparison between two 3D point clouds or between a point cloud and a triangular mesh. It relies on a specific octree structure that enables great performances in this particular function. It was also meant to deal with huge point clouds.

Many algorithms have been implemented into the software thanks to the contribution of different research institution enabling to perform a wide array of analysis from geometrical accuracy check to object and features classification (Figure 32).

[1] http://www.bajr.org/bajrresources/software.asp

[2] http://www.danielgm.net/cc/

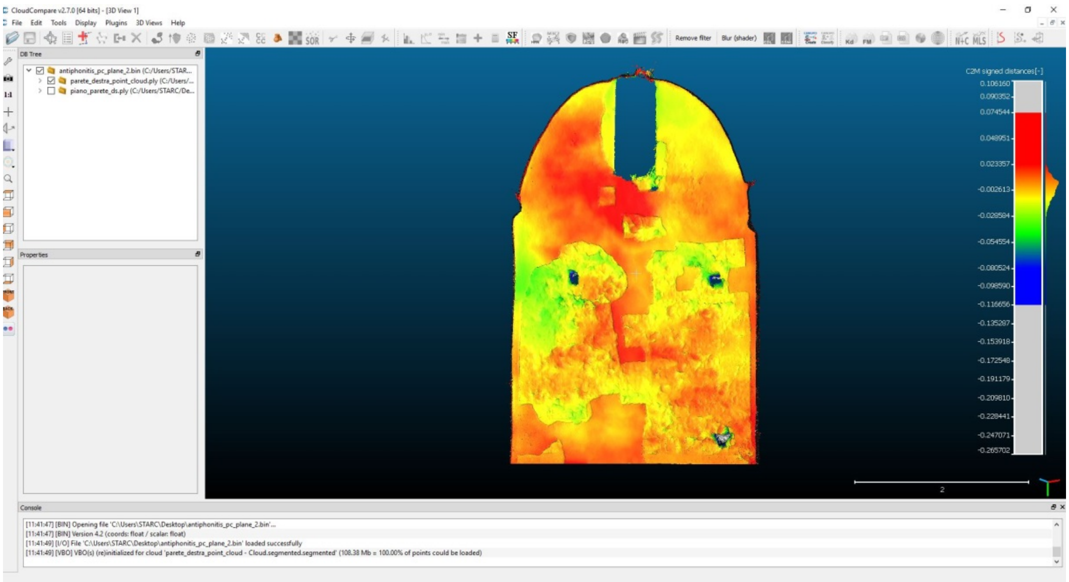

*Figure 32. Cloud Compare UI.*

**MeshLab** is an advanced 3D mesh processing software system that is oriented to the management and processing of unstructured large meshes and provides a set of tools for editing, cleaning, healing, inspecting, rendering, and converting these kinds of meshes[3]. It is well known in the more technical fields of 3D development and data handling but widely used by the heritage documentation and preservation community (Figure 33).

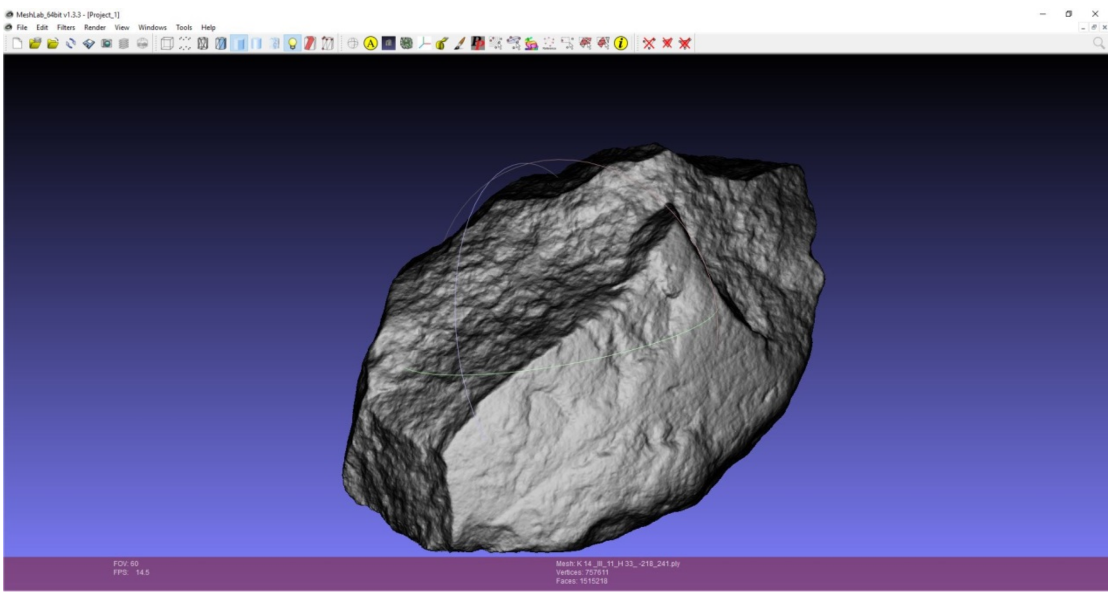

*Figure 33. Meshlab UI.*

## Online Visualization Software

Usually today archaeological data are 'born digital'. This means databases, pictures and 3D models of finds and excavation contexts could be available for public communication and sharing. Researchers

[3] http://meshlab.sourceforge.net/

usually restrict access to their data to a small group of people. It follows that data sharing is not so widespread among archaeologists, and dissemination of research is still mostly based on traditional pre-digital means like scientific papers, journal articles and books.

Dissemination and communication of archaeological data online through the web is today possible thanks to many platforms for data sharing and **3D visualization**. However, this practice is prevented mainly by the issues related to Intellectual Property Rights (IPR), which discourage archaeologists to publish and share data collected on site and elaborated after time consuming process.

Beside not open client server architecture, today are available free tools for the visualization of 3D data on the web.

The most used systems adopted by the virtual archaeological community are **3DHop**[4] and **Potree**[5] which allow creating interactive Web presentations of high-resolution 3D models, oriented to the Cultural Heritage field exploiting traditional web browsers (Figure 34). They are developed adopting a user-friendly approach so even users without dedicated IT skills are able to customize them. Besides visualizing 3D data, freeing the user (client) from any configuration issue, these WebGL open source packages have functionalities for basic 3D geometric features extraction.

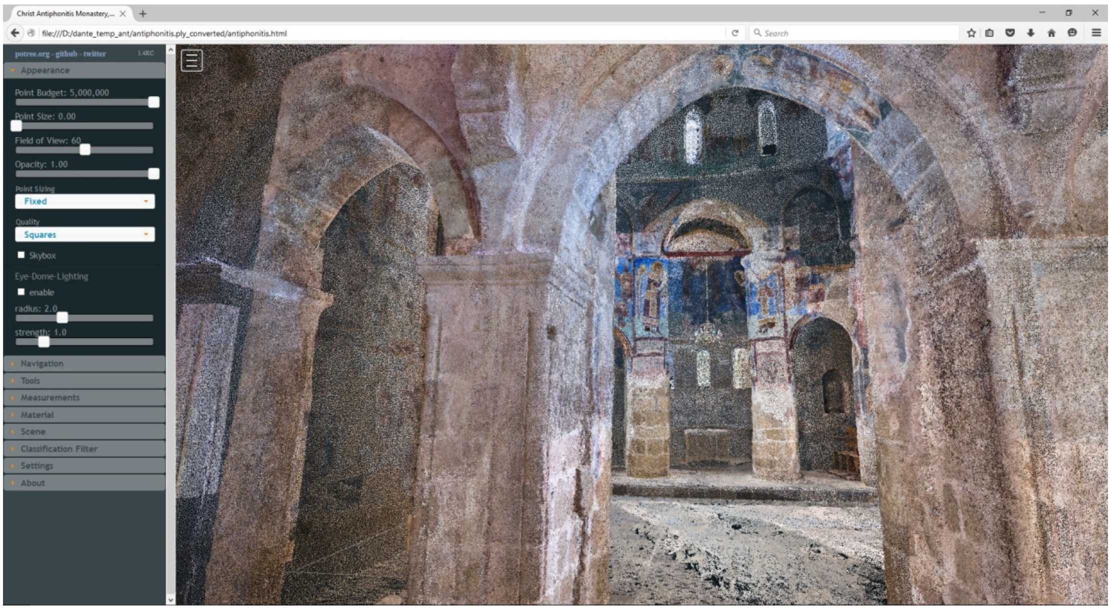

*Figure 34. Point cloud visualization with Potree through Firefox web browser.*

The **OpenSceneGraph** library is an open source high performance 3D graphics toolkit, used by application developers in fields such as visual simulation, games, virtual reality, scientific visualization and modelling. However, compared with the examples mentioned above it requires a deep background in IT and specifically in standard C++ and OpenGL language.

## Simulation

Simulating events and actions have been always a part of archaeological research which have largely benefits from the application of complex computer algorithms.

[4] http://3dhop.net/

[5] http://www.potree.org/

Mathematical tools have been used to describe cultural processes, construct and evaluate simulation models, and explore the potential of archaeology's unique data in the study of long-term cultural change.

Computer simulations in virtual archaeology can largely benefits from the use of Geographical Information System (GIS) software. This research methodology have been used successfully to reproduce, simulate and analyse ancient spaces, providing an interpretative framework which allows archaeologists to detect symbolic meanings embodied in the material evidence of the past. Especially in recent years, advances in 3D visualization and GIS technology have permitted new strategies for investigating human perception and the spatial configuration of human visual space.

3D simulation has shaded lights on the use of spaces and buildings by digital people performing specific rites, acting as guides or merely walking around. The use of virtual crowds for Cultural Heritage can help to predict behaviours or to help scholars draw more educated conclusions on unknown matters (Figure 35).

*Figure 35. Rome Reborn project, mass people simulation (source: http://romereborn.frischerconsulting.com).*

Reconstructing ancient buildings and cities from their remains has been one of the main applications of computer graphics in Archaeology for its visual potential. Behind a generic imaginative effect that might be considered fake or purely spectacular by a branch of the archaeological scientists, in several cases it has been demonstrated that seeing a reconstructed object in a simulated environment, may allow obtaining new archaeological discoveries. The visualization of actual shapes and their geometrical relationships with the context may act as a trigger to imagine novel scenarios (Figure 36).


*Figure 36. Villa of Livia, virtual reconstruction (source: Lucci Baldassari et al. 2013).*

### Direct Analysis (3D Shape)

Many analytical techniques are today available for geometrical analysis for heritage applications. These techniques are directed at experts in archaeology, history and/or conservation, rather than for communication with or engagement of the general public.

The majority of the research projects related to micro-geometric analysis focus on two main cultural heritage applications: perception enhancement and restoration.

Traditional questions which arise in the CH domain, are "how was this object was made?", "why was it realized this way?", "how has this changed through the centuries?", and "how can this object best be protected from damage?"

At micro scale, geometric operators are usually applied to high-resolution 3D models, to **analyze, extract small features and structures, and enhance the details**, such as high-frequency signals that are difficult to perceive (Figure 37).

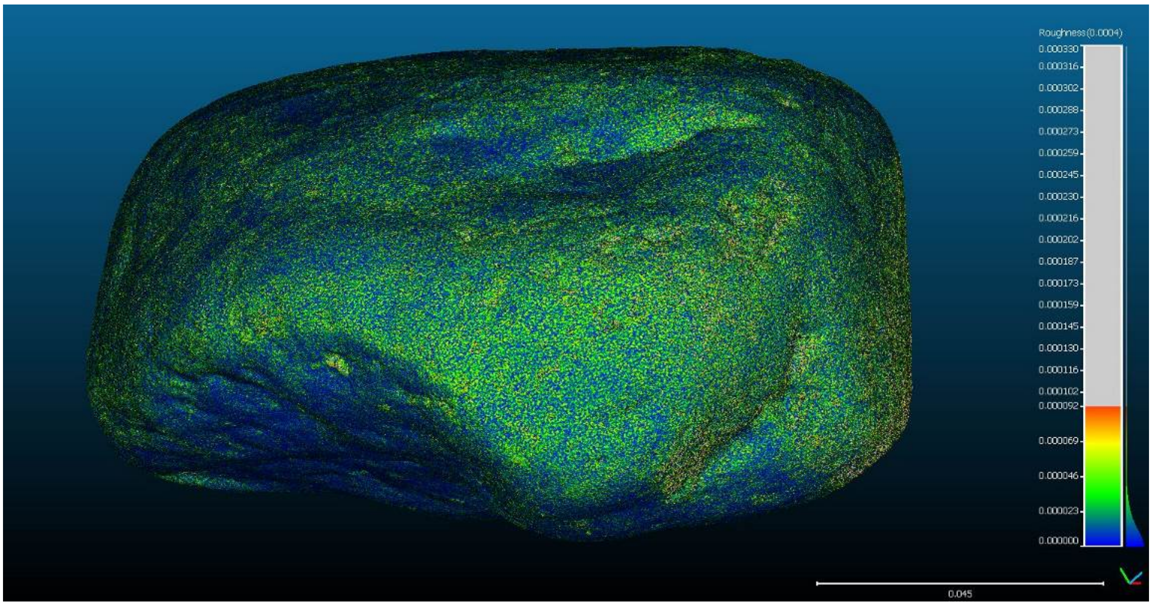


*Figure 37. Grinding stone micro roughness surface analysis.*

Another general problem in cultural heritage is the **monitoring** of micro-geometric changes over time. Many 3D acquisitions performed in a designed time laps are useful to track fine deformation and degradation of artworks switching the concept from three dimensional to fourth dimensional modelling, where the fourth dimension is represented by the time (Figure 38).

*Figure 38. Micro fracture monitoring (Bathow et al. 2010).*

Micro-scale analysis and geometrical features extraction have proven to be a central part of **reassembly** applications in the restoration field of study. When dealing with the reconstruction of fractured physical artefacts often the pieces have generally been scattered over time, so that no a priori information is available about the original aspect and shape. Digital fragments re-composition is a topic still under development according to different approaches proposed in the literature. These applications make use of various types of data primarily geometric, but RGB information and surface properties are also used. Many methods aim to be fully automatic, while others make infer a deep time consuming user interaction (Figure 39).

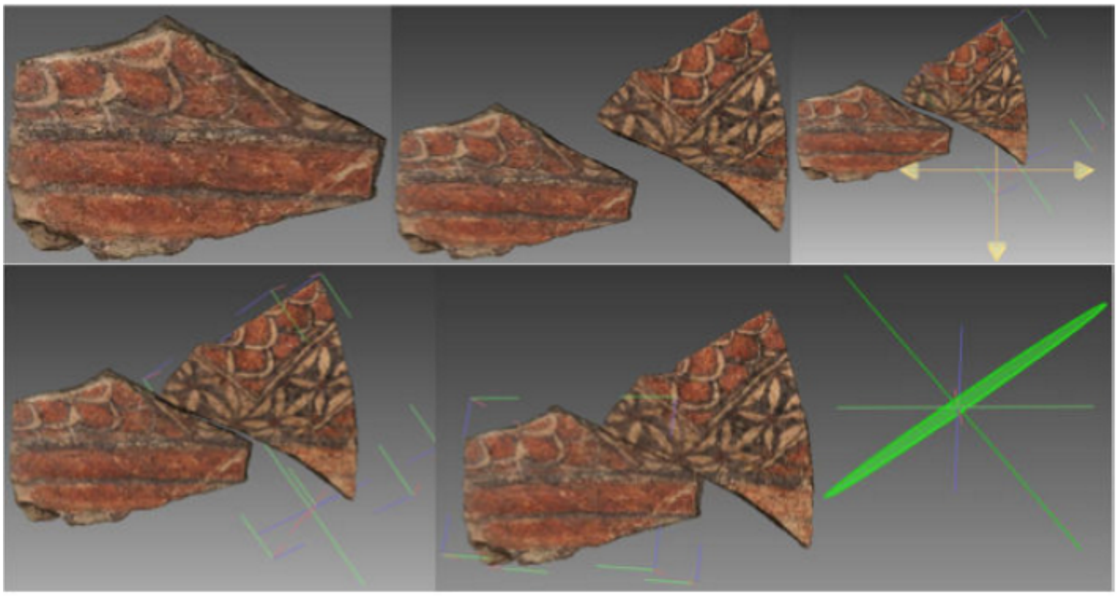

*Figure 39. 3D fragments models re-assembly (source: GRAVITATE project, https://staff.fnwi.uva.nl/l.dorst/gravitate.html).*

At large archaeological scale, **geometrical analysis** is usually used to compute macro measurements and calculations such as distances, areas, volumes which can help both in the quantitative analysis of an excavation and/or in the qualitative assessment of the data. A useful tool is represented by the possibility to create height maps which can enable the user to identify clearly archaeological layers belonging to the same period (Figure 40).

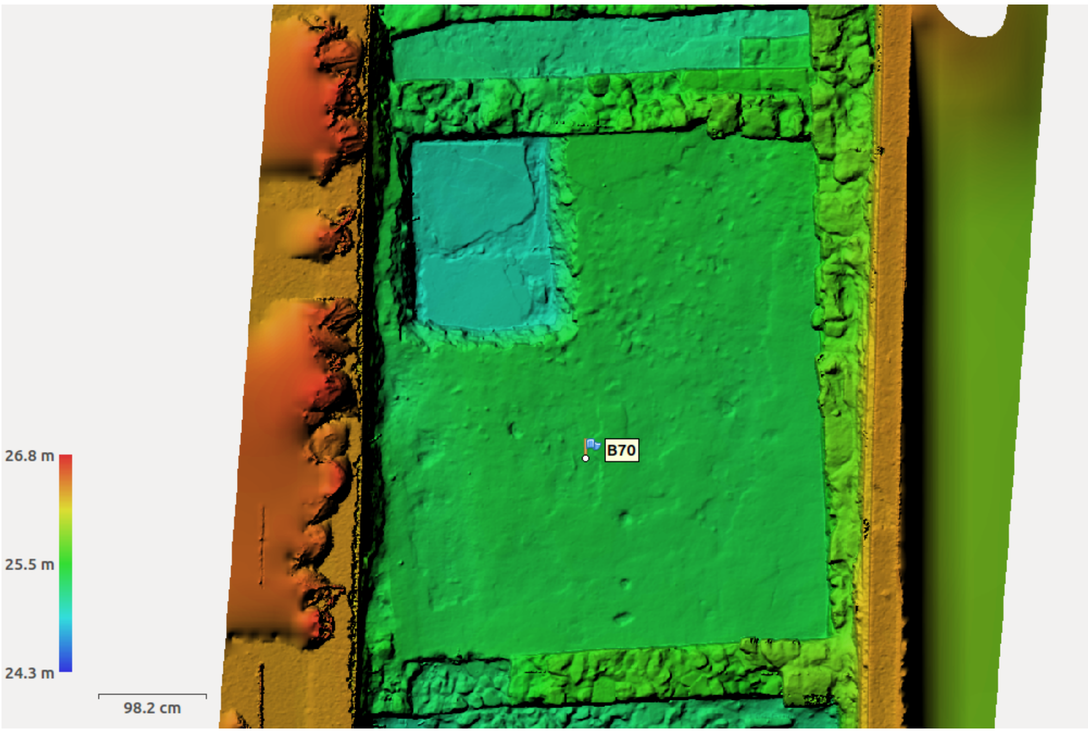


*Figure 40. Height map.*

## Geometry. Comparison and Refitting

Digital metrological methods, techniques and procedures can be fruitfully used for a **comparative geometrical analysis** and evaluation of the 3D data (for each single object/technique and between objects/techniques) of heritage related artefacts.

The data can be compared and analysed using different software in order to obtain qualitative data about a set of similar objects highlighting features otherwise difficult to understand like morpho-logical similarities, manufacturing details (vases production, coins production etc.) or anatomical features when working in the anthropological field (Figure 41).

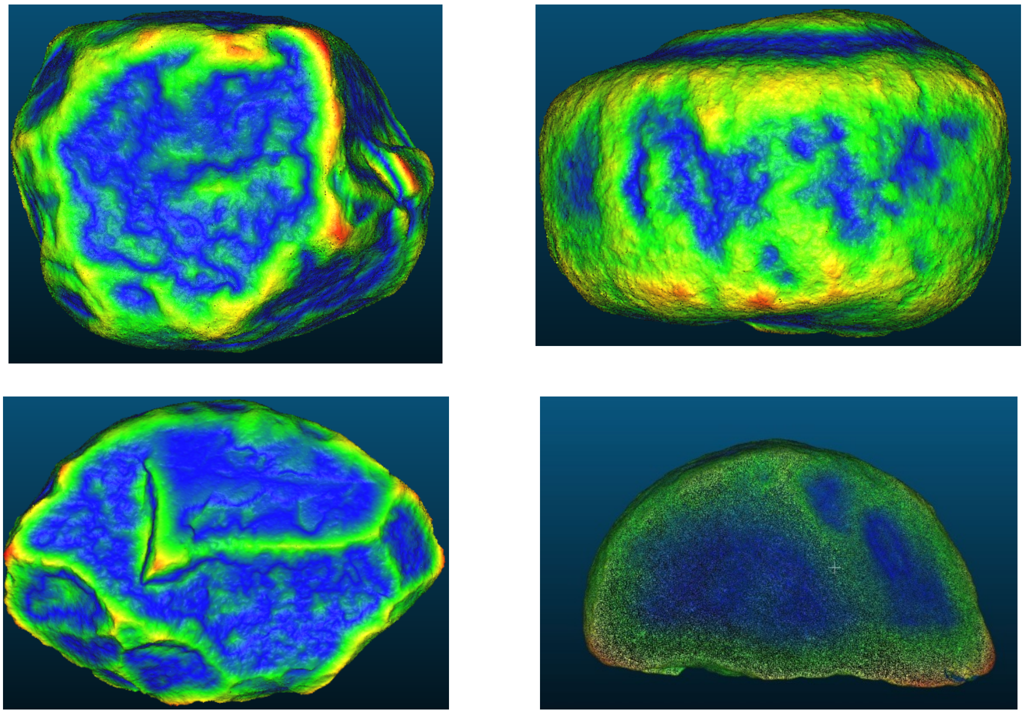

*Figure 41. 3D stone tools comparison.*

Many archaeological finds uncovered during excavations are fragments which may belong to the same artefact. Archaeologists select identifiable ones in order to assign their type, to understand cultural, economic, chronological and social aspects of the site under investigation. The main steps of potsherds study are: orientation of fragments, diameter estimation, profile estimation and drawing (diameter, vertical projection, profile).

In order to accomplish the second task digital techniques can result an invaluable resource to produce accurate reconstruction for the correct identification of the fragments position and serve as important tool for the restoration which will take over. Thus far, virtual reconstruction has been the most common CH application of 3D graphics. The focus of these technologies is not just to produce visual representations, but to permit the experimentation and assessment of different reconstruction hypotheses. These technologies thus increase knowledge rather than just producing visualization-related results. Such 3D applications can also assist with either real or virtual reassembly of broken or dismantled artwork or be used as output for creation of physical replicas through 3D printing techniques (Figure 42).

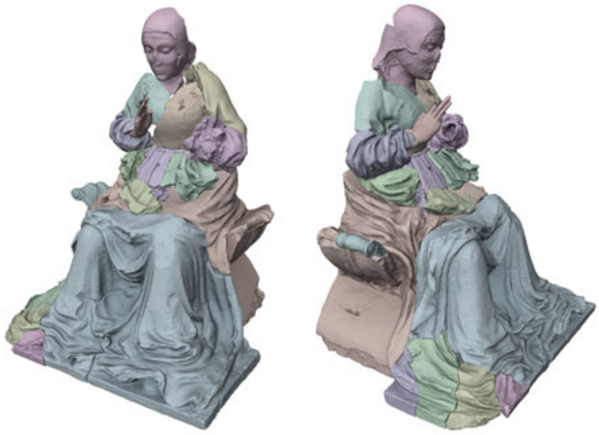

*Figure 42. 3D virtual restoration (source: Scopigno et al. 2011).*

## Structural Analysis

The introduction of new measuring devices such as 3D laser scanners, spherical photogrammetry, structure-from-motion photogrammetry and the latest methods of image-based modelling produced a strong change in the mode of acquisition, treatment and restitution of metric information. The increasing reliability of these techniques has allowed to successfully implement their use in the building surveying and structural modelling pipeline.

Many studies have shown the contribution that digital technologies can provide to:

- understand the structural behaviour of buildings;
- identify the origins and significance of cracks and misplacement of architectonic elements;
- create elaborated simulation using Finite Element Analysis (FEM) software.

In order for such contributions to effectively support decision making on different preservation approaches for complex structures, it is crucial to provide accurate and complete representations (Figure 43). To achieve such representations, all important values such as material properties and material behaviours under stress conditions must be taken into account.

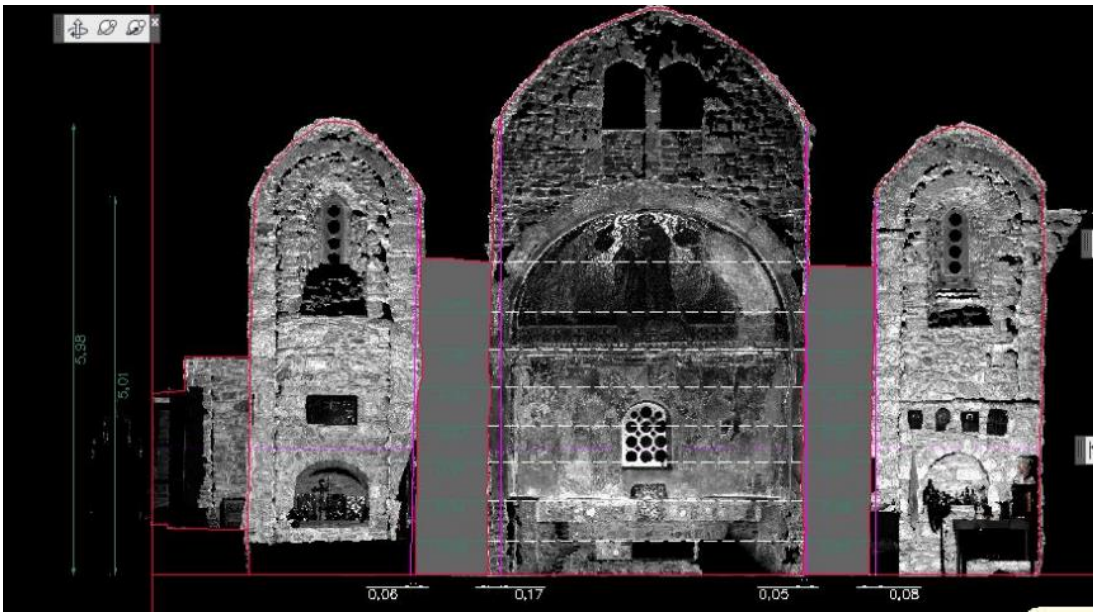


*Figure 43. Structural analysis.*

Only with a good comprehension of the way the entire structure behaves, and with a clear picture of the origins and reasons of damages, it is possible to diagnose and propose further preservation actions.

### 5.4.4 Discussion and Future Directions

#### Discussion of the Current State of 3D Archaeology

In the previous sections we have shown that the field of 3D Archaeology has achieved highly advanced technical capabilities to capture data, model, present and analyse 3D models of archaeological objects and buildings. These capabilities can be used for various research, documentation and conservation purposes.

Despite this successful development the scientific value of 3D representations is still being debated Lanjouw (2016) provides an overview of the discussion since the 1990s. As a brief summary: First there were mainly concerns about inaccurate and potentially deceptive 3D reconstructions, i.e. artistic 3D models for the public. This was followed by a focus on scientific criteria, i.e. finding ways to visualize uncertainty in 3D models and providing detailed background (so called "paradata") to allow scrutinizing representations (see London Charter 2009). Furthermore, the need of going "beyond illustration" by developing 3D based virtual reality into an experimental tool for digital heuristics and hypothesis verification has been emphasised (Frischer & Dakouri-Hild 2008).

The current situation presents a mixed picture. There are archaeologists who largely ignore the discussion about the scientific value of 3D representations and strive to improve their usefulness for archaeological documentation, for example by integrating them in GIS, e.g. the 3D-GIS projects MayaArch3D (von Schwerin *et al*. 2016) and Mapping the Via Appia (de Kleijn *et al*. 2015). Others highlight advances in archaeological 3D achieved based on good practice and suggest areas where technical and research capabilities might be developed further (Remondino & Campana 2014). Still others argue that 3D must be much better exploited in virtual reality environments for research, for example by developing tele-immersive capability (Forte & Pietroni 2009; Kurillo et al. 2010; Forte 2014).

In conclusion: There is a gap between the highly advanced technical state-of-the-art of 3D Archaeology and its capability to use 3D representations for generating new knowledge, for example by integrating and synthesising results of different disciplines.

#### Future Directions

The perceive gap between the technical and the research capability of 3D Archaeology suggest that we need a different approach for exploiting 3D representations as research tools. Generating new scientific knowledge is a collaborative process that proceeds based on scrutinizing and refuting or accepting (always provisionally) knowledge claims. 3D representations essentially are knowledge claims. This is most evident concerning 3D virtual reconstructions of large objects, acknowledged when "adding" missing pieces to smaller objects, and ignored when the representation seems to present an objects "as is".

We suggest that 3D Archaeology research should aim to provide advanced capability for collaborative development, critical discussion and verification of knowledge represented by 3D models. This requires embedding the scientific process in the 3D model generation and representation environment.

Online services recently developed in ARIADNE have very much eased the generation, publication and visualization (ARIADNE Visual Media Service, online). Now the next step could be to provide a virtual research environment that enables researchers to study a published 3D model, examine the research and technical background of this knowledge representation (i.e. meta/para-data), propose incorporation of new research results of different disciplines, discuss suggested revisions, and annotate the current 3D model with information for a such revision. This information could then be fed back into the 3D model generation to be integrated in a new version, which then forms the basis the next loop of this collaborative e-research.

Thus we suggest investigating e-research environments that provide such capability by placing the collaborative process of knowledge generation and validation in the centre of 3D Archaeology.

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## 5.5 Geo-Physical Field Survey (ArheoVest)

### 5.5.1 Introduction and Overview

In recent years digital geo-physical resources, particularly open access resources available on the web, have created a solid basis for various research activities. With the application of different non-invasive surveying technologies, the availability and circulation of information and re-usable data on archaeological sites has improved, providing advantages for both the scientific community and the wider public. This however requires proper organisation of the geo-physical field survey results in web-accessible databases. Such databases can focus on bibliographic information on scientific publications which present and discuss results of geo-physical prospections, technical reports on different survey methods and their application, and the geo-physical data generated in field surveys. Furthermore, there are websites which offer access to specialized programs for data processing (mostly based on a commercial license).

In general, uploading of raw data of geo-physical prospections onto a database does not allow for integrating research results. Because many factors need to be taken account of in the processing and interpretation of survey results, which can result from different methods (e.g. Ground Penetrating Radar (GPR), Electrical Resistivity Tomography (ERT), Magnetometry, and others). Therefore, the development of unifying databases for geo-physical research requires the coverage of various possible components tied together by a precise as well as flexible methodology. Some parts of the methodology may be rather common while others may differ considerably depending on the particular circumstances and techniques employed in different surveys (Becker 1995; Becker & Fassbinder 2001; British Archaeological Jobs Resource 2005; Clark 1997; Kvamme 2006; Schmidt & Ernenwein 2009).

### 5.5.2 Current Digital Practices

Although geo-physical prospections are known since the 1970s, and have been increasingly used to obtain data on archaeological sites, there still are only few central, unifying databases of metadata and datasets of such prospections. There have been a number of initiatives for a more centralised approach to prospection data, for example by organizations in England and Ireland (Historic England 2012; National Roads Authority Ireland 2014). However, no database exists at the European level which integrates the metadata or, even, datasets of prospections conducted in different countries and regions.

The lack of databases for registering datasets on the national level is due to the specific requirements and often restrictive practice of sharing results of geo-physical prospection projects. Such projects require a research methodology which comprises of systematic data acquisition, processing and interpretation, taking account of the particularities of the prospected area. Therefore, geo-physical raw data as such has limited utility. Rather databases must provide access to detailed description of the research methods, tools employed, and the data presented according to established standards.

The integration of the results of such research work in databases indeed is a more recent practice. In the mentioned cases, Historic England and National Roads Authority Ireland, access to the prospection databases has been mainly motivated by the need of making publicly funded research data available.

### 5.5.3 Case Studies

#### Historic England Geophysical Survey Database

The Geophysical Survey Database developed by Historic England (2012) is a good example of how the results of geo-physical prospections can be integrated in a database (Linford & Cottrell 1997). The database contains records of more than 2700 surveys in England stretching back to the late 1960s; furthermore, a small number of surveys in Scotland have been included. The survey database is based on Oracle 7 with a web front-end that facilitates the public access to the data. Importantly, the database provides unique identifiers, English Heritage Survey Visit No. and OASIS (Online Access to the Index of Archaeological Investigations) identifiers, because in 2006 the survey database was merged with the OASIS system to create a more comprehensive record of UK archaeological geophysical surveys.

The survey database provides 21 interrogation possibilities, including location identifications (national or regional monument number, the administrative department, the area's size given in geographical coordinates etc.); methodology elements (instruments type, the reading frequency of data, the electrodes configuration in case of ERT, etc.); details about the researched monument type, data about land use and its geology; and information on the availability of related reports or some bibliography attached to the survey record. Very important is the detailing, within the database, of the work methodology following the standards for the specific methods employed. The database is accompanied by a document which explains its structure and the database tables can be downloaded in CSV format.

#### Problems and Limitations

One limitation of the Geophysical Survey Database is that users cannot employ it for own research and populate it with new data, i.e. only the available data as of 2011 can be downloaded. However the database, particularly its methodology parts are very useful, so that it can serve as basis for other research, with some adaptions according specific requirements of research projects and/or national guidelines.

#### National Roads Authority Archaeological Geophysical Survey Database

The database of the National Roads Authority makes publicly accessible results of geo-physical research conducted between 2001 and 2010, commissioned to identify archaeological sites and monuments in advance of the construction of several roads in Ireland. The online database was launched in April 2013. It records geo-physical surveys on 73 road schemes across the country, covering a total area of just over 1,750 hectares. 733 surveys were undertaken at individual locations, including Recorded Monuments or Areas of Archaeological Potential; surveys for prospecting purposes also took place along the entire length of 26 road schemes, over areas of unknown archaeological potential (Bonsall *et al*. 2013).

The database can be interrogated based on 14 criteria of which two merit special mention, investigation method (Magnetic Gradiometry, Earth Resistance, Ground Penetrating Radar, etc.), and geology type met (Igneous, Metamorphic & Igneous, Sedimentary, etc.). Practically, the database represents a collection of research reports in .pdf format, which contain rich information about each prospection including, for example, the authorization number, geophysical expert, prospected area, etc. Based on geographic coordinates, some information can also be browsed on an interactive map.

#### Problems and Limitations

The database represents mainly a collection of research reports. Therefore, it does not offer multiple possibilities to sort and access data. Furthermore, it cannot be used to document own research and/or to add data. Similar to the previous case, the database is primarily an instrument for disseminating of commissioned research results.

### 5.5.4 Conclusions and Recommendations

The study looked into two databases of geo-physical surveys created and owned by national public authorities. Such databases are useful as a means to disseminate available results of research work commissioned by the authorities. There are not many such central databases and no database exists at the European level which integrates the metadata or, even, datasets of prospections conducted in different countries and regions. The content of the existing online databases may be used for research purposes, but the databases cannot be (re-)used for documenting research projects or contributing new results. For e-research in the field of geo-physical surveys there is a need of standardised databases dedicated to such research.

### 5.5.5 Summary

E-research in the field of geo-physical surveys requires standardised databases capable to document the complex research methodology of such surveys, including the systematic data acquisition, processing and interpretation, taking account of the particularities of the prospected area. An appropriate research database should allow documenting all variables, for example, including the machines type employed, the surfaces sweep method, etc. For further progress in geo-physical surveying, research publications should come with access to the underlying datasets, ideally contained in a shared database of the research community. This would allow that published research results can be scrutinized and corroborated with data from different research methods.

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## 5.6 Physical Anthropology (MNM-NOK)

To enable such research, advances in scholarly practices are required such as standardisation of data recording, data sharing and collaborative development of online databases. In the last decades, information about physical anthropology collections and research has generally become more accessible. Researchers have also shown an increased interest to collaborate online since sharing of data makes cost-effective research on larger datasets possible. A virtual research environment would allow online collaboration of researchers for combining datasets and conducting more complex research with novel analysis tools. But this will require substantial advances in the way databases for physical anthropology are being developed, shared and researched online.

### 5.6.1 Introduction and Overview

In the domain of physical anthropology, the increasing use of dedicated databases and web-based solutions for the dissemination of scientific information have generated fertile ground for sharing of data, which allows faster and more comprehensive research. The demand for effective data management and access first appeared in the context of large industrial developments that have largely increased the number of archaeological rescue excavations. There was strong need to conduct excavations at large scale and faster as well as to employ more effective data management solutions for the growing stock of archaeological documentation.

Physical anthropologists have also been challenged because there was a significant increase of human skeletal remains from the rescue excavations. Therefore, the analytical process, data recording and other methods for these remains needed to be reassessed. Furthermore, these changes promoted the establishment of guidelines and protocols for standardized recording and analytical methods in many countries. Different solutions have been developed such as specialized databases and software to help physical anthropologists record more comprehensive data and fasten their analyses and publication (some of the solutions are described in this case study).

A major advance brought about by the mentioned changes was that, in most cases, the analysis of human remains became connected directly with the archaeological work process, both financially and logistically. This made possible that the anthropological investigations usually could start alongside the archaeological fieldwork. Furthermore, new and expensive analytical methods (e.g. DNA, stable isotope) could be involved which previously were rather exceptional.

This new acquisitions of skeletal material allowed researchers to get acquainted with collection samples from different geographic area and periods, but there was a need for new technical solutions to store, manage, process and analyze the growing volume of data. Also noteworthy is that new digital recording and visualization methods, especially 3D, have been adopted that allow an advanced analysis of skeletal remains.

Initiatives have soon appeared to support the organization and study of data in digital form. Different database solutions have been developed to help researchers record and analyse samples (e.g. Bernert 2005; Osteoware and others) and allow access their documentation (e.g. Museum of London's *Wellcome Osteological Research Database*). Information and data have become more accessible and started to flow, allowing more interaction between research projects and institutes.

Researchers have shown an increased interest in these new advances since obtaining larger samples through the web makes cost and time effective large-scale studies possible. Digital forms of data can be applied in a more complex way, not only in research but also in education or in demonstrations for the public (e.g. 3D models). Indeed, where classical, paper-based methods came to an end, digital methods have opened new avenues for advancing physical anthropology in various respects.

This case study looks into some examples of web-accessible databases in the field of physical anthropology. The study aims to illustrate current approaches, discusses the kind of research fields or phases they support, and indicates existing problems and limitations. The examples include database solutions designed to permit the recording and querying of human remains data for research and curation of museum collections, databases of pathological skeletal remains in new formats (3D), online databases of excavated human remains from archaeological sites, and solutions proposed for specific archaeological research questions.

### 5.6.2 Current Digital Practices

Researchers in the field of physical anthropology need databases for various purposes which include finding and selecting relevant samples for investigations, consultation of reference examples, documentation of samples from new excavations, and use of samples for addressing particular research topics. In recent years a number of databases have been developed which, however, present some problems. Among these problems are that most have been created mainly for use by one institute and that the coverage of samples is limited. Therefore, the data of these samples are not representative regarding the geographical area and/or time periods.

A major issue also is that the existing databases are not harmonized based on an international standard, which is missing, so that the data cannot be easily compared and combined for collaborative projects. Adding to this is that the preferred methods used for data recording can differ between institutes of different countries and, even, within one country. In different countries the same applied methods can vary while others match, so that a database specialised for certain research groups may not allow recording of the data from the variety of methods which are being applied. However, in some countries guidelines for recording human remains have been developed, for example, Buikstra & Ubelaker (1994) in the United States, Megan & McKinley (2004) in the UK and Pap *et al*. (2009) in Hungary.

Still another problem is that the recording of certain skeletal data can be difficult (e.g. codes for lesions due to non-specific infections). Where this is the case, recordings can be interpreted comprehensively only with the integration of other data like sex and age, anatomical elements etc. Sometimes also the application of different statistical methods is necessary to get to a final conclusion. Therefore, databases are required which provide effective solutions for data export/import and combination of different data types (both quantitative and qualitative) so that the required route towards data processing and analysis can be taken.

Moreover, due to new analytical methods some the recording of particular features of skeletal remains can change and become more detailed as well as more complex. This requires a flexible database to be able to incorporate methodological and technical advances. On the other hand, it is also difficult to define how detailed and complex a database and its user interface should be. If it is not user-friendly the data entry and other processes can be cumbersome, and the database solution not acceptable for a wider range of professionals. In that case, if it is not avoidable, much training and support must be provided. In conclusion, a standardized database and widely adopted can only be established by a cooperation of an international team of physical anthropologists with significant IT and financial background.

### 5.6.3 Case Studies

#### Osteoware

The *Osteoware* database has been developed by the Smithsonian National Natural History Museum (2011). It is in use at the museum and available for installation also by other users. *Osteoware* is a good example of a current solution for recording physical anthropology data. In technical terms, it employs the Sybase Advantage Data Architect database, a data management system which is freeware and can be downloaded from the *Osteoware* website.

*Osteoware* allows the systematic recording of human skeletal material from archaeological sites and/or creation of a museum collection catalogue according to basic and widely recognised guidelines (Buikstra & Ubelaker 1994). The database can manage datasets of different sites and each site and even individual can be distinguished by an identification number (called 'catkey'). *Osteoware* provides twelve data entry modules, including modules for inventory, age & sex, pathology, cranial and dental data, etc. The interface provides check boxes and radio buttons for standardised data entry which follows general methods which are named in the relevant module. Additionally, detailed descriptions can be given in comment fields. There are also some special functions, for example, for managing photo and x-ray requests to laboratory staff.

The entered data of each individual can be summarised in reports by arranging texts and comments from the modules in a designed paragraph. In order to efficiently query, extract and process aggregated data some knowledge of SQL is required. With SQL, there are options for creating complex queries based on joining two or more tables, and the extraction of combined data allows subsequent meta-analyses. A detailed user manual is available on the website which provides helpful step-by-step instructions with good quality photos. Registering as a user with the *Osteoware Forum* allows posting questions online, reporting bugs, and voicing suggestions for future versions.

### Problems and Limitations

Using *Osteoware* for data of our skeletal materials catalogue, for example, to enter our catalogue numbers and data subsets (e.g. archaeological sites), first requires installation of the Advantage Data Architect. The *Osteoware* developers note that setting up the database with site data and inventory codes is an advanced function and best left to an experienced database manager. Such a manager is not necessarily available at smaller museums or as a member of an archaeological project team, which makes the database difficult to adopt by many potential users. However, reportedly an easier to implement solution is in development.

The database is very detailed and complex, however, some parts are not compatible with the standards of institutes in other countries (e.g. in Hungary sexing of samples is based on a different standard based on Éry *et al*. 1963). Also, it would be an advantage if certain archaeological data could be entered, for example, cultural periods, whose timespan can vary in different countries. This would allow users filtering sites or individuals to period or combine skeletal and other archaeological data (e.g. like sacral pits). We note again that advanced processing of data with *Osteoware* requires knowledge of SQL methods to query, extract and analyse data, the effectiveness depending on the practical skills.

## On-line Collections of Pathological Specimens

Study of ancient diseases based on pathological skeletal material is a major field of research in physical anthropology. It informs far-ranging archaeological topics such as the impact of infectious diseases on communities or effects of different dietary practices due to social inequalities. With the introduction of digital recording of specimens many new possibilities have appeared. These include high-resolution images or 3D replicas of pathological specimens that can be brought together as online reference collections supporting the identification, comparison and description of new cases. The investigations can be carried out with the digital representations instead of the physical samples which may be curated by different collections. We briefly describe two examples of online accessible collections.

The *Paleopathological Database* of Rizzi Giovanni & Co. Archaeological Research (Bressanone, Italy) is a database of over 650 high-resolution images (including some x-rays and microscopic images) and description of pathological skeletal remains. The skeletal material came from seven excavation sites in the Autonomous Province of Bolzano - Alto Adige, Italy, that has co-financed the production of the database. The database includes some historical background on the different sites.

*Digitised Diseases* is an online digital resource of pathological specimens made up of more than 1600 3D models of human remains. This database has been developed in joint initiative of the University of Bradford (Anthropology Research Centre and Centre for Visual Computing), the Museum of London Archaeology and the Royal College of Surgeons of England, funded by JISC (UK). *Digitised Diseases* contains 3D laser scanning, computed tomography scans and high resolution photography with new clinical descriptions and historical illustrations. The many web-accessible photorealistic 3D models are a useful resource for various disciplines including osteologists, palaeo-pathologists, archaeologists as well as medical historians and trainees. However, for the archaeological specimens the contextual information is rather limited. *Digitised Diseases* enables access to digital replicas of valuable and rare materials that previously may have been available only for certain researchers and studies. Pathological specimens are often the most handled bones within skeletal collections and therefore the most fragile ones. Therefore, initiatives such as *Digitised Diseases* can also play an important role in conserving scientific resources which otherwise are at risk of being degraded or damaged.

### Problems and Limitations

The main problem with such databases from an archaeological perspective is that they will tend to be limited with regard to their coverage. This concerns either the range of pathological specimens, i.e. from a number of regional sites as in the Italian case, or limited archaeological information as *Digitised Diseases.* The latter case arguably is due to an agreed minimal common description template. Bradford's Anthropology Research Centre and Museum of London Archaeology may have richer documentation of samples. However smaller centres due to lack of funds and technical support will find it difficult to contribute 3D models to a shared database. In general, representation of samples in 3D of course exceeds the limits of standard recording by collections of skeletal material.

## Databases of Human Skeletal Remains Collections

New research on skeletal remains from sites in large or different countries could be eased by integrated databases of such remains held by collections of museums and other institutions. The databases would cross-searchable and include sufficient information about the archaeological context from which the stored remains come, if they have already been studied by a physical anthropologist, where study reports are available, etc. This would the researchers spotting online relevant samples for their research, instead of visiting collections and going through specimen catalogues or older finding aids to (maybe) identify specimen they would like to study.

Unfortunately, comprehensive national databases of skeleton collections and samples do not exist as yet, consequently also not at the European level. Sometimes referenced as an existing search index is a "British and Irish On-line Database Index to Excavated human remainS (BODIES)", but this remained a proposal in 2004 to create such an index. The proposers pointed out that a comprehensive index could allow researchers *"locate and access human remains germane to their research questions. It will also enable the state agencies which manage archaeological resources to know what has been excavated, to identify gaps in knowledge (e.g. by period or funerary context) and thus to place new or proposed excavations in a better context"* (Millard & Roberts 2004). A recent guidance document of the British Association of Biological Anthropology and Osteoarchaeology still cannot point to an available index but advises to contact the Historic Environment Record offices and relevant museums (BABAO 2015).

Researchers can try and sift through online collection databases of individual museums that hold skeletal material. However, often they do not include information about such material in the publicly searchable catalogue, and allow access only to legitimate users upon request. Furthermore, researchers may explore burial databases where these have been made accessible online. Typically, such databases concern one excavation (e.g. an urn field or cemetery), although there are examples that have brought together results of a larger number of excavations. For example, *Past People of Oxfordshire*, launched in January 2016, collated over 7000 burials excavated from archaeological sites within the county of Oxfordshire, UK. The database documents archaeological background, burial practices and, where available, osteological information; also if remains were reburied or have become part of a collection is noted.

#### Problems and Limitations

The described situation is limiting the possibility of researchers to easily discover and collect information about available skeletal material that could be relevant to study for their research questions. This problem is present in countries with many museums and other institutions that hold skeletal remains and, subsequently, at the European level. Therefore, international research collaboration and projects are difficult to establish. Such projects, however, could increase our knowledge about past cultures and lifeways in different regions and periods based on comparative studies of human skeleton remains.

### Databases Designed for Special Research Questions

Human bioarchaeology allows posing many research questions that can be addressed by combining information of physical anthropology and other archaeological investigations. The information may require detailed recording of the skeletal and other finds or features of the sites included in the investigation.  As an example here we chose *Index of Care*, which is a website that implements the bioarchaeology of care methodology developed by Lorna Tilley (2013, 2015).

*Index of Care* invites researchers to document archaeological cases that evidence care provision to seriously disabled individuals (Tilley & Cameron 2014). The web-based database application is free to use for registered users. It provides different sections and worksheets designed for organizing and recording available information, guides the user through the process, explains concepts of the methodology, and provides a template for systematic interpretation of the information. The application suggests reflecting about the impact of the disability on the individual, the care giving and its social context. As individual cases are analysed the application supports explicit reasoning to allow transparency in analysis and review. A case study of a prehistoric disabled individual illustrates the approach.

#### Problems and Limitations

Many special studies in archaeology are based on individual cases collected from different sites. Online environments like *Index of Care* that support the systematic conduct of such studies are rare. However, such solutions could help advancing the knowledge base of archaeological research specialties whose studies depend to a large degree on qualitative analysis. In case base studies the cases are of course random so that careful reasoning about the available information, its provenance and limitation is crucial.

Increasing the knowledge base by providing an online facility to document and share case, ideally also an online discussion forum, certainly are good ways of collaborative knowledge generation. A major issue is that researchers are often not willing to contribute data to a community online database. This problem is likely to be present even more where they are meant to follow a methodology and use templates developed by others.

### 5.6.4 Conclusions and Recommendations

Projects in physical anthropology need databases that support the discovery of relevant samples for investigations, data recording and analysis, through to publication of results (reports and data) for further research on various research topics.

At the bottom, the catalogues of institutions that hold collections of or include skeletal material relevant for physical anthropology in the context of archaeology, present several difficulties: the catalogues, if digitised, are not easy to access online (e.g. only for legitimate registered users), and are not yet federated to allow cross-catalogue searches.

Further, at the level of research databases, those which have been developed in recent years also present significant problems: These include lack of international standardisation, hence differences in the data recording; individual solutions of institutes, hence limited coverage of analysed samples with regard to geographical area and/or time periods. Also, a good interoperability of these solutions cannot be assumed.

This leads to a situation where skeletal material samples and data cannot be easily discovered, compared and combined for collaborative projects, especially projects with a cross-country or European scope. Such projects would have a lot of research potential, for example with regard to research on populations of cultures of which remains are distributed over several countries. Also osteopathological research based on data from different countries could yield important results (e.g. on the impact of infectious diseases on cultures).

Moreover, integrated databases with rich documentation could allow identifying of particular cases which are relevant for special studies of bioarchaeologists, for example cases as required for the *Index of Care* and similar online research solutions.

Concerning recent initiatives to provide 3D models of skeletal material, these should come with rich documentation of the archaeological context from which the material has been collected. Otherwise the relevance of such models for archaeological researchers is limited.

#### Conclusions

- *Collections of skeletal material:* There is a need to federate the catalogues to allow cross-collection search of samples relevant for research questions in physical anthropology and archaeology.
- *Research databases:* Physical anthropology research databases should become more standardized and interoperable to allow data recording and integration for comparative studies. This requires a joint initiative of major institutions at the European/international level.
- *Virtual research environment:* Given a higher interoperability of the research databases, including databases of other domains, the development of a virtual research environment for comparative research would be possible. Independent from large-scale database integration, VREs could also be developed for case study based investigations.

#### Recommendations for ARIADNE

- *Coverage of physical anthropology research data:* The ARIADNE dataset catalogue contains only a small number of records concerning data and reports of studies of human skeletal remains. Thus an important area of information for archaeological researchers is not well covered yet. Therefore, more sets of data and reports should be incorporated. This concerns research databases, not databases of skeletal material.
- *Standardization of research data and databases:* Standardization of data recording and databases in physical anthropology (and any other primary archaeological data) is not a focus

area of ARIADNE. However, ARIADNE could promote and contribute to standardisation initiatives, especially from the perspective of dataset registration, federation and integration.

- *Development of virtual research environments (VREs):* Demonstration of the research potential of interoperable physical anthropology databases may promote further standardisation and sharing of databases. Therefore, a VRE would be beneficial that can demonstrate such potential based on a number of integrated databases of physical anthropology and other archaeological data.

It should be clear that the proposed activities require a close collaboration between anthropologists, archaeologists, database managers, and technical researchers and developers.

### 5.6.5 Summary

The case study addresses the development of databases in the field of physical anthropology, describes some current examples, and points out existing issues as well as potential for advances towards innovative e-archaeology.

Identified major challenges for e-archaeology are: data recording that is not based on an international standard, databases that have been developed with only one institution in mind, and lack of federated, cross-searchable databases; the latter concerns both collections of skeletal material and research databases.

For ARIADNE the case study recommends: to include in the ARIADNE registry/portal more sets of research data and reports of physical anthropology; to contribute to the standardisation of databases in this field from ARIADNE's perspective of dataset registration, federation and integration; and to consider the development of a virtual research environment that demonstrates the research potential of interoperable physical anthropology and other archaeological databases.

The case study emphasises that these objectives require a close collaboration between anthropologists, archaeologists, database managers, and technical researchers and developers.

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## 5.7 Archaeobotanical Research (SRFG)

### 5.7.1 Introduction and Overview

This case study first introduces archaeobotany with regard to its disciplinary scope and current developments. The latter include an increased accessibility of studies and data online, i.e. data shared through open access repositories, which contribute to research questions of environmental archaeology. Next, the case study addresses archaeobotanical research in the context of archaeological sites. This concerns the investigation of remains of plants as a contribution to the overall interpretation of sites. The study focuses on the identification of the plant remains, which means determining the plant species. The task often requires comparison of samples to archaeobotanical reference material as well as asking colleagues for help with the identification. This could be eased by a virtual reference collection and environment that collects images and context descriptions from many researchers and provides tools for discussion and collaborative identification. However, an appropriate solution has intricate requirements in professional, technical and other respects. The case study presents a specification of the requirements which includes also interoperability of data with research e-infrastructures, i.e. ARIADNE.

### 5.7.2 Current Digital Practices

This section first introduces archaeobotany as a research specialty within the wide, multi-disciplinary field of archaeology and points out some issues of archaeobotanists. The next section then briefly describes the current state of digital practices in archaeobotany as seen by authors of a major recent volume of the domain.

#### Archaeobotany – Definition, Disciplinary Scope, and Issues

Archaeobotany (also named Palaeobotany or Palaeoethnobotany) concerns the study of plant remains preserved on archaeological sites and their wider natural environment. These can be macro-remains such as wood/charcoal and preserved seeds as well as micro-remains (e.g. spores, pollen, starch grains, phytoliths). In recent years, methods for the identification and analysis of micro-remains have received ever more attention, including molecular analysis (i.e. ancient DNA analysis).

The archaeobotanical study results are being used to analyse what people gathered and cultivated for their subsistence, including how and where it was stored, processed and consumed. Of course agriculture, food supply and diets, and their change over time, are essential archaeobotanical research themes. Other research themes for example are the use of plants for constructions, decoration, drugs and medical treatment. Collected remains of wood are also being for dendrochronology. Moreover, archaeobotanical studies contribute to research questions of environmental archaeology. These concern past conditions and changes of landscapes and vegetation, ecology/biodiversity, land use etc. with a focus on reconstructing human relationships with the natural world.

Archaeobotany is a well-established field of research, with its own topics, methods and procedures (see e.g. Day 2013; Pearsall 2016), a core professional association, the International Work Group for Paleoethnobotany, and subgroups of wider research communities (e.g. International Association of Wood Anatomists, Society of Economic Botany, Society of Ethnobiology and others) as well as regionally focused groups (i.e. International Workshop for African Archaeobotany). The core journal is *Vegetation History and Archaeobotany* and there are many others which regularly publish archaeobotanical papers (e.g. *Archaeological and Anthropological Sciences, Journal of Ethnobiology* and others). To give an impression of the number of researchers active and/or interested to be up to date about publications in this field, on Academia.edu the topic of Archaeobotany has over 7000 followers.

Some years ago the archaeobotanist Naomi Miller conducted an online survey on research practices, issues and potential improvements in the field (Miller 2010 and 2011). 120 respondents completed the survey questionnaire, including contributions from Europe (65), North America (42), Latin America (9) and other countries (4) completed the survey questionnaire. 63 lived and mostly worked in Europe, 42 in North America and 15 in other regions. Most respondents were practicing archaeobotanists with a Ph.D. who had published three or more research reports. About half listed archaeology as their highest degree, about a third listed anthropology, and the remainder studied botany, ecology and earth sciences. Archaeobotanists in Europe mostly had studied archaeology and botany or ecology. The research interests of most respondents were focused on small-scale agricultural communities, food production and diet, and the environment of archaeological sites.

The survey covered all phases of the research process and asked for suggestions on how to address perceived challenges. Issues there were many, including not enough jobs, inadequate time to do the work, and in some countries need of better training and laboratory facilities. The main phase where the archaeobotanists faced problems in their research was the identification of seeds and plant parts (see below). Overall respondents wanted to have their work and results better integrated with the archaeological study, being part of the planning, execution, analysis and publication stages of projects, *"getting the dirt archaeologists to understand the value of our studies and stop them from sticking us into appendices"* (as one respondent summarised the issue).

## Current State of Digital Practices

In 2015 the book *Method and Theory in Paleoethnobotany* (Marston *et al*. 2015a) appeared, according to one reviewer *"an excellent volume that is the first of its kind to be published in over 25 years"* (Perrotti 2015). In the first chapter the editors describe the establishment of archaeobotany as a discipline and end with three future directions they see for the discipline (Marston *et al*. 2015b). The directions are increased accessibility of data online, more training of archaeobotanists in developing countries (leading to more publications from those countries), and a greater relevance of archaeobotanical research beyond archaeology, particularly with regard to issues of environmental and climate change. Our main interest here is in the first direction, which can also support the other two.

As evidence for a trend towards increased publication of data online the editors mention a number of resources such as distributional maps (i.e. Archaeobotanical Database of Eastern Mediterranean and Near Eastern sites), image sharing websites (e.g. Paleobot.org), online bibliographies (e.g. Kroll's Literature on Archaeological Remains of Cultivated Plants 1981–2004, and the JISC Archaeobotany Listserv. The latter is not really that new because this Listserv is active since 2002. A more recent professional practice in archaeobotany, however, is the archiving of entire primary data sets in digital repositories such as DRYAD (biological data), PANGAEA (environmental data), Open Context and tDAR (archaeological repositories). This is increasingly being requested or at least encouraged by funding bodies and journals.

Obviously the editors expect most from this development because *"it has the potential to reduce Balkanization of the field"* and enable re-use and integration of published primary data sets, *"which remains uncommon in the field"*. But this would allow larger-scale analyses and regional syntheses. Indeed, the editors stress that mandatory digital archiving in established repositories (such as those mentioned above) would allow that *"large numbers of botanical data sets that have been buried in grey literature will become accessible and contribute to future paleoethnobotanical research"*.

The impression given by this account is that the landscape of digital practices and resources in archaeobotanical research presents a rather patchy picture. However, one book chapter on *Digitizing* *the Archaeobotanical Record* describes the uptake of data recording (e.g. digital photography), communication (e.g. online forums) and dissemination tools (e.g. image sharing sites) over the last 30 years and addresses some examples in greater detail (Warinner & d'Alpoim Guedes 2015).

Naomi Miller's survey (Miller 2010 [appendix]) provides a valuable, very likely still valid indicator of which kind of web-accessible information archaeobotanists find useful when they are working on a laboratory analysis and report. The top three of the 54 websites, each with over 10 mentions were: *USDA Plants Database* (16), *Digital Seed Atlas of the Netherlands* (12), and *InsideWood* (11). The *Atlas* may require some explanation: it contains over 4000 full colour digital photographs taken with a microscope and represents 1828 taxa, mainly of wild plant species. The high-quality images and descriptions are not only relevant for plant identification of Dutch archaeobotanists (of which 3 participated in the survey), but for many others in Europe and beyond. Most of the other websites were mentioned by only one or two survey participants: "representative" with regard to the type of content are regionally focused databases (e.g. *Tropicos*), seeds characteristics/images (many), ethnobotany, including plant names (*Hawaiian Ethnobotany Online Database*), and scientific plant names (e.g. *International Plant Name Index*).

### 5.7.3 Case Study

The case study addresses archaeobotanical research in the context of archaeological sites. This concerns the investigation of remains of plants as a contribution to the overall interpretation of sites. The study focuses on the identification of the plant remains, which means determining the plant species. The task often requires comparison of samples to archaeobotanical reference material as well as asking colleagues for help with the identification. This could be eased by a virtual reference collection and environment that collects images and context descriptions from many researchers and provides tools for discussion and collaborative identification. But such a collection environment is not easy to build. The case study looks into a number of available options, including a collection management system (*Adlib Museum*), a wiki-based environment (*MediaWiki*), a system for specimen based biological research projects (*Morphbank*), the *Scratchpads* platform, and *Paleobot.org*, a web-site developed by a group of archaeobotanists. Based on the results of the case study a specification of the requirements of an appropriate virtual environment has been developed. The set of requirements is presented and discussed in next section.

#### Digital Practices in the Research Process

The case study looks into the process of archaeobotanical research in the context of archaeological sites. The research process comprises of

- collection of samples of plant remains from excavated soil,
- identification, description and quantification of finds,
- analysis and interpretation of the data,
- writing a report which presents and summarises the results (which are included in an interim or final report on the excavation), and
- use of the research results for academic publications.

This study mainly addresses digital practices and means which are or could be involved in the process, leaving aside general purpose tools for tabular data and text. The focus is on digital images which are very important for the documentation and identification of plant remains. Indeed, digital images of samples play a key role when archaeobotanists must look for reference specimens or ask remote colleagues for help with the identification of finds. The main focus of this study is the identification phase of archaeobotanical studies.

## Reports, Publications and Data Sharing

One general topic worth addressing concerns the archaeobotanical research results, i.e. reports, papers, and data of investigations. Archaeobotanists often complain that their contribution to the interpretation of a site is not being recognised appropriately, and that their data, analysis and interpretation end up as appendices to site excavations reports. This is a problem mainly of contract based work, where the outcomes are not carried forward to academic archaeobotanical papers or, maybe as a first step, a PhD thesis.

*Research papers:* These typically are short research reports on some interesting archaeobotanical results from one site in conference proceedings or journals, or a long journal paper presenting the major final results (and detailed evidence) for one or several sites. Professional contract archaeobotanists may have problems to exploit their data for publications because of contractual conditions, lack of time, or lost interest in academic recognition. A PhD candidate working at an excavation site (see example below) is typically allowed and, indeed, encouraged to publish results based on his/her data, because it extends the academic record of that excavation. The final results on the PhD's archaeobotanical topic, for one or several sites, here is the PhD thesis, which is also exploited for short papers and at least one long paper, ideally in a core journal of the domain.

*Research data:* The full research data of archaeobotanical and other archaeological studies is typically not made available or only after publication of the final results, i.e. by depositing it in a publicly accessible repository. In recent years the latter has become a digital practice because of open data mandates of funding bodies, which means that publicly funded research projects are obliged to make the data available.

*Researchers' reference collections:* Archaeobotanical researchers typically have an own collection of selected physical material and a lot of digital images of samples, which they use for the identification of new finds whose species they cannot easily determine. These images, produced over many years under sometimes difficult circumstances, are an essential professional asset of archaeobotanists. Even more valuable is their expert knowledge when plant finds are difficult to identify. Experts in the field often help colleagues who ask for help, for example, on the JISC Archaeobotany e-mailing list. Sharing of many own images, e.g. to build a community reference collection is a different story, which we address in later sections of this case study.

## Digital Images

Digital images of plant remains are regularly produced in the laboratory, which in larger excavations can also be established on-site. The images are being used to document samples, identify unclear finds, present and discuss finds, and as evidence in reports and publications.

Figure 44 shows the work environment of a British PhD student taking images of charred seeds in a lab at the large-scale excavation of the Neolithic settlement site Çatalhöyük in Turkey (Green 2015). The researcher specialises in wild plant species (weeds), which may be well-preserved in charred form (i.e. in the context of hearths or burned down grains storage). A typical work day of the researcher consisted of sorting through samples of excavated and sieved/flotated soil, picking out what appeared to be charred seeds, and use a light microscope with digital camera to examine and photograph relevant specimens. The detailed identification, documentation and analysis she conducted back home based on these images.

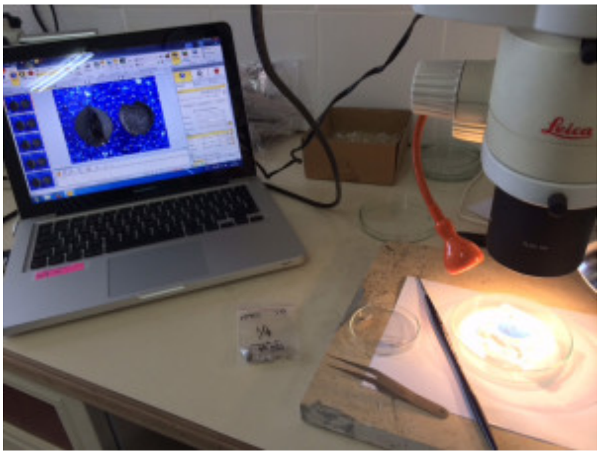



*Figure 44. Photographing charred 'weed' seeds at Çatalhöyük. Source: Green 2015.*

The set up comprises of a Leica light microscope with a digital camera on top from which images taken are transferred via an USB cable onto the laptop; the laptop is equipped with software for managing the image collection. In interviews of the eIUS project with researchers of the large-scale excavations of the Silchester Town Life Project (UK) an archaeobotanist described a similar set up. There the microscope images were also uploaded to a central excavation database and the researcher could give others a context or sample number to look them up (eIUS 2009 [interviewee 5]).

*"I also spent parts of the day photographing some of the wild taxa that I found, using a special camera that fits onto the microscope, in order for them to be more accurately identified back in the UK. Identifying seeds to species can be very time consuming, particularly for wild taxa, and it often requires a comprehensive modern seed reference collection. Unfortunately, this is not something that can be brought along with me, nor did I have enough time this visit, so quality photos of the charred specimens for identification back home are the next best thing. (…) Now back in (rainy) Oxford, I am currently processing through the many images taken during my fieldwork and sorting them into different weed types. The lengthy process of identification now begins…"* (Green 2015).

## Identification as the Main Problem

Identification of the species of the plant remains is the most important phase in the archaeobotanical research process as all further steps and their outcomes depend on this. According to the Miller survey it is the main phase in which the researchers face problems (Miller 2010 and 2011). Here the survey respondents wanted to have better online reference collections/ databases aiding the taxonomic identification. Also online access to other resources (reports, datasets) was on respondents' wish lists. But reference collections/databases for seed and plant part identification, with adequate specimens, images and description, was clearly the most pressing need. This need was expressed also by respondents who work in regions where ancient floras are generally well known.

Naomi Miller notes important requirements for appropriate online databases, which *"need to be institutionally and/or communally maintained and should be set up so that content could be added by individuals"*, and emphasises, *"what we really need are databases that can be contributed to collectively by practitioners and that will outlive their creators"* (Miller 2010: 3 and 21).

### Why Typical Botanical Reference Collections are Often Not Adequate

Since the later 1990s natural history museums, botanical gardens and herbaria have increasingly digitised and brought online their botanical collection records. These records present and describe well-preserved specimens, collected for taxonomic and reference purposes, i.e. some are so called type specimens associated with the authoritative scientific name of the species. Although there have been quite some efforts to aggregate and integrate botanical reference collections online, many are still isolated web versions of the institutions' collection databases. These research resources are in general openly accessible, but structured in different ways, and varied coverage of species and regions as well as quality of specimen documentation (images, description, literature references).

However, the core problem in our study context is that records of such online reference collections are of limited relevance to archaeobotanists. Their visual content is scans of botanical sheets and drawings or photographs of carefully selected and stored specimens. This content may be helpful in some cases to identify well-preserved plant remains recovered in excavations. But archaeological plant remains typically have undergone processes such as desiccation and carbonization, which can alter their appearance and often poses a challenge for their taxonomic identification. Therefore, archaeobotanists need online reference material for such remains with high-quality images, contextual information, and, ideally, identification keys for such remains.

Warinner *et al*. (2011) note that the reference material of botanical online collections (e.g. botanical sheets), *"are generally not useful for aiding in the identification of macro- or micro-fossils"*. They are *"biased toward common taxa"* (i.e. may not include ancient species) and lack the images required for the identification of such plant remains. With regard to the (few) online resources which contain images for archaeobotanical research, the authors note that their geographic coverage *"is generally restricted to only a few, mostly Old World, cultural areas".* Archaeobotanists who work in under-studied regions or are engaged in cross-regional projects will find little for their research online. Moreover, the existing resources are *"heavily biased toward macro-botanical remains"*. Micro-remains such as starch and phytoliths are of course also not covered by standard botanical reference collections.

### Asking colleagues for help

The situation described above raises the question what archaeobotanists do when they are facing difficult to identify plant remains. The answer of course is asking colleagues for help. There are not many archaeobotanical specialists around even at a large excavation or institute. Therefore, they often contact experts of their circle of peers. Before the Internet researchers had to send colleagues copies of slides of unidentified finds physically by mail or arrange an in-person visit.

One opportunity to ask several colleagues for help directly are dedicated workshops. For example, the Archaeological Soil Micromorphology Working Group has organised such meetings since the early 1990s as "hands on" workshops where participants bring thin sections of material for microscope-based examination, discussion and collaborative identification.

In a focus group interview with archaeologists working on the large-scale excavations of the Silchester Town Life Project (UK), one archaeobotanist explained: *"The way I interact with people is going to workshops with all my slides. They have them quite regularly, it's the International Soil Micromorphology Working Group, which happens usually yearly, so I tend to go to those. Then you can take all your slides and ask for other people's opinions. And everyone else brings their slides as well […]. You could [share the images online], but I think the problem with looking at this stuff online is that you're looking at microscope images, so it's often difficult to interpret something just from a photograph. […] Because [if you are there] you can look at the slide as a whole, also the person might have photographs of the site that it's come from, but I really need to look at the whole slide rather than just one little bit. [...] I do email backward and forwards the odd photo and ask for their comments or whatever, but it's not the same as being there. [...] I email individual people [rather than mailing lists], I usually know who to target to ask specific things"* (eIUS 2009 [interviewee 5])

The Internet provided new ways to ask peers for help by e-mailing close colleagues digital images and/or post a request to subscribers of a mailing list of the research community.

### Mailing Lists

The internationally most widely used mailing list is the JISC Archaeobotany Listserv (over 700 subscribers), which facilitates the exchange of information on all relevant topics. Since 2002, hundreds of requests for help with identification of plant remains have been posted and, obviously, useful help has been provided.

Identification requests typically concern one or a few finds and include images, general contextual information (i.e. region and historical period of the project), and further details relevant for the identification of the plant remain. Also posters often mention an assumption of what it might be. In

October 2016, 5 of 14 JISC listserv messages, in November 6 of 18 were such requests for help. Other messages concerned calls for papers, post doc positions, upcoming workshops, change of e-mail addresses, etc. Some requests initiated threads of discussion by several experts, others received at least one suggestion (most often 2-4), and one request concerning seeds from central Thailand by an American researcher did not get a response.

Below one example of a request and suggestions is presented (without the names, institutional affiliation, and courtesies of the participants). The request was on the 17th of October 2016, around 9 am, and the suggestions given during the same day.

ID help Medieval Oslo: "*I need help with the identification of two seeds from the Follo Line Project in Oslo. The first looks a lot like several seeds found in the Lamiaceae family, just not exactly like any one in my literature. The other is unfamiliar to me, and it is plentiful in only one of our samples. The scale in the photos is 1 mm*".

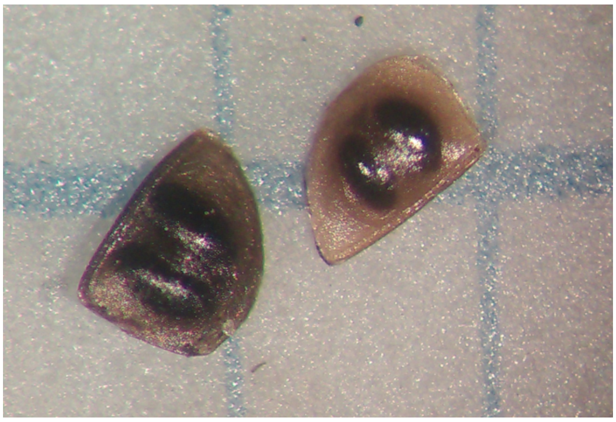


Figure 45. Varia

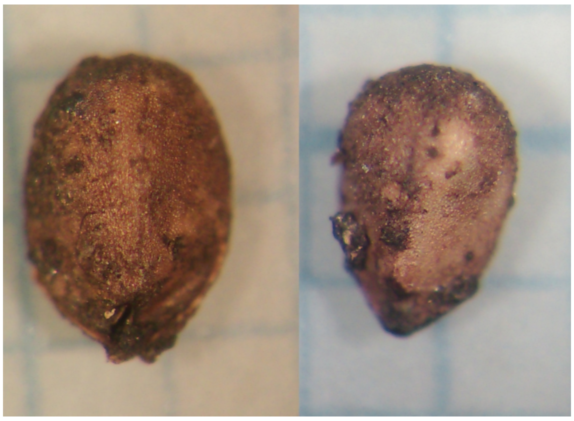


Figure 46. Lamiaceae

R1 [Germany]: *"Two seeds of Daphnia in a pod ... Animal kingdom!"*

R2 [Germany]: *"Varia are ephippia of Daphnidae / Daphnia (water fleas), the Lamiaceae could be a bit corroded Prunella vulgaris, a bit difficult to identify from the foto".*

Response to R2: *"As others have also suggested, my picture shows dormant Ephippia from Daphnia. This is very useful to the interpretation of the structure the sample is taken from. As for the Lamiaceae, it is not a Prunella. These occur frequently in my samples, so I've had the opportunity to compare the two".*

R3 [Netherlands]: *"I would think towards the Stachys direction…arvensis/sylvatica?"*

R4 [Norway]: *"I agree with [R3] for both finds. Finds of Daphnia are indicators of fresh water and local hydrology, and thus of help in the interpretation of past environment.*

Response to R3 and R4: *"I have compared the seeds with Stachys in the literature before, and also with Stachys sylvatica that I have in my reference collection. They seem a bit too round to be a match, but still it may be variations within the species. I have no better suggestion myself".*

Some interesting aspects of the conversation are: The researcher has an own reference collection and also uses the literature, but in the case of these rather well preserved two *Lamiaceae* (of the mint family of flowering plants) no conclusion was reached, also not with the help of other specialists. The *Daphnia* (water fleas), easily identified by two experts, illustrate that archaeobotanists of course also face remains of animals. For example, a thread in November 2016, "Euphorbia lathyris?", discussed the question if images of an (assumed) assemblage of caper spurge seeds from a late medieval French settlement may not show plant tubers or sheep/goat or rabbit faecal pellets. The seed and tuber suggestions were refuted.

What is of particular importance in such discussions (or single responses to an identification request) is that specialists give advice on how to identify unknown remains. For example, *"a closer look reveals the presence of detachment scars, which suggests they are actually tubers. To confirm you can break one in transverse section and look for parenchyma on it"*, or *"Tuber should have a clear 'lower' crown related to where the roots were and I can't see this"*. One specialist also offered a suggestion on how to maybe distinguish between sheep and goat pellets.

Therefore, a collaborative, community-built virtual reference collection aimed to help with the identification of remains should also retain the suggestions and advice given, not only the conclusion.

The key conclusion with regard to the JiscM@il Archaeobotany Listserv (and other such mailing lists) is that it does not build a reference collection. Hundreds of identification requests, images and expert suggestions are buried among other messages, do not follow a common template, and are not structured systematically to allow for easy search and consultation.

## Towards a community online reference collection

The previous sections made clear that the identification of the species of all collected plant remains is the most important step in the archaeobotanical research process. Archaeobotanists with a lot of experience sometimes cannot do this or are unsure about some finds, and even more so younger scholars. Consulting online reference collections of museums and herbaria is not helpful in such cases. Therefore the researchers ask close colleagues for their opinion and/or use the JISC Archaeobotany mailing list to solicit assistance from other experts. This does not generate a community online reference collection which practitioners perceive as an urgent need, i.e., *"what we really need are databases that can be contributed to collectively by practitioners and that will outlive their creators"* (Miller 2010: 21).

Such an online archaeobotanical reference collection, developed collaboratively based on digital images and description shared by many domain researchers, does not exist as yet. There have been attempts by individual and small groups of researchers to promote one, but these were of limited success. There are several reasons for this concerning professional issues and collection system requirements. Among the professional reasons are that archaeobotanists are willing to share content and expertise, but within certain limits. With regard to the system setup a community-built knowledge resource has many requirements which are not fulfilled well by current solutions, particularly not the ones practitioners implemented.

We looked into a number of implemented as well as other options to build a community online reference collection of archaebotanical material which fulfils most or at least some of the requirements identified in this case study. The full set is given in the section Requirements Specification. We did not systematically apply the specification to the examples discussed below, because there are many, mostly not fulfilled requirements. The specification includes also data infrastructure requirements, in view of promoting interoperability between community reference collections and such infrastructures, i.e. ARIADNE.

In the sections that follow first websites of individual researchers are addressed. These of course do not fulfil the core requirement of being community-built, although researchers often invite contributions. The main purpose of including such websites is to make clear why an individual approach is not appropriate for the task at hand. Other examples concern available solutions with a focus on scientific images and/or collaborative online work. We excluded the possibility to create a collaborative environment from scratch.

### Websites of Individual Researchers

Archaeobotanical practitioners emphasise that a community reference collection must be brought together from "bottom up" contributions of individual researchers and research groups in the field.

Due in part to the fact that a solution which support this was missing, many individual researchers created their own websites to share useful information and invite contributions by others. There are quite some problems with this approach.

Individual websites are necessarily limited with regard to the coverage of types of archaeobotanical remains and/or regional coverage. With regard to the technical realization they tend to be rather simple HTML based websites, with no functionality to allow structured input by other scholars. But creating and maintaining a state-of-the-art solution would be costly. There are freely available popular content sharing platforms like Flickr for images. But these may not allow the structured input and presentation required for a reference collection, and also seem not the appropriate place for an online collection of scientific content. Also there is no guarantee that free content sharing platforms will continue to provide their service into the future. Law & Morgan (2014) have analysed the loss of useful websites with the closure in 2009 of Geocities, which was one of the world's largest provider of free web hosting, used also by many archaeologists.

These issues have contributed to the proliferation of individual reference material sites dispersed across the Internet. Most often these take the form of an annotated list of links to useful resources. One initiative, *WikiArc*, intended to collect such websites to allow an overview and possibly implement a search engine capable of finding results across the different resources (Law *et al*. 2013). The idea was to crowd-source contributions of links and descriptions. Unfortunately, *WikiArc* became another link list with a few seed references and no possibility for researchers to effectively contribute.

Among the general problems with individual website also are that researchers who started building a useful resource simple do not find enough time to extend the information. If a funded project allows improving the website, the initiative often stalls when the funding ends and the resource is not maintained and extended. In many cases resources also go offline when the creators move to another institution, change research interests, etc. Important to note is also that providing an information website or, even, rich database is typically not assigned academic recognition. Nevertheless, many individual archaeobotanists provide very useful information online and are recognised by colleagues for doing so.

### Museum Collection Management Systems

In the survey it became clear that using an existing museum collection management system would not fit well for the purpose of a "bottom-up", researcher-managed archaeobotanical reference collection. One point here is limited support of essential community features for discussion and collaborative identification of finds. To provide but one example, representative for many others: The Adlib CMS (customized for museums as well as archives and libraries) is an advanced system that is in wide use in the sector. Adlib Museum is specifically designed for recording, managing and displaying collections information. The Adlib Internet Server includes tagging and commenting features. Museums can "engage" web visitors to apply keywords to database records (to improve search results) or submit comments on collection material; also upload of media files can be allowed. Also what visitors can do with search results is exceptional: the gallery option allows users to select search results which can printed, e-mailed or downloaded. However, these features are for individual users, collaborative activities for building a shared collection are not enabled.

Another important point is that it seems inappropriate to feed community content into a museum collection management system. The museum would not feel comfortable with information about specimens it does not hold and curate. The collection catalogue of a museum of archaeology might be an exception, but the lack of essential features (as mentioned) would pose a problem. On the other hand, such a solution would not necessarily generate the sense of ownership required for a community-generated resource, which promotes shared responsibility and contributions. However, an archaeology or natural history museum might still be an appropriate institution for hosting an online archaeobotanical reference collection of the wider community. An even better solution would be a botanical research centre that has a focus on archaeobotany and also carries out projects in this field, for example institutions like the W. Szafer Institute of Botany of the Polish Academy of Sciences.

### Scientific Wikis-based Systems

A rather easy to use solution for building a reference collection is a Wiki. Wikis fall under the category of solutions for computer supported collaborative work. Beside collaborative online authoring and editing functionality many also provide good support for communication and discussion. The biological research community has developed several Wiki-based systems to advance the collaborative building of collections of research models and data (see *Section 4.5.2*). Examples are EcoliWiki and Proteopedia, which are based on the MediaWiki, or the custom-built Wiki-Pathways. It would be possible to create a Wiki-based collection of structured archaeobotanical images and descriptions, including collaborative annotation, discussion and other functionality. For example, EcoliWiki uses the categorisation functionality of MediaWiki and pairs content pages with pages where users can discuss content. However, it seems difficult to re-use customized MediaWikis for our purpose, and building one from scratch is not intended.

### Morphbank and MorphoBank

*MorphBank* and *MorphoBank* we included in our sample because both are established systems for specimen-based biological research projects and therefore support the annotation of scientific images. Both systems have been developed and are maintained in the United States (based on NSF funding) but are being heavily used also by researchers around the world. *Morphbank* has a broad scope including comparative studies of animals and plants, morphology of species, taxonomy, phylogenetics and other fields. *MorphoBank* focuses on morphology specifically and provides full support to collaboratively produce, edit, illustrate, and annotate morphological character matrices for morphological phylogenetics (Werning 2014).

The problem with these systems in our context is that they do not support well the building of a reference collection, certainly not *MorphoBank*, whose data repository is meant for content associated with peer-reviewed publications. The data is released upon publication. It cannot be cross-searched, only accessed per project. *Morphbank* allows researchers to upload/deposit, organise and describe images they use for their studies. It provides a template to describe the specimens, e.g. taxon name, locality, specimen part, sex, stage, etc. The *Morphbank* database schema is mapped to Darwin Core and ABCD. Support for collaborative work is limited. Researchers may use the same collection and annotate images, but there appears to be no discussion function. The full-text search works well, the taxonomic tree allows (cumbersome) filtering of content; map-based search is not available. A positive aspect is that the content can be linked externally at high granularity. This would allow creating a list of species taxons externally and link to content pages within *Morphbank*. Thereby images of specimens could be discussed externally, but annotations would have to be done by registered users.

### Scratchpads

A virtual research environment which fulfils several of our requirements is the Scratchpads platform. The platform has been created and is being maintained by researchers and developers of the Natural History Museum London (Smith *et al*. 2011). It is in productive use since 2007 and at present freely supports over 1000 Scratchpads sites of large and small user groups (up from 300 in September 2011). Only few have more 50 contributors, many one or two, but sites of small groups are among the most visited. In December 2016 there have over 4800 active users, people who signed in to modify a site's content. Visitors browsing the site without being logged in are not included in this figure, but for views of site objects of which there were 2.7 million.

The platform offers various functionalities for biodiversity researchers and could also be used for building an archaeobotanical reference collection. Some of the functionalities specifically for taxonomists have been developed in EU funded projects, e.g. Virtual Biodiversity Research and Access Network for Taxonomy – ViBRANT (EU, FP7, 2010-2013). However, *Scratchpads* are being used for different purposes, including online reference collections. The individual sites (collaboratories) are maintained and managed by their owners. They can choose to what extent they make the content of their website publicly available. For sharing content the *Scratchpads* platform recommends the Creative Commons Attribution-NonCommercial-ShareAlike (CC BY-NC-SA) license.

Technically the Scratchpads platform offers users a Drupal based site which comes with various general and biodiversity research specific tools. Scratchpads offer users tools to manage biological classifications, rich taxon pages (with structured descriptions, specimen records, and distribution data/maps), media (images, audio-/visual content) and bibliography. Furthermore, various ways of communicating with site members and visitors such as newsletters, blogs, forums and a commenting system. In our context particularly important is that a Scratchpad allows easy creation (or re-use) of web forms to gather user-contributed content such as specimen images and descriptions, link them to taxonomic names/terms, and curate this collection online. Also a number of web services are provided of which the option to include Encyclopedia of Life species pages arguably is the most relevant. As metadata standard for Scratchpads records Darwin Core (DwC-A) is being used. Darwin Core is the main standard in the field biodiversity and natural history which allows exchange of information between many systems in the sector and beyond. I

### Paleobot.org

A solution that fulfils some of our requirements is *Paleobot.org* which, finally, is a website that has been developed by a group of archaeobotanists (Warinner *et al*. 2011). Paleobot.org has been founded and launched in 2010 by two PhD students while at Harvard University, Jade d'Alpoim Guedes (now Paleoethnobotany Laboratory at Washington State University) and Christina Warinner (now Laboratories of Molecular Anthropology and Microbiome Research, University of Oklahoma).

The website states that the goal of *Paleobot.org* is *"to bring together the archaeobotany community to share data, information, and expertise for the common purpose of improving the identification of archaeobotanical specimens. We provide a platform for researchers to upload and share reference collection images and to engage in collaborative identification of unknown archaeobotanical specimens".*

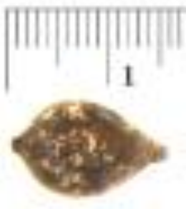
Paleobot.org is based on the Drupal framework. The website has sections for macro-remains (e.g. seeds), pollen, phytoliths, starch, and stable isotopes. At present it contains 112 records of which 103 concern macro-remains, 2 starch, 4 phytoliths, 3 pollen and no one isotopes. 41 records concern unknown macro-remains. A record of a macro-remain comprises of the following information, illustrated by a seed collected and identified by Robert N. Spengler III (uploaded 06/10/2010): http://paleobot.org/node/127

Polygonaceae Polygonum 1

- Taxonomy: Polygonaceae > Polygonum
- Common Name: Knot Weed
- Region: Central Asia
- Location Collected: Tuzusai Alatau, Kazakhstan
- Collection Type: Archaeological

- Collection Context: Hearth
- Cultural Affiliation: -800 to -100
- Cultural Period: Iron Age
- Collection Origin: Archaeological Excavation
- Species Native Homeland: Native Species
- Collector: Robert N Spengler III

Seed Macro 1 Macro Seed




- Image Type: Photo
- Image Credit: Self
- Analyst: Robert N Spengler III
- Botanical Part: Seed

[thumbnail image, but a large one is given]

The website and publications of the Paleobot.org team do not mention if the records are based on a metadata standard. Most specimen records, 47 identified while 23 not, come from the Paleoethno-botany Laboratory at Washington State University which is led by Jade d'Alpoim Guedes and employs further five researchers. The laboratory has reference collections and state of the art facilities for the extraction, identification and interpretation of archaeobotanical materials, including micro-remains (pollen, phytoliths, starch grains), and stable isotopes of such materials and sediments.

16 other researchers uploaded 42 records of macro-remains, 23 identified and 19 unknown. 141 “profiles” of contributors are listed, many with photo and affiliation, and a link to contributions to *Paleobot.org*, but most with none. Importantly, the website does not provide a feature for annotating or discussing unknown material, also not how to download information. Maybe this is possible for registered users, but not mentioned under FAQ. The website mentions plans to supplement the database with additional resources, such as publications, identification guides, laboratory protocols, and instructional videos. But there is a long list of selected links of herbaria and online botanical information, websites on macro- and micro-remains, etc.

In summary, the *Paleobot.org* project must be lauded for providing access to relevant information. But it has not yet achieved its main objective to bring together the archaeobotany community to share information and expertise and engage in collaborative identification of unknown specimens.

### Linking Records and Discussion

Surprisingly *Paleobot.org* does not refer contributors to the JISC Archaeobotany mailing list to possibly receive suggestions for the identification of unknown material. The *BoneCommons* zooarchaeology community website (see *Section 4.5.6*) utilizes the JISC ZOOARCH list for this purpose. *BoneCommons* invites researchers to upload identified and unknown samples and in the latter case post a request for help by specialists. The ZOOARCH list, which has over 1200 subscribers worldwide, does not allow posting images. But researchers can use the link for the sample record in the *Bone Commons* database to point colleagues on the mailing list to the material to be discussed and identified (there are nearly 300 such “ZOOARCH Attachments”). However, the material on *BoneCommons* and the suggestions and discussion on the ZOOARCH list remain separated. Mckechnie & Whitcher-Kansa (2011) describe the setup and mention that *BoneCommons* displays a feed of the discussion threat. Such feeds are not there anymore, maybe too difficult to maintain or due to other reasons. However, the *BoneCommons* website notes that a feed of the ZOOARCH discussion about samples is available via the *Zooarchaeology Ning Network* (which is a closed members-only social network). The reasons for this complex setup remain unclear.

### 5.7.4 Requirements Specification

This section specifies requirements of an online reference collection of archaeobotanical material, developed and maintained by members of the research community, but interoperable with the ARIADNE e-infrastructure. The requirements specification is part of a pilot investigation for a virtual archaeobotanical research environment within the wider network of the ARIADNE data infra-structure and services.

We distinguish between the following requirements:

- Data infrastructure & standards requirements
- Social & technical system requirements
- Content requirements
- Organisational and professional training requirements

Some items in this set of requirements are of course closely intertwined.

#### Data Infrastructure & Standards

A potential interplay of digital reference collections with research e-infrastructures arguably is not yet on the radar of many archaeological researchers as well as curators of museum collections. Geser & Niccolucci (2012) address the topic with regard to virtual museums in the field of cultural heritage and natural history. The paper distinguishes three current variants of virtual museums which focus on content, communication or collaboration, but in rather self-contained ways. A new variant is suggested which is part of an e-infrastructure network and highlight the important role of digital reference collections as e-research resources of arts & humanities, natural history and other disciplines.

As a crucial requirement for the realization of this scenario the paper emphasises to pay careful attention to conceptual reference models (ontologies) and vocabularies. These should allow to reflect the richness of heritage content and contexts (including archaeological) to allow for intelligent, concepts-based discovery, navigation and access. In this regard use of CIDOC-CRM, LIDO (museum metadata standard) and other standards (e.g. W3C Linked Data recommendations) is being suggested.

This requirement becomes even more important in the context of digital reference collections which are intended to be developed "bottom-up" by researchers based on their own content (i.e. not museum collection content). Obviously most researchers are not familiar with metadata standards and formalised vocabulary. For example, articles of proponents of researcher-generated/curated digital reference collections of plant and animal remains do not mention standards and vocabularies, except of course scientific names of species (e.g. Law *et al*. 2013; Warinner *et al*. 2011). Therefore, support by experts in these matters is necessary, ideally experts in the respective research domain and with careful attention to data interoperability

The same, however, concerns developers of e-infrastructures which are meant to serve a whole discipline and, even more so, in the case of multi-disciplinary fields of research such as archaeology. If the ARIADNE project aims to incorporate research resources of domains such as archaeobotany and zooarchaeology, the ARIADNE e-infrastructure and services must be able to support at least essential standards such as Darwin Core, nomenclature and taxonomies (i.e. scientific names of plants and animals). These are the major pillars on which most biodiversity informatics applications rely.

Therefore ARIADNE, among other requirements, would have to include in the data registration and portal services a taxonomic backbone (Catalogue of Life), so that records contain the proper scientific names of species (also vernaculars) and the portal users can search & browse data resources based on these names and taxonomic hierarchy. The same of course applies to VREs with regard to the data organisation of underlying databases and/or annotation of any new digital content that is being used or generated in such VREs, for example, in our case, a digital reference collection of archaeobotanical material. This would also include specialised vocabularies for material such as phytoliths (Madella *et al*. 2005).

#### Requirements summary:

- A tight interplay between reference collections, VREs and e-infrastructure services is required. The interoperability must be ensured bottom up by community reference collections that are based on essential domain standards.
- In the case of archaeobotany (and zooarchaeology) the general biodiversity standard Darwin Core might fit best (see Wieczorek *et al*. 2012), although it seems that it is not in wide use yet in the field of archaeobotany. Another option is Dublin Core with a few additional elements, if required.
- Use of vocabularies needs careful attention, especially scientific names, type of plant remains, etc., but also general ones such as gazetteers for places, periods, and others.
- Most archaeological researchers (i.e. archaeobotanists) are not familiar with metadata standards and formalize vocabularies or, even, semantic Linked Data. Therefore “bottom up” initiatives for researcher-generated/curated digital reference collections need support by experts in these matters.
- E-infrastructure systems and services (i.e. ARIADNE) must be capable to support the main standards in the domains they aim to serve. A key role in the domains addressed play scientific names of plants (and animals) which must be included in records of specimen datasets.
- A taxonomic backbone is necessary for data registration and portal services so that users can search & browse data resources based on scientific names (also vernaculars) and taxonomic hierarchy. The richest and regularly updated backbone is the Catalogue of Life.
- All of the above applies also to VREs for the domains addressed, with regard to underlying databases and annotation of any new digital content that is being generated, shared and used in such VREs (in our case, a digital reference collection system).

### Social & Technical System Requirements

Some of these requirements are mentioned, albeit often implicitly, in publications of proponents of researcher-generated digital reference collections of plant and animal remain (i.e. Law *et al*. 2013; Miller 2010 and 2011; Warinner *et al*. 2011):

- The core requirement is that an online archaeobotanical reference collection must be developed collaboratively based on content (digital images and description) shared by domain researchers.
- It is understood that the reference collection should be an open access resource that allows free access to the content. While free/open access content, the terms and conditions of (re-)use must be clear (i.e. open content licensing).
- The reference collection system must allow individual researchers (but also research groups / projects) to upload images and description (i.e. site information) of plant remains they have identified or are unknown / unclear to them. The shared identifications of the plant species of “difficult” archaeobotanical remains can then help to with other such cases.
- The system should allow and request proper citation (attribution) of records based on a standard “how to cite” form, including the link for the record.

- The system must provide a stable link (URL/URI) for this purpose and for pointing researchers to reference material as well as specimen which have yet to be identified.
- The system should also enable researchers to solicit assistance with difficult identifications by other experts in the field. Therefore the system needs to allow comments and discussion, capture this information (i.e. discussion threads) and add it to the record of the sample.

Here some explanation may be helpful to understand important professional implications of these requirements: Promoters of a community-based reference collection for archaeobotanists will be aware, but do not make explicit, that identifications of difficult materials, including images and archaeological context information, are valuable assets of researchers who work as professional archaeobotanists. Also of course the special knowledge, which experts sometimes share, when they help others on e-mail lists with detailed suggestions on how to identify difficult samples. Therefore, identifications they share deserve recognition, attribution, and proper citation in any use made thereof. A system which does not very well support this is unlikely to receive many contributions.

### Content requirements

The content for the main purposes of the reference collections are high-quality images of plant remains and sufficient context information.

Descriptive information:

- Key among the descriptive information of a specimen record is the scientific name of the species, where the specimen has been collected, and who collected and identified it. The descriptive elements of the Paleobot.org records (see the example above) could be a good starting point for a standardised record.
- For the purposes of the online reference collection a much more detailed record is not necessary. For example, various measurements as expected for physical specimens by the UQ Archaeobotany Reference Collection would not be required.
- For the relatively small set of sufficient context information support of several languages will not be necessary.

Requirements concerning images and coverage:

- High-quality images of specimens are required to allow comparison to (and possibly identification of) collected remains of plants whose species is often difficult to determine. For micro-remains these would for example be high-quality light microscope or scanning electron microscope (SEM) images which contain the distinguishing features of the species.
- Thus high-quality here does not mean the state of preservation of the specimens, rather the images should present plant remains as encountered by archaeobotanists, which often means poorly preserved specimens.
- Images of well-preserved specimens of museum and herbaria collections are often not helpful for the identification task. This does not mean that such images are irrelevant. There may be cases where linking of museum/herbaria records can be beneficial. For example, researchers may encounter remains of old plant species, but no or only few archaeobotanical images are in the community system.
- Archaeobotanists mention as particularly relevant reference material images of “old”, “rare”, “under-recorded” and “unusual cases”. It is also often assumed that researchers lack reference material for some regions more than for others. Therefore, the reference collection should make clear for which cases contributions are most welcome.

### Organisational and professional training requirements

Building and maintaining the community reference collection requires community and institutional support, furthermore its professional training function should be highlighted:

- Community support means many researchers who wish to have and will contribute to the collection and support by associations in this field (i.e. International Work Group for Paleoethno-botany, Society of Economic Botany, Society of Ethnobiology, and others).
- Institutional support means an institution that hosts the collection and provides some technical assistance (IT services, data storage, etc.). A good candidate could be a botanical research centre that has a focus on archaeobotany and also carries out projects in this field; also a major archaeology or natural history museum may fit.
- The described reference collection could greatly support professional training: it provides cases of difficult to identify material (which have been solved), captures experts often “implicit knowledge” (here expressed when advising on how to tackle difficult cases), and promotes mutual assistance and open data.
- Training programmes / workshops could benefit from the system as well as contribute to it (i.e. identification of plant remains in workshops and upload of the results); the system could also offer a central digital library of identification keys and other relevant material.
- We do not address approaches for ensuring the sustainability of the system, but meeting the above requirements could help.

## 5.7.5 Conclusions and Recommendations

The study investigates the requirements of an online reference collection and research environment for archaeobotanists. The online collection and environment would allow archaeobotanists to tackle a common problem collaboratively: the often difficult identification of the species of plant remains from excavations. The study presents a specification of the requirements.

For the ARIADNE project mainly the requirements concerning the interplay of its data infrastructure and services with online reference collections are important. These requirements are essential not only in the case of archaeobotany, but concern all cases where ARIADNE aims to incorporate data resources and to support scholars in special fields of archaeological research.

These can be briefly summarises as follows:

- It is necessary to investigate how a tight interplay between the ARIADNE e-infrastructure and the environments and resources of special fields of research can be achieved. In each case the research resources (i.e. numerical data, 3D models, reference material, etc.) may be different and the virtual research environments have a focus on particular tasks.
- In the present case the resources are relatively simple: images of plant remains and basic information of the archaeological context. The main task (identification) is demanding and requires expert knowledge. Some of this expertise is explicit (identification keys), but hardly knowledge in the sense of formalised, machine-processible semantics.
- The focus of ARIADNE in each case should be on ensuring interoperability with regard to the data, metadata and knowledge organization systems (KOSs), i.e. thesauri and ontologies. This concerns Linked Data solutions, while other technologies will be required for specific tasks (i.e. 3D or image recognition technologies).
- With regard to interoperability at the level of metadata and KOSs, the research field of archaeobotany presents a disciplinary overlap of applied botany, biodiversity and archaeology. If

the ARIADNE project aims to cover such fields, its e-infrastructure system and services must be capable to align with the main standards (metadata, KOSs) of the involved disciplines.

- In the present case these are Darwin Core, the core standard for biodiversity data, botanical nomenclature (scientific names of species) and taxonomy, and archaeological metadata and KOSs as required.
- For the ARIADNE e-infrastructure capability to use scientific names of species (animals, plants and others) and taxonomy for various services can be recommended. Data records in archaeobotany and zooarchaeology will generally include the scientific species names and of course all records in biodiversity and many other disciplines. Furthermore, records of various archaeological investigations may include such names.
- Use of a taxonomic backbone is recommended for data registration and portal services so that users can search & browse data resources based on scientific names (also common names) and taxonomic hierarchy. The richest and regularly updated backbone is the Catalogue of Life.
- Datasets of archaeobotanical reference collections and investigations will generally include information on locations, cultural period (date range) and basic contexts (cf. the metadata of the Paleobot.org system). Vocabulary support in dataset registration and search based on locations (i.e. GeoNames gazetter), periods (PeriodO) and related subjects (i.e. AAT) are already available in the ARIADNE registry and portal.

### 5.7.6 Summary

The study addresses archaeobotanical investigations and data which contribute to the interpretation of archaeological sites as well as research questions of environmental archaeology. The study found that the most important step in the archaeobotanical research process is the identification of the plant remains. Researchers often cannot easily determine the plant species, need specific reference material as well as ask colleagues for help with the identification.

This could be eased by a virtual reference collection and environment that collects images and context descriptions from many researchers and provides tools for discussion and collaborative identification. However, an appropriate solution has intricate requirements in professional, technical and other respects. The study presents a specification of the requirements. Essential for ARIADNE are mainly the requirements concerning the interoperability of e-infrastructure and virtual research environments (VREs), including reference collections.

With regard to this interoperability the study recommends taking account of the main metadata and knowledge organization systems in the respective field of research. Archaeobotany presents a disciplinary overlap of applied botany, biodiversity and archaeology. Therefore, the study suggests that the ARIADNE e-infrastructure and services (data registry/portal) should provide support for Darwin Core, the core standard for biodiversity data, and botanical nomenclature (scientific names of species) and taxonomy (i.e. Catalogue of Life).

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BoneCommons, http://alexandriaarchive.org/bonecommons/

Catalogue of Life, http://www.catalogueoflife.org

Digital Seed Atlas of the Netherlands, http://seeds.eldoc.ub.rug.nl

Encyclopedia of Life (EOL), http://eol.org

Hawaiian Ethnobotany Online Database (Bishop Museum), http://www2.bishopmuseum.org/ethnobotanydb/

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## 5.8 Virtual Research Environment for Czech Archaeology (ARUP-CAS)

### 5.8.1 Introduction and Overview

The case study comprises of two main parts: The first part presents recent e-infrastructure developments for the archaeological sector of the Czech Republic. As a specific case the Aerial Archaeology Archive (AAA) of the Institute of Archaeology is described, as an element of the Digital Archive of the Institute and the recently launched Archaeological Map of the Czech Republic (AMČR).

The AMČR aims to integrate the various data resources generated by archaeological research and heritage management institutions; furthermore, advanced services and tools are being developed for the tasks of the institutions, archaeologists and heritage managers. It is envisaged that the AMČR will become a virtual research environment for the whole sector of archaeology in the Czech Republic. Therefore, the second part of the case study addresses major requirements of such an integrating environment, with a particular focus on requirements for progress and innovation in the area of research.

### 5.8.2 Current Digital Practices

The last twenty years have proven ever clearer that high-quality, complete and easily-available archaeological data are a key factor in the effective scientific research and the management of archaeological heritage. It has also been demonstrated that it does not suffice to merely collect data, it is necessary to describe it using reliable metadata and to interconnect data of various categories.

Systematic collecting, organizing and presentation represent an imperative demand of the archaeological discipline: if not done in due course, the archaeological sector, research and resource management will be severely restricted in their capability to address effectively existing and emerging challenges, for example, increased development work, pressure on historic landscapes, and costs of heritage preservation.

Aerial photography, both historical and newly generated, contributes to our understanding of landscape development, monitoring of known archaeological sites as well as discovery of new locations. Thus archives of aerial photography can play an important role in archaeology; however, more needs to be done to improve their accessibility (i.e. digitisation, state-of-the-art metadata) and integration in digital research environments (Cowley and Stichelbaut 2012, Hanson and Oltean 2013; Standring *et al*. 2010). For both, digitised historical material as well as newly collected images novel tools will be necessary to identify, interpret and annotate relevant features.

Aearial photography is of course still a booming field of research, thanks to easy employable new data capture vehicles such as drones (The SAA Archaeological Record 2016), or the application of advance sensing technologies such as LiDAR, which allow rediscovering archaeological sites and landscapes (Chase *et al*. 2012; Edgeworth 2014; Johnson & Quimet 2014).

### 5.8.3 Case Studies

#### Part 1: Building Systems

The first part of the case study describes the Aerial Archaeology Archive as a part of both, the Digital Archive of the Institute of Archaeology and the Archaeological Map of the Czech Republic (AMČR). The setup, data models and integration of the systems is outlined and their role as e-infrastructure components highlighted.

#### The Archaeological Map of the Czech Republic (AMČR)

The Archaeological Map of the Czech Republic system (henceforth AMČR) has been developed as a part of the spinal infrastructure for Czech archaeology. It combines the daily duties of the management of archaeological fieldwork (i.e. registry of field interventions, a means for assigning rescue excavations to the organizations authorized to carry them out) with the summarizing database of archaeological data. Furthermore, it supports the retrospective collection of information on archaeological fieldwork, sites and finds in the 19th century (which means a database of the 'sites and monuments record' type).

The structure and functions of the AMČR System were designed at the Institute of Archaeology, Prague (henceforth IAP), in the course of a project of the same name in the years 2012–5; in 2017 this system will be put into full operation. It is a desktop application working with data stored in the net and allowing the users to draw database information or to contribute to it.

The system is based on a dynamic model of archaeological fieldwork as the means of obtaining specialized scientific information (Figure 47). Typically, archaeological fieldwork undergoes a number of phases from defining its aims and spatial planning, including the fieldwork itself, a functional and chronological analysis of the results, up to a synthesis of the data and its interpretation.

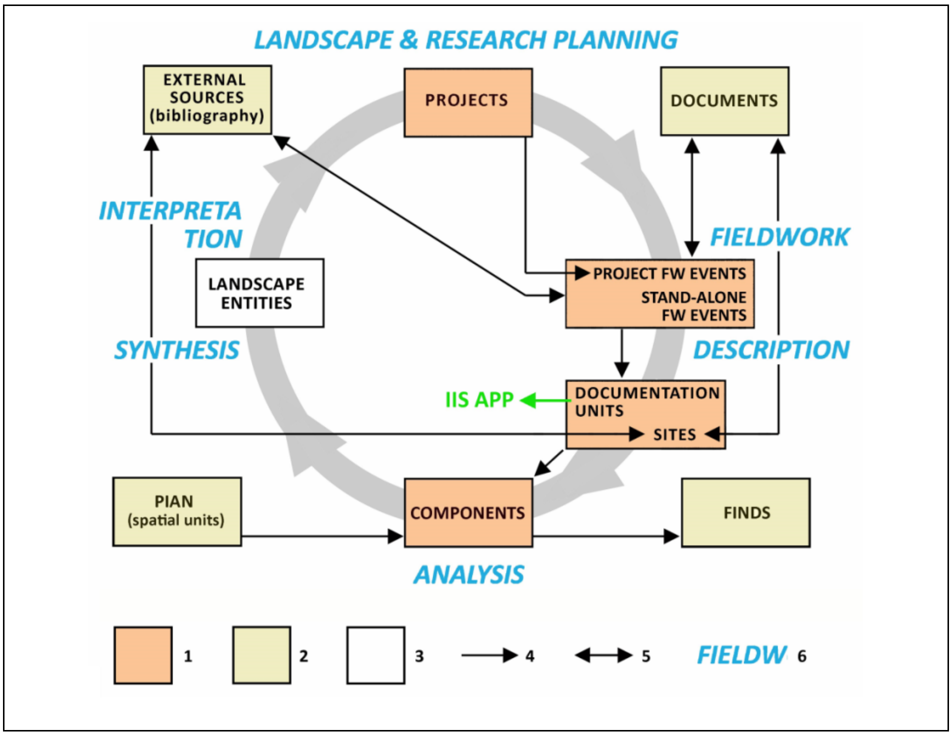


*Figure 47. A generalized model of the information flow and data classes of the AMČR.*

Each phase uses specific terminology and evidence units corresponding to individual categories of the system: 'projects', 'fieldwork events' and 'sites', 'components' and 'landscape entities' (the last-mentioned category has only been suggested and does not bear any contents yet). Apart from these categories, the AMČR offers additional four data categories, which serve the detailed description and contextual classification of the former categories. These are the 'finds' (details on the archaeologically recorded movable and immovable items), 'PIAN spatial units' (PIAN being an abbreviation of the Czech phrase for 'spatial identification of archaeological finds'), 'documents' (metadata of the field records) and 'external sources', i.e. bibliographic entries.

The AMČR system understands aerial photographs, of which about 20,000 are stored at the Institute of Archaeology, as a sort of 'documents' that share the same way of description and storage as other documents. The analogue aerial images (slides and negatives) and associated documents (maps, positive enlarged copies, print views, etc.) are stored in the Aerial Archaeology Archive, a part of the Archive of the IAP. In the AMČR project, digital (digital-born) images and electronic copies of analogue images have been integrated into the Digital Archive of the IAP as a part of the AMČR system (see below).

### Aerial Archaeology Archive of the IAP

The Aerial Archaeology Archive (AAA) was founded in 1992 in view of storing the photographs from aerial prospection (Gojda 2008). In the 1990s aerial prospection was wholeheartedly promoted in the IAP (until 1989 this activity had been more or less forbidden under the communist regime); between 1998 and 2016 the IAP even owned a Cessna 172 for its surveys. Currently, as charter flights have become more affordable, owning an aircraft is not favourable anymore; apart from this, other means are used in aerial survey, such as drones. Of growing importance is also the information that can be obtained from publically available map servers (e.g. Google Earth, and www.mapy.cz for the Czech Republic), which offer permanent access to geo-referential surveying aerial photographs continuously covering the surface of the whole continent (in some countries available even in a number of time series) and most recently even digital contour models of the earth surface (LLS images, hitherto only in a number of countries including the Czech Republic).

After 2002, in connection with the consequences of the Prague Flood, we started to digitize all archival material of the IAP, which concerned the aerial photographs as well. The digitization (scanning) of analogue documents in the archive of the IAP was accomplished in 2012. Simultaneously we also made a transition from analogue documents to digital technologies as the main way of collecting primary data (digital-born data; especially photographs, gradually also plans and database files). Currently all images in the AAA are part of the Digital Archive of the IAP, for which (partially also with the support of the ARIADNE project) the web application has been created.

### Data Model for Aerial Archaeology

The AAA data model consists of a number of interconnected tables linked to three basic categories of data: photographed sites, individual photographs (documents) and flights ('events' of aerial surveys; cf. Figure 48). In the sites data class (SITES), individual spatial units with archaeological marks or features are identified. They are also assigned unambiguous identifiers and a basic description including the name of the site, the cadastre (parish), region, PIAN spatial unit and other information. The AMČR distinguishes between two main sorts of sites: (i) sites intrinsic to aerial archaeology and mostly newly discovered using this method (mainly through crop or soil marks, etc.) and (ii) sites that were primarily recorded by other methods of archaeological and/or historical survey. In the case of the latter category the aerial photography just provides additional information or attractive illustrations (mostly standing buildings or ruins surviving above the ground such as castles, hillforts, etc.). Therefore attention must be paid to the harmonization of identifiers that must be shared with other parts of the information system.

Individual sites can be described in more detail using so-called documentation units (spatial units; data class DOCUMENTATION UNITS) and components (data class COMPONENTS), which are spatial groups of finds tied to specific periods and functions (specific 'activity areas' in the terminology of Neustupný 1998). In the case of sites that are recognised by aerial photographs only, the chronological and functional specification can of course be difficult; it is, however, not impossible (see below). Anyway, we suppose that the identification of components at sites determined by aerial survey will be carried out as automatically generated summarization of the information from the components of individual aerial photographs. A further data class is FLIGHTS, which contains information on the date and hour of the flight, the name of the pilot and surveyor, departure and arrival airport, weather conditions, visibility, etc.

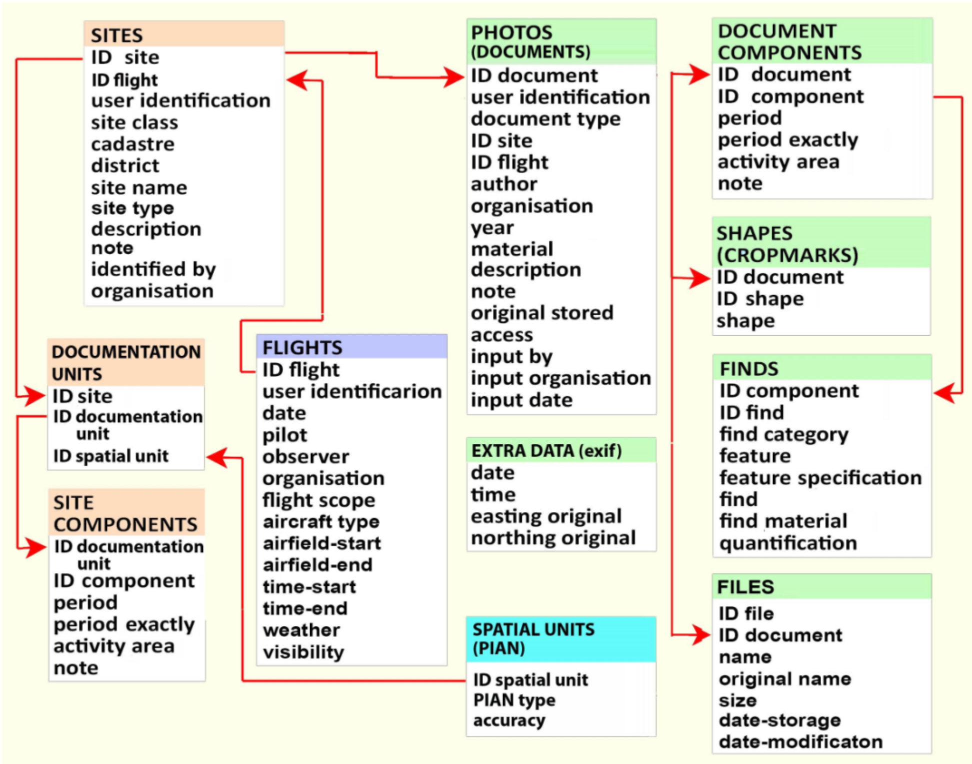


*Figure 48. The AMČR data model: tables concerning aerial archaeology.*

In the AMČR, aerial photographs (PHOTOS) represent a subcategory of the DOCUMENTS data class and its EXTRA DATA extension. We will mainly include information on the photographer and his/her organisation, date of the photograph, description of the image and the definition of its 'access', i.e. the group of persons that will be allowed access. In the case of aerial photographs the last mentioned aspect is especially important since the images may often include information that could be misused, for example, by looters with metal detectors. In all cases it is necessary to decide, who may see them: a choice will be done between 'all users', 'registered users', 'research specialists only' or 'nobody except the archivist or system administrator'.

The aerial photographs are described from the view of their scientific contents. If chronological and functional categories of the finds can be deduced, they will be inserted into the data classes of DOCUMENT COMPONENTS and FINDS. If we can identify, for example, a Neolithic settlement with characteristic ground plans of houses, we will enter 'Neolithic-settlement', the second will contain 'immovable object-building/building-dwelling + pole/post construction'. Apart from this, the SHAPES data class will provide a formal description of the surveyed features using descriptive categories specific to aerial survey (for example 'maculae', 'large rectangular enclosure', etc.).

The metadata in the PHOTOS data class are linked to physical files in the digital repository of the IAP. The FILES description linked to these files contains technical details of the associated files, as, for example, its size in MB, the file type and last modified date.

## The Digital Archive of the IAP Web Application

The above description of the aerial photographs of the IAP was also applied to the data file provided for the vast network of the ARIADNE research infrastructure. The web application of the Digital Archive (Figure 49) was developed with support by the ARIADNE project; it makes the aerial photographs from AAA and other documents of the AMČR available to the scientific and lay community. The web application of the Digital Archive is linked to the AMČR, from which it automatically transfers documents and metadata. The application offers a multi-criteria search of the documents, their sorting and display, as well as a spatial query using a map.

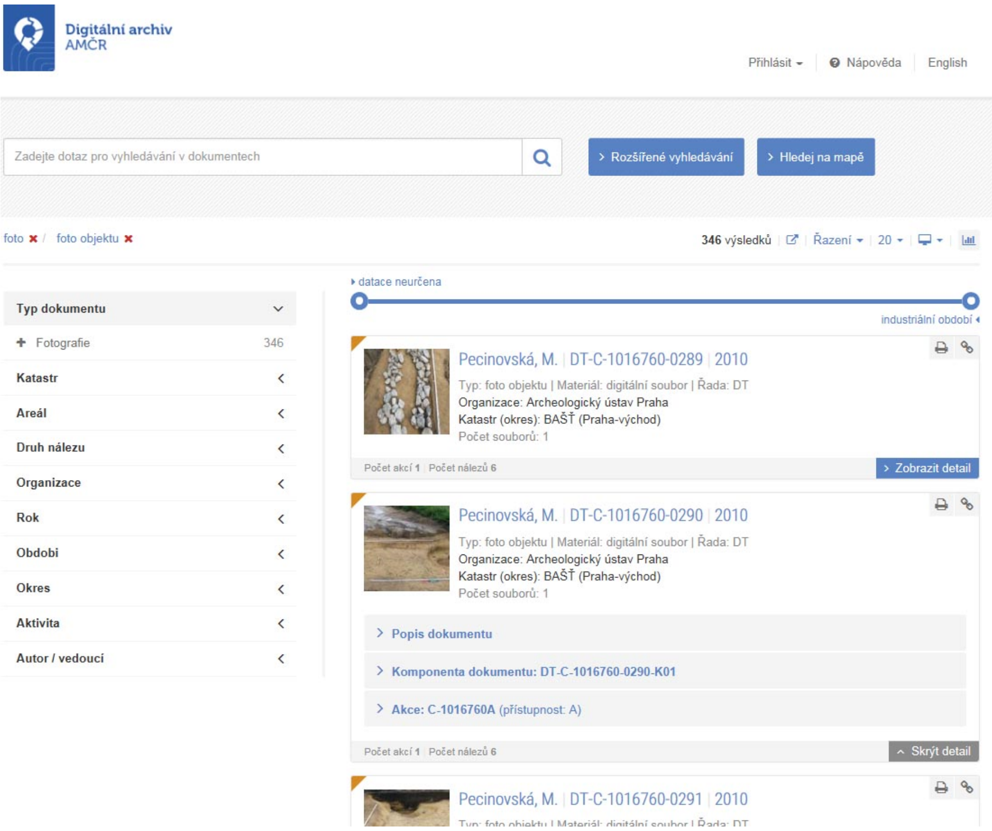


*Figure 49. One of the screens of the Digital Archive web application.*

The Digital Archive divides the documents into five categories (TEXTS, PHOTOS, AERIAL PHOTOS, PLANS AND MAPS and DIGITAL DATA); as soon as the data will be ready and transferred, the application will contain about 250K files. AERIAL PHOTOS can further be indexed using filters and facets (for example by author, year, cadastre, site type and others) or they can be subjected according to similar principles to an advanced multi-criteria search. Each document is assigned information on the site, the document, its contents (components), etc. that were extracted from the data categories of the AMČR.

The metadata of the selected documents can be displayed in a number of different ways: table with miniatures, gallery or the metadata table alone. Clicking the buttons will unfold information on the contents of the documents and the according site; clicking the miniatures opens a window with a view of the document. The viewer window has sufficient resolution to enable viewing the photographs in greater detail and to read the text documents; the current setting of the application does not allow downloading documents. A movable timeline to define the chronological scope of the documents according to historical periods represents a utility rather for the broader public. The map window shows the position of the site, from which the images are taken; using this window, we can also perform a geographic query of the documents.

To show the geographic location of aerial photographs can be forbidden by system administrator if the presentation could endanger the site. Access can be limited in two ways: either it is not possible to open a certain document in the viewer window (the user will be provided only with metadata and miniatures of the document) or the link to the appropriate site is interrupted (the image may be viewed, but the user can view information on the cadastral area only, not the site).

We consider the Digital Archive application an important step towards the opening up of archaeology to a broader audience. Currently the application is being translated into English. The translation considers the screens, filters, facets and all index-like metadata. This way, the AMČR Digital Archive will allow persistent linking to individual documents. The web application will be released simultaneously with the AMČR system in mid-2017.

## Part 2: From Information Systems to an Integrating VRE

It is envisaged that the AMČR will become a virtual research environment for the whole sector of archaeology in the Czech Republic. Therefore, the second part of the case study addresses major requirements of such an environment, with a particular focus on requirements for progress and innovation in the area of research.

### Towards a Qualitative Shift in Archaeology

The fundamental courses for any future development in the field of "digital archaeology" include multidisciplinary approaches, implementation of international standards, Open Source as well as Open Access concepts, ensuring broader application of archaeological data, and, mainly, creative infrastructure utilisation in the field of research as well as archaeological heritage management.

The authors believe that the development of archaeological information sources in the Czech Republic should aim at the integration of departmental information systems both in terms of data connectivity and user interfaces in order to design and deliver this data with common heuristic and analytic tools. These efforts should result in the creation of a unified virtual research environment.

A qualitative shift can occur in Czech archaeology only if the approach to processing primary data is fundamentally changed. The quantity of commonly processed data should increase along with their accessibility; the variety of analytical procedures and tools should expand and, last but not least, fundamental theoretical and methodological concepts should be codified. In the following sections we address some of the requirements of this qualitative shift.

### Ensuring Appropriate Licensing Conditions

The decisive factors in creating e-infrastructures, among other things, are the stipulation of licensing terms, the editing of user rights as well as arrangements applied for the sharing and secondary application of the content. One of the most important problems hindering the development of existing digital services appears to be a dependency on particular software providers, their competence to meet the needs of research infrastructures as well as the long-term sustainability of the resulting solutions. The application of Open Source concepts can provide an answer to these as well as other challenges. Software based on the Open Source code is open both in terms of accessibility and licenses for sharing and changing. Thus, its further development is independent of the original suppliers and there are no problems regarding its replication in other systems.

Data provided within the scope of e-infrastructures are protected in the same way as the software itself. Currently, Czech archaeology suffers in this respect by a certain vacuum stemming from (i) the ill-defined relationships between the providers and the data administrators and (ii) the application of common copyright law protection instead of specifically defined licensing terms. The general intention is, however, providing the largest possible amount of research data to the general public for use and distribution in the Open Access mode. This approach manifests itself in an increase in freely available digital resources. Research data should be understood as a product of public service and their concealing cannot be rationally based, as it only burdens the academic environment.

### Bringing Together the Archaeological and IT Expertise

Further development of archaeological e-infrastructures will lead to the direct involvement of IT specialists in scientific projects and, at the same time, the strengthening of similar competencies of professional archaeological staff will be also supported. We are currently facing a situation in which information science in archaeology is not only the matter of archaeologists but also technically-oriented professionals with an interdisciplinary overlap. In a longer perspective, it will probably become standard procedure to employ software developers in the academic institutions. Moreover, it will be necessary for such specialists to have direct insight into archaeology and a close mutual cooperation within the scope of joint multidisciplinary teams.

### Enabling Advanced Interoperability of Digital Resources

The integration and interoperability of digital resources requires not only the coordination of the activities of institutions involved in building common information systems, but also the establishment of long-term existing rules and regulations that allow orientation within the data and metadata. The aim is to unite the data models of the related but still independent systems in such a way that the extraction of information will not require any additional user intervention, but will proceed on a semiautomatic or fully automated level.

To achieve this goal, nationally and mainly internationally recognized standards need to be applied; their observance helps to streamline the digital space. The standards can be applied in two ways: either by building the system directly on the basis of the standard, or by utilizing specific tools for mapping the data classes into standard forms. Standardization is one of the key pillars of data integration in heritage management, promoting networking services and contents that can be very heterogeneous. At the same time, standardization encourages the creation and growth of catalogue and aggregation services that combine independently generated data, open up new possibilities for the comparative study of different data sets, and, thanks to uniform semantics, reduce the impact of language barriers.

The AMČR system was built to include basic components of international standards (e.g. Dublin Core), but it will be necessary to establish new procedures for the mapping of individual schemes within the framework of the planned public API. The standardization of outputs mainly in the form of machine-readable data represents a task that requires the further conceptual development of the system. The rapid spread and efficiency of the CIDOC-CRM reference model shows that in the course of the development of the branch infrastructures standardization will necessarily have to come into focus.

### Preventing Information Loss

While looking at the complex system and immense volumes of information and considering the development of digital infrastructures we are inevitably led to ponder how much information escapes our current scope. Unquestionably, it is a problem we have tried to solve for years, but it was only the complex approach and the insight (that could never be achieved in the analogue environment) that has revealed the wide range of topics whose solution represents a task for the coming years. These problems were caused by the methods of existing evidence systems, their historical and regionally conditioned development as well as by the nature of archaeology. The creation of integration of information resources has been hindered by division of competences, different institutional arrangements of archaeological fieldwork, varying technical capabilities and information management systems, selective access to the data, varying funding, and other aspects. Developing the idea of a unified platform is anchored in an attempt to reduce the information loss rate within archaeological fieldwork as well as to ensure a stable position for Czech archaeology in an interdisciplinary and international environment. However, this path also envisages the development of new competencies among archaeologists, notably in the field of digital resources management.

### Recognising Additional Sources of Evidence

The contextualisation through data and resources built on alternative source evidence is a task that is as equally important as the collection of old and the creation of new archaeological data. Written historical records of a narrative and official nature describing independently from archaeological evidence the past landscape as well as the distribution of human activity areas, represent a natural source of information that have not been significantly and systematically exploited in the CR so far. A significant amount of critical editions of historical documents that have been published already for over two centuries and that especially for the earlier part of the Middle Ages have covered most relevant sources for the territory of the CR may serve as a good starting point to meet such a goal. The problem with this group of sources lies, of course, in the different level of editorial practice and editorial apparatus (e.g. local and data indexes, etc.) and the almost complete absence of efforts to present the data in a spatial manner. In this regard, it is necessary to perform a great deal of methodological work that will be followed up by a demanding retrieval of structured data from various sources.

### Required Advances in Research Tools

With the exception of securing the infrastructure itself, system management and data collection, it is crucial for any further development to offer utilities that will be helpful (1) in the course of theoretical research; (2) as methodological and practical support for archaeological data collection; and (3) as an efficient tool for data analysis. The fulfilment of these tasks is an ongoing and never-ending process that will actually react to and ideally also anticipate the needs of the target groups as well as the professional environment as a whole.

At the theoretical level it is necessary to further develop the idea of the landscape as an area given meaning in the course of human activities (landscape as "an environment with purpose", a complex artefact). The landscape can be seen as a set of chronologically and spatially overlapping areas (i.e. artefacts) which underwent dynamic development, the static reflections of which are depicted in various categories of sources. The existing evidence, including the AMČR, is primarily based on collecting these static images. If you wish to understand the landscape's past dynamics, it is necessary to model these processes on the basis of acquired data. The resulting models have to again undergo further critical discussion. To reach viable models we have to agree on the basic concepts and to modify the existing infrastructures to match their applications.

Thus, we see three basic directions for further development that are complementary and validate each other, they are as follows:

- The creation and application of a common data model for sciences studying the past landscapes (archaeology, history, historical geography, etc.) that will allow fundamental syntheses of data independently of the source category.
- The application of archaeological remote sensing as a source of new information on the past landscape.
- The creation of tools for predictive modelling, which must be based on a set of complex criteria, respecting the nature of archaeological data (transformation processes, the process of their collection, etc.).

However, neither of these approaches can be meaningfully applied without enough quality data collected by a uniform method. Data acquisition is time-consuming and the most personnel demanding phase of building an archaeological infrastructure. Thus, it cannot be assumed that one organisation or any of its working groups will be able to consistently cover this activity institutionally or even just within the scope of short-term projects. The temporary suspension or interruption of data collection will always cause a gap in their consistency, and its reverse filling is usually very difficult. For this reason, it is necessary to lay the weight of data acquisition upon the whole community of users (data consumers), i.e. to apply a kind of crowdsourcing principle. The concept should cover as many as possible areas, especially considering the huge increase in data collected by the uncoordinated application of the remote sensing, the need to process the as yet non-digitized lists and surveys (published and unpublished as well) and the need to initiate intensive cooperation in the integration of interdisciplinary data. Data sharing by the whole community also represents an extremely valuable opportunity to professionally engage amateur archaeologists, mainly the users of metal detectors.

Unlike a special-purpose information system, the creation of infrastructures is only meaningful in the long-term perspective. This aspect should also be reflected in the significance given to such task in the evaluation of professional institutions engaged both in theoretical and applied research (i.e. heritage management in the case of archaeology). On the other hand, research infrastructures need to be understood as an integral and necessary part of the cycle of scientific cognition, not as its alternative. They are a welcome tool, not a goal in and of themselves.

### 5.8.4 Conclusions and Recommendations

Whether the development of the AMCR and other archaeological infrastructures will take any of the outlined directions or not, it is necessary to repay the debt resulting from the underestimation of this sphere of archaeology in the long-term perspective. In the text above, several topics have been mentioned which are seen as crucial for a proper development of a VRE in Czech archaeology. In the following paragraphs, let us summarize the main points.

Currently, the key task represents the effective involvement of users. If we really want to talk about the provision of services within the framework of archaeological VREs, users must be seen as an integral part of them and must, therefore, be given the same attention as system administration, technical solutions and the contained data. Practice has clearly shown that addressing such crucial tasks in the Czech Republic cannot be carried out within the current arrangement of decentralized data management. Thus, the formation of a coordination platform in the form of a working group, where representatives of the main institutions and projects will take part, must be initiated. Such a working group should disseminate information about the current state as well as planned developments in the field of archaeological informatics. Moreover, it can act as a spokesperson representing the archaeological infrastructures as a whole to not only state administration and other humanities, but mainly to the wider archaeological environment and educational institutions. It should also be a partner on the international level and serve as a medium for the transfer of appropriate models, ideas and standards that will be actively sought after through participation in relevant international fora.

Unlike a special-purpose information system, the creation of infrastructures is only meaningful in the long-term perspective. This aspect should also be reflected in the significance given to such task in the evaluation of professional institutions engaged both in theoretical and applied research (i.e. heritage management in the case of archaeology). On the other hand, research infrastructures need to be understood as an integral and necessary part of the cycle of scientific cognition, not as its alternative. They are a welcome tool, not a goal in and of themselves.

Conclusions:

- It is necessary to pay more attention to data; in archaeology, if data is not properly collected, recorded and protected, major parts of it may be soon lost forever.
- Integration and standardization of information on a national (or even wider) level is urgently needed.
- Users must be seen as part of the VREs.

**Recommendations:**

- New types of data available should be considered (e.g. LLS images) and its impact on the general data model should be discussed.
- National and/or international platforms (working groups) should be created.
- Long-term visions of the VRE scopes and development should be articulated and followed.
- Critical evaluations of the achievements within the VREs should be carried out.
- Archaeology should be open to the public as much as possible; it is necessary to persuade the public that “archaeological knowledge matters”.

### 5.8.5 Summary

Archaeological research infrastructures must be developed with a vision for the needs of the future professional community. The authors from the ARUP-CAS team are convinced that it is crucial to systemize access to archaeological knowledge at the central level and to involve users directly in the process of data creation. They put an emphasis on the importance of a suitable legal framework and institutional cooperation, the advantages of Open Access, Open Source and data standardization, and outline directions of data harvesting and new tool development. These “future visons” may be considered as a roadmap sketch of the process leading to a national archaeological virtual research environment.

### 5.8.6 References

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## 5.9 Summary of Case Studies Results (SRFG)

The case studies describe exemplary current practices in the respective area, recent advances and/or existing shortcomings, and outline how the area could be developed further. The conclusions and recommendations can concern adoption of novel approaches, standards, methods, tools or other means, depending on the subject area covered.

### Summary of individual case studies

We briefly summarise the individual case studies with regard to their subjects, perspectives, and main conclusions.

***Archaeological Methodology**:* The case study addresses the methodologies which are being used in archaeological research. The study does not focus on methodological theory, but extraction of methods components from actual practice and description in a form that could allow better support by e-archaeology applications. The work takes a Situational Method Engineering (SME) approach and applies the ISO/IEC 24744 standard (Metamodel for Development Methodologies) which defines a “grammar” for SME. The study then shows that this modelling language allows expressing and communicating in a formalised way methodologies in archaeology. This work involved the extraction of methods components from textual accounts of actual archaeological practices, and the development of a repository to store and manage their formalised descriptions. Furthermore a number of application scenarios have been identified.

***Archaeological Ontology***: The case study presents an application case of CRMarchaeo, an extension of the ISO standard CIDOC CRM specifically designed to model the archaeological excavation process and to integrate the complex documentation of excavations which are often recorded according to different standards. The study presents the application of CIDOC-CRM/CRMarchaeo to a very complex documentation schema, which has been achieved with good results, and suggests that CRMarchaeo arguably can be utilized in most other cases. Indeed, work is underway on a number of cases. Importantly, a tool, the Mapping Memory Manager (3M) is available for this work. The case study concludes that CIDOC-CRM/CRMarchaeo allow addressing better the complexity of archaeological documentation in efforts aimed to integrate such documentation. Therefore their application can be recommended to archaeological research centres and projects for data integration. This is recommended for integration at the local/project level as well as across different projects and institutions, for example in the framework of ARIADNE.

***3D Archaeology**:* The case study first describes a framework of 3D Archaeology in which 3D models would represent and allow scrutinizing the result of bringing together knowledge from researchers of different disciplines concerning archaeological artefacts. Next the study describes the wide range of 3D methods that are being used by archaeologists, however, mainly to represent, not to enable advancement of archaeological knowledge in collaborative e-archaeology. Such e-archaeology would use online representation, annotation and critical discussion of knowledge claims, feeding the results back into the 3D model development process. Thus the scientific, essentially collaborative process of knowledge generation, in which researchers scrutinize, refute or accept (always provisionally) knowledge claims should be built into the 3D environment. The study suggests investigating e-research environments that provide such capability and place the collaborative research process in the centre of 3D Archaeology.

***Geo-Physical Field Survey**:* The case study addresses the situation of databases of geo-physical survey data which can provide essential information for studies on archaeological sites and areas. As examples two databases of national authorities have been inspected, showing limited capability to (re-)use the databases for documenting research projects or to directly contribute new results. The study notes that are not many such central databases and no database exists at the European level which integrates the metadata or, even, datasets of prospections conducted in different countries and regions. The study suggests that for e-archaeology involving geo-physical surveys there is a need of standardised databases dedicated to such research. Such databases should allow documenting the systematic data acquisition, processing and interpretation, taking account of the particularities of the prospected area. Furthermore, to allow further progress in the research field of geo-physical surveys for archaeological purposes, scientific publications should be published with the underlying datasets (i.e. in a publicly accessible repository), so that results can be scrutinized and the data used for investigations with different methods.

***Physical Anthropology****:* The case study addresses the development of databases in the field of physical anthropology, describes some current examples, and points out existing issues as well as potential for advances towards innovative e-archaeology. Identified major challenges for e-archaeology are: data recording that is not based on an international standard, databases that have been developed with only one institution in mind, and lack of federated, cross-searchable databases; the latter concerns both collections of skeletal material and research databases. For ARIADNE the case study recommends: to include in the ARIADNE registry/portal more sets of research data and reports of physical anthropology; to contribute to the standardisation of databases in this field from ARIADNE's perspective of dataset registration, federation and integration; and to consider the development of a virtual research environment that demonstrates the research potential of interoperable physical anthropology and other archaeological databases. The case study emphasises that these objectives require a close collaboration between anthropologists, archaeologists, database managers, and technical researchers and developers.

***Archaeobotanical Research****:* The case study introduces archaeobotany with regard to its disciplinary scope and current developments. The latter include an increased accessibility of studies and data online, i.e. data shared through open access repositories, which contribute to research questions of environmental archaeology. The case study addresses archaeobotanical research in the context of archaeological sites. This concerns the investigation of remains of plants as a contribution to the overall interpretation of sites. The study focuses on the identification of the plant remains, which often requires comparison to archaeobotanical reference material and asking colleagues for help with the identification. This could be eased by a virtual reference collection and environment that collects images and context descriptions by many researchers and provides tools for discussion and collaborative identification. However, an appropriate solution has intricate requirements in professional, technical and other respects. The case study presents a specification of the requirements which includes also interoperability of data with research e-infrastructures, i.e. ARIADNE.

***VRE for Czech Archaeology****:* The case study first presents recent e-infrastructure developments for the archaeological sector of the Czech Republic, the Archaeological Map of the Czech Republic (AMČR) and ARUP-CAS' Digital Archive, including the Aerial Archaeology Archive. The case study argues that these, particularly the AMČR, are elements of an emerging comprehensive VRE for archaeological research at the national level. The study then addresses important perspectives and requirements of such an integrating virtual environment. These include: that the long-term vision of the VRE scope and development must be communicated, followed, and evaluated; standardisation and integration of information across the sector in the country (and beyond); and the users must be seen as part of the emerging VRE (i.e. national working groups). The study also stresses that archaeology should be open to the public as much as possible, contributing to the recognition that "archaeological knowledge matters".

## Summary of results and recommendations

We briefly summarise the overall results and recommendations of the cases studies:

### Common themes of the case studies

- The case studies looked into current practices and solutions for e-archaeology, including shortcomings and potential for improvements.
- One theme that is present in most cases studies is that any solution, VREs or other, should support collaboration between researchers aimed to generate, validate and integrate archaeo-logical knowledge.
- Various resources are addressed including methods, models, databases, reference collections, and others. Among the identified needs for e-archaeology especially are standardization of data and databases as well as better coverage and access. Furthermore, databases should allow easy contribution as well as re-use of data. Also there is a need of data federation initiatives to allow cross-searching of existing databases.
- Case studies also stressed that enabling advanced e-research capability will require a close collaboration between archaeological researchers, database managers, and technical researchers and developers.

### Databases

- Databases are essential elements of VREs as they allow researchers collect, share and expand the factual evidence in their fields of study collaboratively. The current state of databases in various fields of study presents a difficult situation, which also limits their potential integration in the ARIADNE e-infrastructure and portfolio of services.
- Standardization of data recording and databases in particular fields of archaeological research is not a focus area of ARIADNE. However, ARIADNE could promote and contribute to standardisation initiatives, especially from the perspective of dataset registration, federation and integration.
- Demonstration of the research potential of interoperable databases, i.e. based on CIDOC-CRM and its recent extensions (i.e. CRMsci, CRMarchaeo and others), and dedicated VREs for certain types of studies, may promote further standardisation and sharing of databases.

### Scientific reference collections

- A common need is reference collections that allow comparison and identification of remains of cultural products, humans, animals and plants as well as physical material (i.e. soils, sediments) in the archaeological record.
- Some of these need to be developed by expert in the respective specialties to ensure their practical usefulness in archaeological practice (i.e. archaeobotany, zooarchaeology, and others); existing reference collections of natural history museums are not necessarily helpful for the identification of archaeological samples.
- Similar to databases of research results, the development of these research resources is not a task in the remit of ARIADNE. However, ARIADNE could promote the creation of VREs that support the building of reference collections. Furthermore, explore if virtual reference collections could be generated from samples documented in datasets shared through the ARIADNE registry.

### 3D representation of archaeological knowledge

- 3D models and other visual media are increasingly employed to present outcomes of archaeological research. In ARIADNE this has been supported by the development of online services which ease the generation, publication and visualization of 3D models of objects and landscapes (Visual Media Service, Landscape Factory).

- Now the next step could be to provide a collaborative VRE that enables researchers to examine a model (i.e. meta/para-data of research and technical background), discuss the model and suggest improvements taking account of new research results, if required.

### Formal description of e-research activities, methods and data

- To build effective e-archaeology environments there is a need to describe various elements of e-research (i.e. methods, tools, data) in a way that allows (semi-)automatic support of tasks and outcomes.
- ARIADNE recommends using the CIDOC-CRM (with the recent extensions CRMsci, CRMarchaeo, CRMba and others) for the description and integration of archaeological documentation. For VREs in addition ontologies and applications are necessary which support the actual research process. The research process comprises of sequences of different activities (i.e. workflow) which involve certain methods, tools, data and other resources. Applications that support the research process would suggest available resources, link them together, and also provide other support to carry out research tasks.

# 6 Conclusions and Recommendations

## Positioning of the ARIADNE data infrastructure

Research e-infrastructures are implemented based on a multi-layered architecture with many data resources (i.e. repositories) at the bottom, a layer of common e-infrastructure and services in the middle, and flexible combinations of more specific services and tools on top. The top level can be virtual research environments (VREs) tailored to the needs of research communities of particular domains or cross-domain, multi-disciplinary research projects.

ARIADNE provides a data infrastructure in the middle layer which incorporates data resources from many archaeological institutions in Europe and provides cross-resource data discovery, access and other services. ARIADNE has implemented a platform where dispersed archaeological data resources can be uniformly registered/described, discovered and accessed. The data is being shared by archaeological research centres and projects to allow use and re-use further research, for example, asking new questions from combined datasets.

The ARIADNE e-infrastructure helps to overcome a situation of high fragmentation of archaeological data in Europe (and elsewhere). At the same time, it is a step towards the even more ambitious goal of providing a platform capable to support web-based research aimed to create new knowledge.

Thus a major next step could be to implement VREs that, in addition to data access, provide services and tools which allow archaeological researchers carrying out research tasks online. Such VREs may range from loosely coupled services/tools and data resources to tightly integrated workbenches for researchers of different domains of archaeology.

The current ARIADNE project has not been charged to develop VREs, but the implemented data infrastructure and services provide a basis for future archaeological VREs.

## ARIADNE and e-archaeology

The present report presents an investigation of general and domain-specific e-research frameworks, especially of e-archaeology. E-archaeology in general means the use of web-based digital data, tools and services for archaeological research purposes.

The investigation compared e-archaeology to other “digital humanities” and identified several important differences. For example: digital humanities scholars mostly work with digitised cultural content from cultural heritage institutions, archaeologists work with data they produce themselves, generated in field and laboratory work with methods and tools typically not used by other humanities researchers.

Both e-archaeologists and digital humanities scholars need appropriate solutions for collecting, handling, bringing together and studying their data/content. But, except generic technologies such as databases, the digital tools and products are different: Typical digital humanities products are scholarly editions (e.g. of literary works), which require tools that support tasks such as transcription, translation, annotation etc. Typical for e-archaeology is GIS based integration of data of sites or virtual reconstruction of ancient built structures or landscapes.

*With regard to support of e-archaeology the study concludes and recommends:*

- ARIADNE would not incorporate cultural heritage collections, as for example Europeana does, and not provide tools for digital humanities products such as scholarly editions.
- ARIADNE should focus on major archaeological data resources, in particular field survey and excavation data, including data of research specialties.

- Concerning data of research specialities ARIADNE will have to consider which fields should be focus areas of future incorporation of additional data resources. For example, one case study in this report suggests mobilizing physical anthropology research data (but, similar to cultural heritage collections, not catalogues of skeletal material collections).
- Concerning research tools the focus should be on tools/services of particular relevance to archaeologists:
  - One area already present in ARIADNE's portfolio is online services for the generation, visualization and exploration of 3D models (Visual Media Service and Landscape Factory). The case study on 3D Archaeology suggests that a step towards advanced e-archaeology could be addition of capability for online discussion and verification of the knowledge represented by 3D models, with the outcome fed back into the knowledge representation process.
  - Other priority areas of future additional tools/services should be investigated. These could focus on certain types of data (e.g. remote sensing data) and/or tasks (e.g. collaborative building of online reference collections). In general types of data and tasks that are relevant for broad segments of researchers are preferable, at least in a first phase of extension of the ARIADNE service portfolio.

## Multi-disciplinary E-archaeology as the Main Challenge

The main challenge for ARIADNE to support e-archaeology is the multi-disciplinary of archaeological research. Archaeology indeed utilizes knowledge, methods and data from different disciplinary fields of which some present mainly characteristics of the humanities (e.g. ancient languages, classical studies), others lean heavily towards the natural sciences and employ methods of archaeometry or biological sciences, others relate to the earth & environmental sciences, while still others use models and methods of the social sciences (e.g. models of social structure and ethnological methods, for instance).

Archaeology studies past cultures based on their material remains and traces in the environment, including remains such as biological material, artefacts, built structures as well as traces in the landscape (e.g. agriculture, routes between places, etc.). Knowledge, methods and results of different disciplines need to be combined to arrive at rich and solid conclusions.

The paradigmatic case of this multi-disciplinary of archaeological research is excavation projects. These projects are carried out by teams involving the excavating archaeologists and finds experts of different specialities who identify and analyse physical and biological remains such as ceramics, metals, bones, plants, etc. They all contribute to the interpretation of archaeological sites, but their work requires different subject knowledge, methods and tools.

*With regard to multi-disciplinary e-archaeology the study concludes and recommends:*

- There is a need for two types of collaborative virtual research environments (VREs):

  a) VREs that allow to bringing together, integrate and interpret (synthesise) the results of the different investigations on archaeological sites, and

  b) VREs for researchers in specialities (e.g. physical anthropology, archaeobotany and others) that are specialised for their particular data (incl. data standards, terminology) and include services/tools for the identification, description and analysis of their finds (e.g. access to reference collections for the identification of finds).
- Both should be developed in view of wider range investigations (i.e. beyond individual sites) based on sharing of the collected data through ARIADNE.

- Also important to consider is that unearthed material remains of past cultures include objects such as cuneiform tablets, inscriptions, papyri and others. These are studied by scholars of ancient languages, literatures, religions, etc. In turn, they can contribute to the interpretation of archaeological sites.
- However, the study does not recommend ARIADNE to engage in the development of VREs for such humanities scholars. But to explore how information from existing databases might be integrated. One area of interest here could be epigraphical databases.

## Development of ARIADNE VREs

VREs are web-based collaboration environment that provide a set of integrated tools and services as well as data resources as needed by research communities to carry out research tasks online. There are some contradictory or at least difficult to fulfil expectations from a VRE, i.e. open vs. controlled, flexible vs. tailored, and domain vs. cross-domain. In any case, VREs should not be stand-alone solution for one project or institution, but based on common e-infrastructure.

Use of VREs on top the ARIADNE e-infrastructure could bring about significant progress in e-archaeology, in particular through enabling collaboration between and cross-fertilization of knowledge and research agendas of scholars of different domains.

Sharing and linking through the ARIADNE e-infrastructure various data generates some (limited) potential to stimulate such cross-domain fertilization. The potential could be expanded by VREs for cross-domain research.

Different areas of the multi-disciplinary map of archaeological research will present distinctly different needs with regard to data, services or tools, classical archaeology versus environmental archaeology, for instance. Therefore VREs will tend to become area-specific, e.g. support to build and study a database of classical texts (e.g. epigraphy) or, in the case of environmental archaeology, for example aggregation, visualization and analysis of vegetation, land use and other data.

Alternatively, VREs for cross-domain research will tend to provide generic services/tools or need to be built specifically to support such research. Therefore an essential question is how VREs could be developed which enable effective cross-domain research aimed at archaeological knowledge generation, integration and synthesis.

*With regard to the development of ARIADNE VREs the study concludes and recommends:*

- Investigate further different concepts of virtual environments for archaeological research, e.g. which research tasks could research groups conduct more effectively online and which requirements need to be fulfilled.
- Promote the development of relevant VREs with functionalities (tools, services) and data resources required by archaeologists to carry out various research tasks online.
- Take account of the particular requirements of archaeological researchers in different domains as well as in cross-domain/disciplinary collaboration.
- Consider cases where researchers use data mediated by ARIADNE and by data infrastructures and services of other disciplines (e.g. geo, environmental, biological data). For the development of cross-domain VREs collaboration between e-infrastructure initiatives of different disciplines may be necessary.
- Support the use of domain-specific vocabulary as well as integrating ontologies such as the CIDOC Conceptual Reference Model (CIDOC CRM) and its recent extensions CRMsci, CRMarchaeo, CRMba, and others.

- Aim to develop VREs that enable collaboration between and cross-fertilization of knowledge and research agendas of scholars of different domains.
- Foster cross-fertilization also between scholars and developers of software tools for research purposes, in which developers learn about the requirements of scholars' projects, and scholars how to apply novel technological solutions.
- Consider that archaeological researchers currently seldom use advanced computation offered by Grid/Cloud-based Distributed Computing Infrastructures (DCIs), and explore where such computation may be needed by VREs for "big data" based research.

# 7 Main References

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